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Options Under Uncertainty: An Empirical Investigation of Patterns of Commitment in Display Technologies in the Flat Panel TV Set Industry

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A thesis submitted in partial fulfillment of the requirements for the Doctor of Philosophy degree in Business

OPTIONS UNDER UNCERTAINTY: AN EMPIRICAL INVESTIGATION OF PATTERNS OF COMMITMENT IN DISPLAY TECHNOLOGIES IN THE FLAT PANEL TV SET INDUSTRY

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ABSTRACT

This dissertation considers fundamental questions about real options reasoning and its application in the face of uncertainty: do firms behave as real options reasoning predicts, and are there performance benefits from its application? The concept of uncertainty is further developed by considering two primary types: technological uncertainty and market needs uncertainty.

A qualitative industry level historical case study is performed on the flat panel TV industry, chosen because it exhibits high technological uncertainty and low market needs uncertainty. Real options logic predicts, in such an industry, that firms will develop and maintain technology options until uncertainty is resolved. Firm level case studies for major incumbent Japanese TV set manufacturers and other relevant firms are performed. Comparison across the cases, and between several specific firms is conducted to test and further develop theory.

The firms studied are found to generally behave as predicted by real options logic. Evidence from the study does not present a clear relation between options-related behavior and performance. Although this study identifies evidence not holding options can have large negative performance results, firms holding options as predicted by theory did not realize lasting performance improvements. With one exception, firms attempting to leverage technological capabilities into improved market positions were unable to realize durable improvements in their positions. The development and release of flat panel TV coincided with changes in performance for many firms in the industry; however, these performance changes were short lived. By the end of the study period, industry players had generally returned to the trajectories they were previously on. Between-case analysis of several outlying firms in the sample provides a rich and nuanced view of requirements for firms to dramatically improve performance in the face of high technological uncertainty in a market with very large size potential and relatively well-understood customer needs.

This research contributes to the empirical literature on real options and is novel amongst academic research in its coverage of the flat panel display history using Japanese sources. Finally, this dissertation includes managerial implications regarding the usefulness of real options reasoning as well as practical issues in its implementation.

Keywords: real options, uncertainty, strategic commitment, flat panel display industry, television set industry.

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TABLE OF CONTENTS

LIST OF CHARTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICIES

CHAPTER ONE: INTRODUCTION, BACKGROUND, AND THEORY DEVELOPMENT

Strategy may be defined as commitments made by the firm in the face of an uncertain future largely beyond its prediction or control. Strategic commitments are path dependent, non-reversible decisions. Commitments constrain future decisions because they are costly and difficult to reverse (Barney, 1991; Ghemawat, 1991; Raynor, 2007). The logic of competitive advantage suggests a firm unwilling to make commitments until uncertainties are largely resolved will be unable to achieve competitive advantage; although it may survive it will never excel (Gemawat, 1991; Raynor, 2007). Because such a firm will wait to enter markets until after uncertainty has been resolved, it will miss the opportunities to create competitive advantage through positioning or development of competencies (Raynor, 2007).

Commitments matter precisely because the future is uncertain. Commitments can be thought of as bets made by the firm; even with the most thorough strategizing and forecasting, the firm often will make the wrong bet (e.g., Raynor, 2007). If the future were knowable, firms would be able to make investments with certain returns rather than risky bets. Herein lies what Raynor (2007) termed the “strategy paradox;” firms making strategic commitments experience the extremes in performance outcomes, with those on the bottom extreme frequently going bankrupt.

Decision makers face a conundrum. If they do not make commitments, the firm will be limited to market returns, whereas if they make commitments, the firm may perform very well or very poorly. It might have to exit the industry or even go bankrupt. Because of the downsides, uncertainty tends to drive out action. Confronted with a high chance of undesired outcome, how do firms make commitments under high levels of uncertainty? How can managers mitigate uncertainty while still gaining the advantages of commitment?

One possible answer is real options reasoning (e.g., McGrath, 1997, 1999; McGrath, Ferrier & Mendelow, 2004). It suggests firms can develop and maintain option-like investments to keep open the opportunity to reap the benefits of commitment while maintaining flexibility to abandon these investments with a relatively small cost. Although this theory appears to offer a way for firms to manage uncertainty, extant research does not document the performance impact of its application. Additionally, whether firms actually behave in a way consistent with real options reasoning (ROR) or not is a question yet unanswered.

To examine these questions, this research performs an historical case study of the flat panel TV industry. This method is appropriate for the study because it allows the inclusion of extreme performance events (i.e., exit), it allows for flexibility to examine a variety of relevant sources of data, and will be generalizeable to industries with similar attributes. The industry is interesting because it exhibits a high level of technological uncertainty.

This dissertation is organized as follows. This chapter develops theory based upon real options reasoning under uncertainty. A model is developed and propositions argued. Chapter two specifies the methodology and research setting, the flat panel TV set industry. The flat panel TV set industry faced technological uncertainty due to competing display technologies, while it exhibited relatively low market needs uncertainty. Chapter three describes the former, and chapter four the latter. Chapter five contains firm-level case studies identifying options portfolios held over time. Chapter six performs analysis across and between the cases to identify patterns in behavior and performance. Based upon data and analysis from Chapters five and six, Chapter seven develops findings in terms of theory and propositions developed in Chapter one. Chapter seven also develops some post hoc theorizing and analysis. Chapter eight contains the discussion and conclusion.

BACKGROUND AND THEORY DEVELOPMENT

The introduction briefly discussed real options. Below, uncertainty, real options, and strategic commitment are discussed in more detail. A distinction is made between two different types of uncertainty: customer needs uncertainty and technological uncertainty. Based upon this distinction, a model is developed and propositions presented.

Uncertainty

It is important to distinguish the concept of uncertainty from that of risk. The notion of risk is that although the outcome of a given event is not known in advance, its probability distribution is known or at least knowable (Knight, 2006). In the case of uncertainty, the probability distribution is not known (Knight, 2006); arguably, even the range of possible outcomes may not be knowable in advance in many cases. Uncertainty has been framed in terms of complexity and dynamism (e.g., Duncan, 1972). Regardless of how one tries to break down and define it, however, the level of uncertainty itself is not knowable in advance or while it is being experienced, but can be classified with more accuracy retrospectively. Many of the different underlying causes may be not visible or knowable until after unexpected changes have occurred. The nature of their impact may also change over time.

Because uncertainty can be endogenous or exogenous to the firm, overall uncertainty levels are not identical across firms, even those competing in the same product market and geographical locations. Folta (1998) described endogenous uncertainty as uncertainty that can be reduced by the firm taking action and learning from the feedback, and exogenous uncertainty as uncertainty that cannot be wholly resolved by the firm. For the purpose of this research, it makes more sense to define endogenous and exogenous uncertainty based upon the source of uncertainty. Endogenous uncertainty is due to the firm's own capabilities including its ability to understand customers and competitors. Exogenous uncertainty is uncertainty caused by things outside of the firm. Such uncertainty is not necessarily beyond the firm's ability to reduce. For instance, expeditionary marketing can be used to reduce uncertainty of needs in a new product market (Hamel & Prahalad, 1991). Similarly, pre-investments such as taking on lobbying activities in the face of uncertain legislation may also reduce uncertainty (McGrath, 1997). These uncertainty reduction approaches would be classified differently using the definitions used by Folta (1998) and that proposed here. As the source of uncertainty is outside the firm in both cases (uncertain market needs in one case and uncertain legislation in another), the definition proposed here would code them both as exogenous, however, Folta's (1998) definition would code them as endogenous as both can be reduced through firm actions.

This distinction is important because the research in this dissertation is primarily focused on exogenous uncertainty. The level and type of endogenous uncertainty is by nature firm-specific. Because of this, it is difficult to compare the actions and performance of firms relating to endogenous uncertainty. Exogenous uncertainty, on the other hand, affects all firms in the product market in question, and for this reason allows comparison between firms more readily. However, it should be noted that the distinction – although useful – may not always be clearly visible to the outside observer.

Uncertainty Types

Different types of uncertainty have different implications for the firm. The ways that firms can make commitments and manage uncertainty depends upon the nature and type of uncertainty it faces. Firms make commitments in the face of market needs uncertainty and technological uncertainty. Others have made this distinction in the literature (e.g., MacMillan & McGrath, 2002; Oriani & Sobrero, 2008), although specific definitions vary between authors. Below, market needs uncertainty is discussed before moving on to consider technological uncertainty. Although this discussion of market needs includes technologically related examples, its focus is on the market needs.

Uncertainty of market needs, the needs of current and potential customers in a given product market, may exist at a number of levels. The spectrum of needs runs from basic needs to ever changing trends in desirability of specific aspects of a good or service (Kaldor, 1971). For example, nourishment and clothing are basic needs. Although many basic needs do not change much over time, the way they are best served does. Sometimes these may appear to be predictable trends, and other times not.

At any point in time, there may be latent needs and preferences that cannot be met due to technological limitations. Some latent needs may be predictable, at least for a certain timeframe. For instance, the consumer preference for a flat panel television was fairly clear even when Cathode Ray Tube (CRT) technology was the only feasible way to create video displays. If given the choice, consumers would prefer something that provided a larger picture size but took up less space in their homes. With many products, customers will tend to prefer faster, higher quality, greater reliability, more convenience if the price is the same – and often even it is higher. In the case of televisions, thinness is another of these attributes. In the case of hard disk drives, storage capacity has been a differentiating attribute. Given the choice between drives of the same format size in the same price range, historically customers have chosen drives with larger storage capacity.

Christensen (1997) argues that these kinds of needs can become oversupplied. In other words, improvements are made past the point where further increases are no longer seen as beneficial to customers. At the point that they have become oversupplied, improvements in this dimension no longer differentiate the product. A good example of this is hard disk space. After a point, the average customer cannot use additional storage space, so he no longer values additional capacity. From this point onward, other differentiators will become more important in customers' choices. Literature on product and industry development cycles (e.g., Geroski, 2003) and customers' usage development cycles (e.g., Moore, 2005) describes how these changes occur over time. Firms work to make technological improvements to their product along the attribute dimensions historically valued by customers. As one attribute reaches a point of oversupply, the dimension of needs it represents is replaced by another dimension. When and where these points will be reached and what the next dimension of differentiation will be are uncertain.

Although future customer preferences appear to be relatively clear in some cases, they are much more speculative in others. Exogenous economic and demographic changes increase needs uncertainty (Oriani & Sobrero, 2008). For instance, the 1970s oil shocks drove American car buyers to place greater value on fuel economy and less value on vehicle size. Exogenous change may or may not be predictable by the firm in advance. Even when its existence is predicted, however, the magnitude of impact is highly uncertain.

Furthermore, customers typically do not know how to value a product with which they are not familiar. Latent needs are particularly uncertain where no offerings currently exist (Geroski, 2003). Potential customers may not be known, nor may be the way of best serving them or the price they are willing to pay (MacMillan & McGrath, 2002). Although the television set customer may be able to say that he would prefer a larger thinner screen before LCD technology became viable, the potential PDA user did not know what to value in a PDA prior to their introduction.

Interestingly, seemingly minor changes to product characteristics can fuel large changes in customer demand levels. For example, the first Apple iPod entered into an existing market for mp3 based portable music players. It had a superior interface and larger storage than existing products, but was not cutting edge from a technological perspective. Sony, which had been a pioneer in portable audio, first with the world's first transistor radio and later with the Walkman, was already in the mp3 player market. Audio electronics firms such as Sony – who thought they understood market needs for portable consumer audio – were probably very surprised to see customers prefer the offering of a computer company to their own.

The above discussion of market needs uncertainty has considered unknowable latent market needs, changes in attribute dimensions that customers value, and the potential for exogenous demographic and economic change to impact customer needs. Below, technological uncertainty is discussed.

Where multiple technologies vie to fulfill a customer need, existing or latent, technological uncertainty can be said to exist (e.g., Tegarden, Hatfield, & Echols, 1999; Anderson & Tushman, 1990, Oriani & Sobrero, 2008). However, just because a technology grows to dominate an industry does not mean that technological uncertainty is completely absent. There is still the possibility that a competitive or substitute technology will arise from outside the firm (e.g., Stuart & Podolny, 1996). Furthermore, future convergence of different technologies cannot be accurately forecast (Sherden, 1998). It is not clear which technologies will emerge or become feasible at any future point in time. In general, the ability to accurately predict how technologies will evolve and co-evolve in the future is limited. There are some notable exceptions to this observation, such as

Moore's law for microprocessors that predicts the number of components that can be placed on integrated circuits doubles every two years (e.g., Schaller, 1997).

The distinction between endogenous and exogenous uncertainty is particularly important to make with regard to technology. Folta (1998) described endogenous uncertainty as uncertainty that can be reduced by the firm taking action and learning from the feedback, and exogenous uncertainty as uncertainty that cannot be wholly resolved by the firm. Oriani & Sobrero (2008) defined *technical* uncertainty as being *endogenous* to the firm. The ability of a firm to complete a technology development project is an example of this type. Firms can reduce this kind of *endogenous* uncertainty by pursuing multiple parallel projects on the same technology (Nelson, 1961). (As compared with *exogenous* technological uncertainty, which can be addressed by pursuing parallel projects on competing technologies.) Oriani & Sobrero (2008) further defined *technological* uncertainty as exogenous to the firm, and occurring at industry level. This definition agrees with the one employed by this research.

This distinction does not mean that R&D investment has no impact on uncertainty levels. Indeed, unlike risk in financial markets which is resolved over time, exogenous technological uncertainty is reduced through R&D investments. Where financial options are concerned, investors do not impact the future outcome probability distribution by buying or selling options. In the case of technology options, investments can change the level of uncertainty. The same is true for market needs uncertainty.

Although technological development and market needs may appear to be predictable in the very short term, this appearance may be misleading. Very little can be forecast or predicted with any accuracy except in the very short term (Sherden, 1998). Strategic uncertainty is greater over the long run than the short run (Raynor, 2007). Capabilities that are further upstream, such as research-related capabilities, have longer-term impact, therefore they face a greater level of uncertainty (Raynor, 2007).

The antecedents of variation in technologies and market needs differ; accordingly the types of uncertainties are not symmetrical. In other words, uncertainty in the technology development vector is different from uncertainty in the evolution of market needs. They are related in that new technologies enable new products fulfilling previously unmet needs, and identification of unmet needs can stimulate additional investment in technologies potentially capable of meeting these needs. Therefore, a change in the level of one kind of uncertainty may impact the level of the other.

Commitment Types

Like uncertainty, commitments can also be thought of in terms of market needs and technologies (Ghemawat, 1991). Firms can make commitments to one or both types. For instance, a firm may commit to developing a technology at an early stage where its ultimate benefits are not concretely known. This would be a commitment to the technology but not to a market need. Alternatively, a firm could commit to a market without having a technology at all. A supermarket chain, for instance, can commit to the beverage market using its own brand and distribution infrastructure and outsource development, formulation, production and other functions. In this case, it would have made a commitment to the market need, but not to technology needed to fulfill this need.

Developing technologies requires commitment because of time compression diseconomies inherent in knowledge building (Dierickx & Cool, 1989). In other words, once a technology is known to be of value, it may be too late to catch up to the leaders. Technological lockout may result (Schilling, 1998), and keep the firm from entering (or remaining) in the product market in question. At the same time, it is costly to maintain technological capabilities (e.g. Miller, 2002).

Firms making early commitments to market needs benefit in several ways. There are limitations to customer attention; therefore early branding may capture attention more effectively than later brand building efforts. Similarly, there are limitations to distribution channels. Strong positions in these channels may be easier to achieve at an early stage rather than after uncertainty has been reduced. Some market commitments may create switching costs, protecting market share and making it difficult for new firms to enter the market (e.g. Lieberman & Montgomery, 1988). Finally, early commitment to market needs may result in a fine tuned understanding of needs and therefore greater ability to meet them (Carpenter & Nakamoto, 1989, 1990 in Kerin, Varadarajan & Peterson, 1992).

These two kinds of commitment are not symmetric. Costs and capabilities required to undertake them are different. Furthermore, as can be seen from the discussion above, the nature of spillover effects on learning is also different (McGrath, 1997).

Real Options

Application of real options has been suggested as a way to manage uncertainty. The fundamental idea behind a real option is that uncertainty can be managed by making a partial commitment rather than a full commitment (Anand, Oriani & Vassolo, 2007). These partial commitments are sequential and irreversible (Dixit & Pindyck, 1994). By holding the real option, the firm benefits from the flexibility to make future decisions to commmit (Li, James, Madhavan & Mahoney, 2007). Tong and Reuer (2007:5) formally defined real options as "investments in real assets, as opposed to financial assets, which confer the firm the right, but not the obligation, to undertake certain actions in the future." Two aspects of this definition separate real options from investments in general. First, real options do not include financial assets. Second, some kinds of investments do carry obligations to undertake future action.

Although there is agreement about these fundamental descriptions, there is disagreement upon what constitutes a real option in the strategy literature (Adner & Levinthal, 2004; McGrath, Ferrier & Mendelow, 2004). On the one extreme, Adner & Levinthal (2004) argue for a relatively narrow and specific definition. They suggest that real options theory requires a discrete investment logic. In other words, investment decisions must be characterized by clearly demarcated stages with “go, no-go” investment decision points. Furthermore, where there is too much flexibility regarding the technology to be developed or market in which to apply it, the option becomes more difficult to clearly define or analyze, and the investment logic ceases to be discrete. In these cases, they argue real options theory ceases to apply (Adner & Levinthal, 2004).

McGrath et al. (2004), on the other hand, suggest a broader definition of real options. They identify four different conceptualizations of real options appearing in the literature: (1) the notion that the firm's market value includes a growth option component, (2) a single and clearly defined proposed investment which has qualities similar to options – often this approach considers how to value the option in question and sometimes compares this with other project evaluation techniques, (3) more generic types of choices made by managers that can be applied to more than one proposal – the focus here is on the choice and not the underlying assets; and (4) the notion of real options reasoning as a heuristic applicable to strategy. These conceptions represent sub-streams, however they do not appear to be mutually exclusive. For instance, considering real options as a strategy heuristic does not mean that one dismisses the idea that a portion of the firm's market value is due to growth options. McGrath et al. (2004) is strongly supportive of the inclusion of the real options as a heuristic in strategy research.

The second conceptualization, which some have called option pricing or options valuation, has received attention as an alternative to net present value (NPV) for evaluating potential investments. NPV ignores the option value in projects and therefore may lead to underinvestment in projects having higher option value but lower NPVs than competing proposals. This approach puts its emphasis on numerical calculation with its origins in finance. Although this approach has apparent benefits, case studies have found that firms have difficulty implementing it (Bowman & Moskowitz, 2001). Furthermore, as a decision making tool, option pricing does not lead to the same conclusions as other real options conceptualizations, as can be seen in the discussion below.

When Miller and Arikan (2004) simulated search under uncertainty, they made the distinction between option reasoning and option pricing. The option pricing approach was strongly related to financial conceptions of option value, whereas option reasoning was based upon the conceptualization of options as a heuristic. In Miller and Arikan's (2004) model, the real options logic firm searched by developing two competing technologies and putting off specialization until the value of one technology significantly outweighed the other. The options pricing firm, on the other hand, compared the two option values and put all its investment in one of the two technologies, assuming that the value of the option was greater than its cost. The differences in the models clarify the different ways of thinking about real options. Not surprisingly, the outcomes for the real options reasoning firm and real options pricing firm differ in this simulation.

While the conceptualization of real options as a valuation technique has merit, it faces limitations in its applicability in situations where technological and/or market needs uncertainty are high. First, it is hard to identify a suitable basis for valuation of options in these situations. Second, while time may resolve uncertainty relating around the value of the underlying assets of financial options, uncertainty relating to market needs and technologies is resolved by development and feedback loops. The number of firms and the size of their efforts to develop technologies and markets have an impact on how long it takes for uncertainty to be resolved. However, real options as a valuation technique does not take this into full consideration.

This research follows the option reasoning conceptualization and considers real options to be a strategy heuristic. This conceptualization has also been called real options logic, real options thinking, or real options reasoning in the literature. Real option pricing and real options reasoning seek to address strategic investment decisions. While real option pricing is a prescriptive evaluation methodology that has been promoted for practitioner use, real options reasoning is a strategy heuristic managers are often thought to follow even if they do not categorize it as such. McGrath and Nerkar (2004:2) describe this reasoning as implying that "decision-makers implicitly (or explicitly) respond to the value of the right to preserve decision rights in the future in their investment choices." Bowman and Hurry (1993) presents a relatively broad picture of real options that includes elements of real options logic. They emphasize the idea that small incremental investments in options can be made to learn and develop capabilities, and that these should be followed by large commitments (option exercises) later on. They suggest the timing of the commitment has a major impact on the actual performance achieved by the firm (Bowman & Hurry, 1993).

McGrath (1999) further argues that real options reasoning allows the potential benefits of entrepreneurial failure to be properly understood. In other words, a failed project can bring valuable knowledge that is exploitable in the future, and if the investments are made in stages, losses can be contained at the same time. More generally, this logic suggests that attempts to avoid failure may result in lost opportunities for growth and for learning. To the extent that investments are staged suitably, it is possible to limit the cost of failure without limiting the benefits of success (McGrath, 1999).

Maritan and Alessandri (2007) suggest that some real options are available to all firms in an industry, whereas others are proprietary and available only to particular firms. Options values depend on the bundle held by the firm; additional options can be subadditive or super-additive, and the value of an option available to all firms in the industry is not necessarily the same to each firm (Anand et al., 2007; Vassolo, Anand & Folta, 2004).

It appears likely that not all types of real options have been identified. This is partially due to the different conceptions of real options. Real options can be considered in terms of generic choices made by managers (e.g., the option to abandon an investment or the option to invest) or by the object of the option (e.g., research and development options). Tong and Reuer (2007) suggest the economics and finance literatures have assembled a taxonomy of generic choice options. However, the identification and categorization of options as objects, on the other hand, is far from complete. Research focusing on options as objects rather than choices has identified different types of investments that can be option-like including capabilities (Kogut & Kulatilaka, 2001), sequential R&D investment (McGrath & Nerkar, 2004), technology licensing (Bowman & Moskowitz, 2001), joint ventures (e.g., Kogut, 1991), equity investments (e.g., Folta, 1998; Vassolo et al., 2004), and venture capital investments (Hurry, Miller & Bowman, 1992). However, this area is still developing and cannot be considered to represent the entire universe of potential objects for options. While this leaves open the opportunity for future development, at the same time it represents a risk that the current empirical work fails to identify all option-like investments that have not appeared in the prior literature, potentially resulting in misleading results.

Although real options has great appeal and substantial theoretical work has been done, empirical work in the area is lacking (Reuer & Tong, 2007). Published empirical work on real options is very limited. Several papers have used pharmaceutical patent data to perform research relating to real options (e.g., Chi & Levitas, 2007; McGrath & Nerkar, 2004). Guler (2007) analyzed venture capital firms investments in startups from a real options perspective. Other empirical research has studied firms attempts to integrate real options valuation techniques into their investment decision making processes (e.g., Bowman & Moskowitz, 2001). It should be noted some of these papers used the conceptualization of real options reasoning, while others focused on real options as an investment valuation technique. Empirical work to date has not differentiated between alternative kinds of uncertainty. Li et al. (2007) called for future studies to investigate different kinds of uncertainty, how they may interact, and the impact upon how investments in options are made. This dissertation contributes to the real options literature by performing an empirical study of option-like investment in an industry encountering uncertainty of a specific nature.

Model of Uncertainty Environments

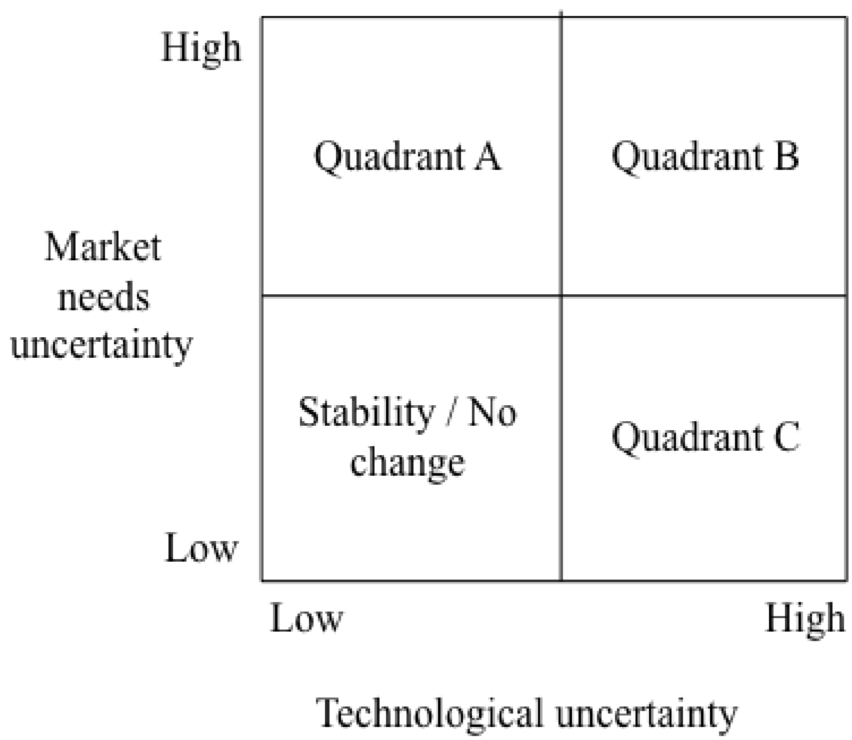
Firms face different degrees of technological and market needs uncertainty at different times and in different industries. Although it is not possible to define the type and degree of uncertainty an industry will experience in the future, it is possible to define time periods in specific industries where large or small amounts of uncertain change occurred in the past. The model introduced here integrates these kinds of uncertainties with the commitment types discussed above. Macmillan and McGrath (2002) propose what appears to be a similar model, however it differs in several important ways. First, they consider (endogenous) *technical* uncertainty, as opposed to (exogenous) *technological* uncertainty. Second, they suggest that practitioners can identify the level of uncertainty they face. This research argues that levels of uncertainty cannot be accurately identified ex ante and are more reliably observed and understood in retrospect. While there are some readily observable indicators that identify high uncertainty at the time it is present, the absence of these indicators does not preclude a high level of uncertainty. For instance, the existence of multiple competing technologies for the same application indicates a high level of technological uncertainty, however the absence of competing technologies does not necessarily mean that technological uncertainty is low, as new technologies can emerge at any point in time. As this suggests, managers may be able to identify high uncertainty in some circumstances but they cannot identify low uncertainty.

To facilitate analysis, the degree of environmental uncertainty is dichotomized into low and high levels along the two axes representing market needs uncertainty and technological uncertainty types (See figure 1-1). The resulting model describes four different types of environments. In the upper right hand corner, quadrant B, both market needs and technology uncertainty is high. When both types of uncertainty are high, the environment described is typically that of a product market in its infancy before a dominant design has emerged (Abernathy, 1978). Despite the lack of a dominant design, there significant activity may be observed in this environment. This kind of market is typically described by large numbers of small competitors, a large variation in the products in the market, and generally low sales volume. Geroski's (2003) analysis of the American automobile industry provides such an example. The Ford Model T represented a dominant design that drastically changed the entire industry. Approximately 400 firms entered the market between 1885 and the Model T's introduction in 1908, and about 275 of these were operating in 1907 (Geroski, 2003). Both technological and market needs were quite uncertain during this period before the Model T was introduced. However after its introduction, uncertainty regarding market needs as well as uncertainty regarding production technology were both greatly reduced. Consequently, the number of manufacturers declined and industry sales grew rapidly.

The lower left-hand quadrant represents a stable environment with no significant uncertainties. Product markets in this quadrant are typically long established industries. Examples of these kinds of industries include rail transport and dry cleaning.

FIGURE 1-1

Four Environment Types Depending on Uncertainty Levels



The upper left hand corner, quadrant A, describes a situation where uncertainty surrounding market needs is high but technological uncertainty is low. Such an environment can be the result of an external shock that changes demand in a previously developed product market. Alternatively this situation can arise when a proven technology is applied to an unknown market need. A large regulatory change, for instance banking deregulation, is an example of an external shock. Regulation can prevent the firm from using different levers such as pricing and accessibility, thereby making it impossible for the firm to explore (and exploit) latent market needs through market interaction. Accordingly, when regulation is removed, the market needs may appear to change dramatically, when in fact they are just reverting to latent needs that could not be met due to regulation. The situation where a proven technology is introduced into an undeveloped latent market would also be categorized into this quadrant. The introduction of microwave technology - originally developed in the military - into restaurant and consumer cooking appliance usage is one example of this situation. Raytheon engineers knew that microwave energy could be used to heat objects, but they didn't know much about non-military customer needs that could be addressed using this capability. Cooking was an application of heating technology. After entering this application market, Raytheon had to discover the customer needs for microwave cooking. For example, they did not originally have answers to basic questions such as: how big should the oven be? how powerful? at what price level would it start to be attractive (Hammack, 2005)?

In the lower right hand quadrant technological uncertainty is high, quadrant C, but market needs uncertainty is low. In other words, although market needs are clear, the way to best meet these needs is not. This description fits what Helfat and Raubitschek (2000: 965) termed a "replacement product market." Frequently, this situation occurs when newly developed technologies vie for satisfying a need previously met by an earlier technology. For example, the basic need to be able to listen to music where and when wanted has been known for some time, however the industry went through several periods of high technological uncertainty as numerous technologies, each with its own benefits and drawbacks, have vied to be the portable music playing technology of choice. As a result, new portable audio technologies have replaced existing ones over time. Cassette players were largely replaced by Compact Disk players, which in turn were largely replaced by hard drive based mp3 players and later DRAM based mp3 players.

For the purpose of building this model, the levels of customer needs uncertainty and technological uncertainty were dichotomized. This simplification facilitated categorization and analysis of the different situations represented by the four quadrants. It also enables identification of option usage patterns expected to outperform alternatives for each quadrant. The ability to classify industries is important to the research process here in that it allows focus and reduction of alternative hypotheses.

However, at the same time it is important to note that uncertainty levels are not, strictly speaking, binary in nature (i.e., low or high) but rather belong somewhere along some continuum. Uncertainty levels change over time and can result in movement between the quadrants when they are large, and more nuanced movement within a quadrant when small. Also, unlike risk in financial markets, levels of customer needs uncertainty and technological uncertainty are affected by firms' investments. For example, introducing a "new to the world" product into a market that had not previously been supplied results in feedback from the market and changes the uncertainty of demand. While time resolves risks in financial markets, action reduces the types of uncertainty discussed here.

Real options reasoning suggests firms hold options to manage uncertainty. Since the kind and type of uncertainty differs between the different quadrants in the model, the type of options held by the firm following real options logic in each quadrant would also differ. The firm following real options reasoning reduces the likelihood of unwanted performance outcomes, but this benefit does not come without cost. Developing and holding options is expensive, which in turn has performance implications.

Full Commitment and Survival Bias

In each environment the single highest performing firms may be those that made winning bets on market and technologies in advance and held no options, if there were such lucky firms. Conversely, the firms that made incorrect bets in their full commitments to both are likely to exhibit the worst performance. These groups of firms may be effectively thought of as representing one type – full strategic commitment to both technologies and needs. These firms serve as exemplars of what Raynor (2007:1) terms "the strategy paradox." Both groups make bold strategic commitments, which result in high performance when the firm guesses right and poor performance or exit when the firm guesses incorrectly.

Consider the introduction and evolution of the videocassette recorder business discussed in Raynor (2007). The consumer VCR was a new to the world technology.

Market needs were largely unknown. What premium would customers put on higher picture and sound quality? How would consumers use it: for watching prepackaged videos or time shifting over the air TV shows? Sony and Matsushita both made commitments based upon specific guesses of what customers would value. Sony bet that high picture and sound quality would be worth a price premium to consumers and that consumers would use the machines for time shifting. It developed Betamax. Matsushita bet customer needs would be greater for lower cost, lower picture quality machines with longer recording and playback capabilities capable of recording feature length films. Matsushita developed VHS. As the market developed, VHS won over Betamax. Sony stopped making Betamax and eventually licensed VHS. Neither firm could have known what would happen prior to product introduction. Sony's bet on Betamax was not stupid, it was just unlucky. It is unlikely Matsushita was prescient, rather it was lucky in this case.

The extreme performance outcomes of firms making strategic commitments increases the possibility for attribution bias and survivor bias in research topics such as this one. In the case of the firm guessing successfully, it would be a mistake to attribute the performance solely to their approach. In order to see whether such firms actually have consistently high performance, as opposed to being lucky at one point in time, they need to be studied over time. Frequently, the firm that is unlucky in its commitments exits. Most research methods do not correctly identify or investigate firms that do not survive. Accordingly they risk mistaking the relationship between the firm's actions and its performance. Further complicating this picture is the tendency of firms that survive initially to become more competent, or more reliable, and further reduce their mortality rate (Levinthal, 1991). Firms with past successes may be buffered from current troubles by their organizational capital, financial and otherwise (Levinthal, 1991). This means that they may exhibit relatively high long-term performance at the firm level even though specific commitments that they make may sometimes fail.

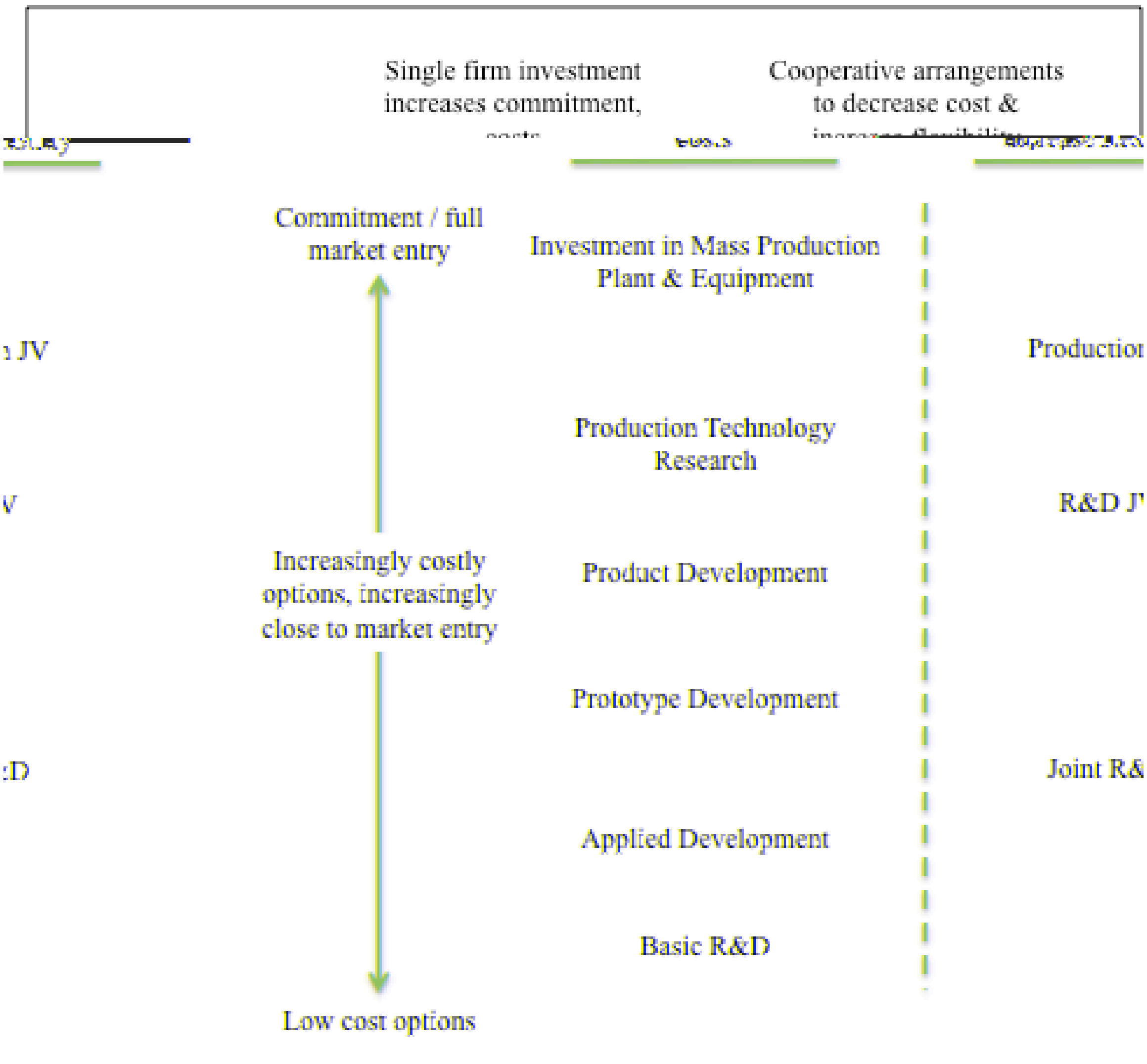
While these issues could be serious in a cross sectional study design, they are reduced by a design that considers firm and industry attributes and performance over time, as a string of luck is far less likely than a single lucky hit. A study design that covers an industry also has the benefit of capturing exit in addition to performance of firms that stayed in the industry. Accordingly, the research approach followed here addresses the survival bias issue by looking at a whole industry over an extended time period.

Width and Depth of Real Options Portfolios

This research identifies portfolios of real options, relating to technologies, held by firms in a single industry. The width and depth of these portfolios is important as these portfolios can take a variety of shapes. These different shapes will have different cost structures and implications about the relative flexibility they offer.

Investments in technologies can be conceptualized as belonging to different levels relating to the degree of commitment, flexibility gained, and proximity to market entry they reflect. The metaphor used below is that of an option ladder, where higher rungs represent increasingly expensive options that come increasingly close to a major commitment and market entry. Figure 1-2 below illustrates a simple technology option ladder.

Figure 1-2: Technology Option Ladder



Each additional option generated increases the value of the previous options in the same technology (e.g., McGrath & Nerkar, 2004). At the bottom of the ladder, several levels of R&D represent relatively low cost, flexible option-like investments. Moving up the ladder increases the proximity to a product market, but at an increase in cost and a decrease in flexibility. At the top of the ladder is investment in mass production plant and equipment. The cooperative arrangements to the right of the ladder represent ways firms can reduce required investment levels and share risk while increasing their proximity toward the market. Firms holding options on a single technology at many levels of this ladder are considered to have a “deep” portfolio of options in this technology.

The existence of multiple competing technologies is indicative of high technological uncertainty. Creating options on competing technologies increases the breadth of options held by the firm. A firm with all of its options on a single technology can be characterized as holding a narrow portfolio, whereas a firm holding options on a large number of competing technologies can be said to have a wide portfolio.

Propositions

This section develops theory and introduces propositions based there upon. As discussed in the following chapter on research methods, the current research is only able to address a portion of the propositions introduced below because it focuses on one combination of uncertainty levels mirroring one of the quadrants in the environmental model. Failure to include propositions relating to other uncertainty level combinations would naturally raise questions in the reader’s mind. Accordingly, the propositions are presented in their entirety although some cannot be evaluated in this dissertation.

This research seeks to consider several basic questions about real options reasoning. First, do firms behave as real options reasoning (ROR) would predict? Second, do firms behaving as prescribed by ROR enjoy performance benefits over those not behaving as prescribed?

Real options reasoning predicts that firms will hold options in the face of uncertainty (e.g., Bowman & Hurry, 1993; McGrath, 1997). Published empirical research seeking to test this prediction is almost non-existent. The one exception, McGrath and Nerkar's (2004) study of patenting behavior in the pharmaceutical industry, found firms behaved in a manner consistent with ROR. However, one single-industry study is not enough to sufficiently support or refute this prediction. Accordingly additional research is required.

This dissertation develops theory based upon the existence of two types of uncertainty: market needs uncertainty and technological uncertainty. It develops a model with four combinations of high and low levels of these two uncertainty types. ROR would predict firms hold different portfolios of options based upon which quadrant they are in. For example, if technological uncertainty is high, ROR would suggest firms hold technology options, but if low ROR would predict firms not hold technology options.

Given this general framework, there are several potential analytical approaches that could be used to consider ROR's prediction. Comparison of the ratio of different options types (e.g., customer needs options versus technological options) held by firms in a single industry, would at first appear to be a suitable approach. However, customer needs options and technology options are not symmetrical and therefore attempts to compare across the two types are likely to lead to misleading or difficult to interpret results. Another potential analytical approach would be to compare between options portfolios held by firms in industries belonging to different quadrants in the model. However, without some major methodological breakthrough (e.g., discovery of a high quality, easy to measure, accessible proxy measure for options held), this approach would necessitate a research project much larger in scope than this one.

Rephrasing the question as: "Do firms generate and hold options in the face of uncertainty?" provides an alternative way to approach the issue; that is, to ascertain whether firms hold options relating to the type of uncertainty they face. The question, thus stated, does not require analysis between different types of uncertainty, but is nonetheless in line with theory. To control for the level and type of uncertainty, firms studied should belong to a single industry. Propositions stated below relate to the quadrants in the model where one uncertainty type is low and the other high.

> **P1*[1]:** If firms belonging to a single industry exhibiting high technological uncertainty and low market needs uncertainty follow real options reasoning, they will, all else equal, hold options on more than one alternative technology.

[1] Asterisks mark those propositions addressed by empirical research in this dissertation.

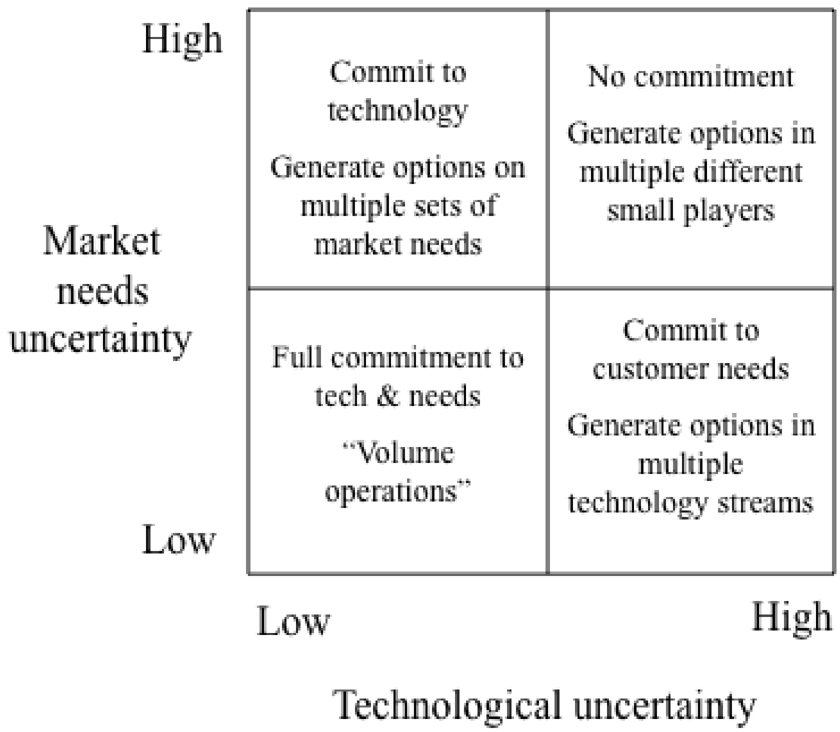
P2: If firms belonging to a single industry exhibiting low technological uncertainty and high market needs uncertainty follow real options reasoning, they will, all else equal, hold options on more than one competing market need.

Real options reasoning predicts firms in the low-low quadrant would hold no options and the high-high quadrant (quadrant C) would hold options on both market needs and technologies. Propositions are not developed for these quadrants. The high-high case may include complex hybrid options, which although of interest, are beyond the scope of this research.

Performance depends on how well the firm manages uncertainty, or in other words, how well the mixture of commitments and options the firm holds fit with the environment in which it operates. Looking retrospectively it is possible to categorize the firm's commitments and options portfolios as well as the level of revealed market needs and technological uncertainty. Firms that made commitments in the face of uncertainty are expected to exhibit performance extremes, and firms that made commitments in the face of *certainty* and held options in the face of *uncertainty* to exhibit more consistent performance. Figure 1-3 depicts the mixture of commitment and options this line of thinking predicts to fit best in the four environment types.

FIGURE 1-3

Uncertainty Levels and Best-fitting Uncertainty Management Approach



The lower right quadrant (quadrant C of the environment types model) of figure 1-3 above depicts a situation where needs are certain but technology is not. Here, firms committing to market needs and holding options on technologies are expected to outperform other firms when compared as groups. Firms making commitments to technologies in the face of uncertainty may exhibit higher performance than those holding options, but only when they are lucky enough to have committed to a bet that later paid off. Those firms making commitments which were not lucky would be left holding expensive, difficult to reverse investments that have small or no payoffs. Accordingly, they will exhibit low performance and may exit the market. Together, those firms making technology commitments in the face of technological uncertainty are expected to exhibit extreme performance outcomes. While most will underperform industry competitors holding options, occasionally a firm will be lucky and exhibit very high performance.

> **P3***: In the face of technological uncertainty, firms making substantial commitments to single technologies will exhibit the highest performance and lowest performance in their industry.

Firms developing and maintaining options on multiple competing technologies will have the opportunity to select the most appropriate technology as technological uncertainty is resolved over time, while having limited exposure to the downside on the technologies that did not pan out in the end. Technology options can be created through in-house investment in multiple R&D streams, licensing technologies developed by other firms, entering into joint ventures or other equity based investments with firms developing competing technologies. By committing to market needs, these firms will develop a greater understanding of market needs than outside firms, and will also benefit from markets being familiar with their branding.

> **P4***: In the face of technological uncertainty, firms that commit to a market need and generate options on multiple technologies to fulfill these needs will not exhibit performance extremes when compared to other firms in their industry.

Propositions P3 and P4 considered the situation in an environment characterized by high levels of technological uncertainty and low levels of market needs uncertainty. The upper left hand quadrant of figure 1-3 above describes an environment of high market needs uncertainty and low technological uncertainty, analogous with quadrant A of the environment types model. As a group, the most successful firms in this quadrant will commit to a technology and create options on product-markets where the technology may potentially be useful. These options may take one of several different forms, including working with multiple marketing partners, expeditionary marketing, and rapid cyclical product development to clarify needs in a particular market (Hamel & Prahalad, 1991). Firms that bet on a single customer need, rather than holding options on several, face a greater chance of betting on one that never materializes. This was the case with Sony's bet on Betamax VCR already discussed. Sony made one bet on market needs for VCRs. This bet was that market needs for VCRs would be for high picture and sound quality for use in time shifting over the air TV shows. Sony guessed wrong and the Betamax was beaten by VHS in the marketplace.

Similar to the case with technological uncertainty, those firms making lucky bets on market needs are expected to exhibit high performance because they do not have the cost of developing and maintaining options but gain the benefit of access to the market need that emerge. Those making unlucky bets and not holding options are expected to exhibit low performance and may exit. Rephrasing this logic into proposition form, P5 below states firms making market needs commitments in the face of market needs uncertainty will exhibit two performance extremes, high and low, when compared with competitors in their industry. Firms that made commitments based upon lucky guesses will have the highest performance; meanwhile firms making commitments based upon guesses that were not lucky are expected to exhibit very low performance, including exit.

> **P5**: In the face of market needs uncertainty, firms exhibiting the highest performance and lowest performance in their industry will have previously made commitments to market needs.

P6 predicts the situation for firms developing and holding market needs options in the face of market needs uncertainty. Developing and maintaining multiple market needs options is costly, therefore these firms are not expected to exhibit as high performance as those that make lucky singular commitments. However, by holding options on multiple competing market needs, these firms increase the odds that some of the options will eventually become "in the money." Accordingly, the likelihood of extremely low performance is much less than that of the committing firms discussed in P5.

> **P6**: In the face of market needs uncertainty, firms that commit to a technology and hold options on different market needs applications will not exhibit performance extremes when compared to other firms in their industry.

The propositions above have considered the two quadrants of the model where one uncertainty type is high and the other low. Firms facing an environment in which both market needs and technologies are highly uncertain, as in the upper right hand quadrant, will benefit from developing both market and technology options. This may be achieved by holding multiple hybrid options, each of which represents a different combination of commitments to market needs and technologies. Examples of such options include ownership positions in multiple competing startup firms or equity based investments or joint ventures with existing firms (Folta, 1998; Hurry et al., 1992). This type of environment is complex as are the potential hybrid options. While of interest, this quadrant does not present an opportunity to isolate and study one of the two uncertainty types discussed here. For these reasons, detailed theorizing relating to options behavior and performance for environments represented by this quadrant is left for future research.

This section has developed and introduced propositions based upon real options reasoning. The empirical research in this dissertation is comprised of a historical case study of the flat panel (FP) TV industry, for reasons discussed in Chapter two (See Method Choice and Industry Selection Requirements sections). The FP TV industry aligns well with quadrant C of the model. This research does not include other quadrants of the model. The empirical research in this dissertation applies to the propositions marked by an asterisk.

CHAPTER TWO: RESEARCH SETTING AND METHODS

The purpose of this research is to investigate how firms manage uncertainty through the use of option-like commitments. This study includes both confirmatory and exploratory aspects. The previous chapter presented theory suggesting firms should hold options in the face of uncertainty. It also posited that, in the face of uncertainty, firms mainly investing in substantial commitments rather than multiple, option-like investments (which may also be considered partial commitments), will exhibit extreme performance outcomes, including both very high or very low performance. Accordingly, confirmatory questions of this study include: "Do firms generate and hold options in the face of uncertainty?" and, "Do the firms holding options portfolios appropriate for the uncertainties they face appear to benefit from them?" The exploratory aspect of this research seeks to develop deeper understanding of real options based upon observations of patterns of firm behavior relating to option-like investments over time.

This chapter begins by stating basic assumptions and reasons for choosing the research methods and setting employed in this dissertation. It continues to introduce details of the study approach, including data requirements, detailed description of data sources, study management, and study scope.

Method Choice

Based upon the questions asked and the goals of this research, an historical case study covering a single industry is the most appropriate approach to empirical study. This research investigates the size, nature, and frequency of incremental commitments made by firms in a single industry over time. In doing so, it seeks to answer how, who, why and when questions regarding options generation, options maintenance, exercise, and abandonment. Yin (2003) suggests the case study method is suitable for research relating to these kinds of questions. The research approach is similar that used by Numagami's (1999) study of the development of the liquid crystal display industry, and can be described as an historical embedded case study. It is embedded in the sense that both firm level and industry level are considered.

The historical, industry wide approach is particularly suited to the research questions of this thesis because it allows investigation of firms through the entire spectrum of performance outcomes over time. The ability to include firms that exit the industry is a crucial requirement for this research. Firms making large commitments and holding few options are expected to exhibit extreme performance outcomes (i.e., high performance or organizational mortality). Therefore, to avoid producing misleading results showing only part of the picture, this study needed to include firms that failed or exited the industry.

The ability to handle a variety of different kinds of data is also a requirement for this study. There are a large number of potential types of incremental commitments firms make simultaneously relating to the same uncertainty. A study that limits itself to a single type may fail to capture alternative types of incremental commitments. Because the historical case study method does not limit itself to a single type, it allows for a broad view of the different incremental commitments that are made in the context they were made. Importantly, it also allows for opportunistic inclusion of additional data sources as they were identified in the course of performing the research (Eisenhardt, 2002).

As the levels of options developed or maintained are expected to change with the degree of uncertainty, the impact of timing and sequence are important to building an understanding of this phenomenon. Unlike some other methods, the historical industry wide case study approach allows incremental commitments to be understood in the relevant temporal contexts in which they were made.

Several requirements of this study are met by the focus on a single industry. First, this study requires the entire spectrum of performance outcomes, including exit, be observable. Focusing on a single industry enables identification of players at different times, and therefore exiting firms. Second, firms should face similar levels of environmental uncertainty to allow comparison between their performance outcomes. Third, the relevance and costs of different potential option types differs across industries. Accordingly, controlling for industry reduces potential for misinterpretation involving comparison of investments in and management of options.

As discussed in more detail below, this study includes industry-level and firm-level components. The industry-level component consists of an historical account of developments in the industry, and is intended to provide a background for general understanding of the industry including uncertainty and technological developments. The firm-level component tracks options and commitments developed, maintained, and abandoned by the firm as well as performance realized, in a series of firm-level case studies. Investment behavior and performance outcomes are analyzed at the firm (single case) level as well as between-firm (e.g., between-case) levels.

Alternative approaches to the historical case study, including statistical analysis of archival data, survey methodology, and simulation, were considered, however given the questions and goals of this research, there were significant shortcomings with each of these approaches. Statistical analysis would have required suitable archival proxy measures for uncertainty as well as technological and customer needs options, however suitable proxies could not be identified. Issues with a survey-based approach included the inability to sample firms that exited as well as difficulties of identifying suitable respondents. Finally, simulation is another alternative that has been used in prior studies investigating organizational search (Levinthal & March, 1981 in Miller & Arikan, 2004; Miller & Arikan, 2004). However, there is no clear way to differentiate between the different kinds of uncertainty, market needs uncertainty and technological uncertainty, that reflects the asymmetries between the two. Based upon an evaluation of the pros and cons of the different potential research approaches, the historical case study approach taken here is not only suitable for the goals and questions of this research; it stands out as being far superior to alternatives given the situation.

The theory presented in the prior chapter considers four different types of environments (four quadrants in the model). In light of this, the reader may be asking: why study only one industry? Or, why limit the research to only one of the quadrants? Obviously, it would have been better – all else equal – to have a research design that allowed for analysis of multiple quadrants. Unfortunately, it simply was not feasible to do while ensuring a high quality level of data gathering and analysis. Building a deep understanding of the industry necessary to properly analyze events is time consuming. The resource requirements to perform this research on a single industry were quite substantial. To put this in perspective, the entire relevant holdings of the Japanese National Diet Library (the Japanese equivalent of the United States Library of Congress) were examined in the course of performing this research. An approach using more limited sources would have been possible, however, it would not have produced the rich and thorough picture this dissertation seeks to provide. Given this situation, the author decided to focus on performing high quality research on a single industry at the expense of being able to talk about other quadrants in the model.

This section gave a brief overview of the method and why it was chosen. The following section discusses general assumptions made in this research.

Methodological Assumptions

This section introduces basic assumptions behind this research and how it was conducted. At a fundamental level, reality is assumed not to be fractured and events are real, however observation is imperfect. This research process is, by nature, subjective and can never perfectly objective, although the ways and degrees in which it is subjective may differ substantially depending on the research approach taken.

This dissertation uses qualitative research methods relying heavily upon publicly available data sources. It is assumed that data from the sources used is imperfect but in general reflects real events. The data sources used are likely to contain mistakes in measurement and recording of observations. They may fail to recognize or include observations as well. Most importantly this means that even the most exhaustive gathering of existing data cannot be assumed to uncover all relevant observations. In other words, a failure to observe an event cannot be construed as evidence that it did not occur. It also implies that triangulation is useful to reduce errors in the recorded observations. Having said that, there is no reason to expect a systematic bias in how the data is flawed that would have impact on this study.

In addition to gathering publicly available data, interviews were also conducted. The accuracy of interview data is assumed to be limited. In addition to errors discussed above, informants may fail to remember correctly past events or color these events differently.

Research can never be considered perfectly objective, but rather is always to some degree subjective in nature. This research develops historical timelines and case studies of events at the firm and industry levels. This process is subjective in the sense that it requires choice of data to use and also interpretation of the data in question. Therefore, there exists the potential for this analysis of the data to stray from reality.

This section discussed the basic assumptions behind this research. The following section presents the reasoning behind the selection of the target industry for this research, the flat panel TV industry.

Industry Selection Requirements

The flat panel TV industry was chosen for study because it was suitable both with concern to its ability to inform theory discussed above and because it met other criteria including feasibility discussed below. To aid interpretation, an industry exhibiting high uncertainty of one type together with low uncertainty of the other was a requirement of this study. Over the study period, this industry was characterized by high levels of technological uncertainty due to competing technologies, while exhibiting low levels of customer needs uncertainty. This combination therefore meets the requirement.

Feasibility related criteria included the number of players in the industry as well as data accessibility. This research performs analysis at the firm level as well as at the industry level. Accordingly, an industry with a large number of players would not be suitable, as analysis of individual firms becomes less feasible as the number of players increases. The Flat Panel TV industry had a manageable number of players and therefore fit this criteria. It was also judged to be suitable with regard to data accessibility. Major players in the industry are publicly traded firms, and accordingly have to make public financial and other information judged to be material with regard to current and future prospects. Furthermore, the industry is followed by the business press and the technology media, financial analysts, and market research firms. Accordingly, access to a large variety of relevant data was judged to be feasible. In the course of discussing industry selection requirements, this section found the flat panel TV industry is suitable because of the pattern of uncertainty it exhibits. The following section describes the uncertainty levels in the industry in more detail.

Uncertainty levels in the flat panel TV industry

As discussed above, the flat panel TV industry is characterized by high technological uncertainty and low market needs uncertainty. Over the study period, the TV set business exhibited dramatic changes in technology, moving from TV sets based upon a combination of CRT displays using analog circuitry to those using flat panel displays driven by digital circuitry. The change to digital standards was made by the industry using standards groups and with government involvement. New standards were agreed upon and understood by industry members far in advance of their implementation. As such, they actually may have reduced rather than increased uncertainty. Display technology used in TV sets, on the other hand, exhibited high technological uncertainty. Multiple display technologies, including active matrix liquid crystal, organic electroluminescence, plasma display, and others competed to be the technology of choice for TV sets. These technologies offered different advantages and disadvantages as TV displays. Given these differences along with different technology development vectors for each, it was uncertain which would become most viable in the marketplace. The technologies are discussed in more detail in Chapter three.

Market needs uncertainty for the flat panel TV set industry was low. Incumbent firms in the industry had produced CRT based TV sets for many years and had well developed understanding of how people watched TV and what their needs and expectations from TV sets were. The preference for flatter, thinner TV sets had been known long before their introduction. Although market needs uncertainty was low, it would be an overstatement to suggest it was zero. In particular, uncertainty remained regarding how the market would react to different pricing levels for flat panel TVs.

However, the flat panel TV market size was expected to be very large once production costs fell to a level at which consumers would buy TVs. The potential for gaining access to a very large future market may have reduced firms' perceived uncertainty levels toward developing flat panel technology. Indeed, uncertainty about future market size may have mattered little to firms because it was very large in any estimation. Chapter four provides more detail on the history of this industry's development.

The characteristics of uncertainty identified in this industry fit the requirements of this study. It is also worth noting, as discussed below, that this setting has the advantage of being novel in the academic literature on strategic management.

Novelty of this research setting

Characterized by dramatic innovation and investment, the area of flat panel displays and TVs has gathered much attention recently. Improvements in image quality, and at the same time, dramatic increases in affordability have taken flat panel television from novelty to mainstream status. Despite the dynamic nature of this industry, it has not received major attention in the academic literature in the field of management. There are as yet no articles relating to it in strategy journals, and only one academic journal article in management more broadly (i.e., Mathews, 2005). This low level of attention to date increases the potential novelty of the contribution of this research.

The discussion above has introduced the research setting and argued why it is suitable for this study. The remainder of this chapter discusses how the study was designed and implemented, including the data requirements, data sources used, and scope of the study.

Data Requirements

This section begins by presenting data requirements for identification of option-like investments and commitments. Next, performance data is discussed. Finally, it presents requirements for additional types of data used to aid interpretation of the above.

Option-like investments may be identified through direct and indirect observations. These investments are directly observable in some cases (see Table 2-1 below), but in many cases they are not directly observable to parties outside the firm in question. In such cases, indirect observation may be possible. For example, if a firm does not report specific R&D streams or funding, the existence of relevant R&D may not be directly observable, however the existence of relevant patents is observable and implies that an investment in developing such technologies has been made. Accordingly, this research requires data sources covering both direct and indirect observations of option-like investments.

The ability to place option-like investments in temporal perspective is important to this research, and therefore many of the observations are organized as events in a timeline. Historical data on other events important in the industry development was required in order to provide perspective. Beyond historical events, historical data trends including production volume, investment in plant and equipment, sales, and market share were additional requirements to further augment the historical picture.

Table 2-1: Directly and Indirectly Observable Evidence of Real Options

Directly observable evidence	Indirectly observable evidence
• Announcement of new production plant or fabrication line (investment plan and/or startup) • Announcement of Joint Venture or other cooperative activity • Announcement of sourcing agreement • M&A activity	• Prototype development announcements • Trade show presentations • Announcements of sample shipments • Changes to product lineup • Patents

This research seeks to understand performance outcomes relating to the use of option-like investments by firms. Accordingly, performance data is required. Relevant performance data included both financial performance data and market share data. Additionally, evidence of industry entrance and exit was required.

Additional data sources that can aid interpretation of events in this research increase the richness of description and are therefore of considerable value. Interviews are one suitable data source for this purpose, however additional sources (e.g., published interviews and presentations) were also available in some cases and therefore were added to the data requirements.

Data Sources Used

The flat panel TV set manufacturing industry and the related flat panel display industry are large and gather a significant amount of attention from industry players, industry groups, industry analysts, governments, journalists and consultants. In fact, the amount of coverage is substantial enough that it is important to narrow the sources down to a manageable number. Data sources are classified into two groups: the main sources used for the bulk of the data, and supplementary sources which were used to augment the main sources. The main sources used were primarily annual publications covering the industry, including the Sangyo Times series, the Nikkei FPD series, and the Fuji-Chimera series introduced in more detail below. Supplementary sources of data included reports by financial analysts, newspaper and monthly publications, and press releases.

The three annual publication series above were chosen as main data sources for several reasons. With first issues beginning in 1990, the length of coverage over time offered by Nikkei FPD and Sangyo Times was important. Although the length of coverage of the Fuji-Chimera series is more limited, it was included because it contains valuable data not available in the other two sources. More generally, there is some overlap of data included between the different series, however each one includes substantial unique data. All three main sources are written in Japanese.

Access to these sources was also important. The Japan National Diet Library holdings include all issues of the Sangyo Times series as well as the majority of the issues in the Nikkei FPD series, and Fuji-Chimera series for the period 2000 - 2007. Finally, it is also worth noting that these sources have been cited in other academic research on flat panel technologies (e.g., Numagami, 1999). The three series are examined in more detail below.

The Sangyo Times series began in 1990 and has been published annually with the exception of 1991. It focuses on flat panel display technologies, and covers televisions as a major application of these. Earlier issues cover only LCD, but coverage of additional flat panel technologies commenced as soon as R&D activity became visible through prototyping and other activities. Each issue includes an overview section at industry level as well as firm level and plant level entries. Firm level entries cover both past and planned R&D, cooperative arrangements, prototype exhibitions, and investments in production. Plant level entries include location, capacity, product line, and number of employees. Past and future changes at the plant level are also listed. Sangyo Times Incorporated also publishes an annual semiconductor industry series and a daily semiconductor newspaper in addition to other business related publications.

Access was arranged for all issues of this series. The firm level data gathered from this series included: timeline event data, locations and capacities of production facilities, and production volume and investment trend data.

Nikkei FPD series is published by Nikkei BP, and belongs to the same group as the Nikkei Shimbun, the major Japanese daily business newspaper. Nikkei FPD is closely related to a monthly periodical called Nikkei Microdevice, which covers semiconductor and flat panel technology and industry developments. Nikkei FPD is also related to an annual trade show and conference held in Japan. Each year, FPD includes summaries of interviews with key managers in firms producing flat panel displays, computer monitors, televisions, and other related equipment. It also contains presentations by industry insiders relating to the industry, applications such as television, and new technological developments. Prototypes and new products of particular importance are listed. Finally, FPD also provides a multi-year summary of production capacity, investment in plant and equipment, and flat panel production revenue at the firm level.

Access to Nikkei FPD issues including 1990 and 1994-2008 was arranged. In 2002, the series changed from having one issue per year to having several specialized issues per year. Specialized issues were focused upon industry analysis, strategy, technology, etc. Although the format changed to a degree and coverage increased with this move from single to multiple issues, the portions of relevance to this research continued to be included. Not all of the specialized issues were publicly available for each year. However, this did not significantly impact the research. Interview summaries were available for all years. Production, investment, and capacity data were available for all years except 1999, as the multiyear data presented in each issue covered gaps in prior years. The FPD series includes a list of related Nikkei Microdevice articles for the prior year starting in 2003. It would have been convenient if this data were available for every year, however, as these contents overlap with the firm level information in the Sangyo Times, it wasn’t a requirement. Table 2-2 below provides a summary of the Nikkei FPD issues used, and the contents of each. Finally, it is worth noting that additional timeline and other data were gathered from additional articles and presentation data as it appeared throughout the issues for which access could be obtained.

Table 2-2: Nikkei FPD Issues Used

Year	Special issues included	Prototype, New Products List	Nikkei Microdevice Article List	Production, Capacity, and Investment Data	Interview Data
1990		Y			Y
1994		Y		Y	Y
1995		Y		Y	Y
1996		Y		Y	Y
1997		Y		Y	Y
1998		Y		Y	Y
1999		Y		Y	Y
2000		Y		Y	Y
2001		Y		Y	Y
2002	Business	Y		Y	Y
2003	Business, Strategy	Y	Y	Y	Y
2004	Business, Strategy	Y	Y	Y	Y
2005	Business, Strategy, Technology	Y	Y	Y	Y
2006	Business, Strategy	Y	Y	Y	Y
2007	Strategy, Industry Analysis, Television				Y
2008	Market, OLED, Television	Y	Y	Y	Y
2009	Company Analysis				Y

Fuji-Chimera series is an annual publication produced by a market research firm, Fuji Chimera Research Institute. This series is regularly used by academic researchers in Japan[2]. Access was arranged for all issues for years 1998 to 2007.

Fuji-Chimera includes detailed quantitative data on production volume, pricing, and market share for both displays and products including televisions using displays not available in Sangyo Times or Nikkei FPD. Data is segmented by display technology type and application. Inside major display technology types, the data is further segmented in

[2] Professor Munehiko Itoh of Kobe University.

to different size groups. Firm level analysis, including recent developments, performance, and future plans is included for major firms within each display technology.

Supplementary Data – Print sources

The need for performance data was mentioned in the section on data requirements. This need is partially addressed by the market share data in the Fuji Chimera series. Evidence of exit is also available in the three annual series introduced above. Additional performance data was gathered from company annual reports.

Focal firms of this study are diversified and generally do not provide financial data for the TV business on its own. Furthermore, segment naming and content varies by firm and changes over time. For example, recent reporting of business segments including television set business vary from Sanyo's consumer segment to Sony's electronics segment to Toshiba's digital products segment. Given these issues, this performance data must be interpreted with care.

Other supplementary data sources included company press releases, newspaper articles, and security analyst reports. These sources served to augment and add greater detail to the annual series data introduced above. Although each was useful in its own way, they all had disadvantages as well. Available and relevant press releases and security analyst reports are all relatively new, and therefore it is difficult to gain an understanding of events more than a few years in the past. Furthermore, an evaluation of press release content failed to identify events that other sources had not already captured.

Newspaper articles could have been used as the main source of timeline data in place of the three annual series discussed above. However, for several reasons discussed below, newspaper articles were used to supplement other sources instead. Historical events were identified using the annual serials, and newspaper articles were used to obtain additional details of specific events where needed. This approach was adopted for a number of reasons. First, access to relevant daily news sources could not be arranged consistently through the entire study period. Second, an examination of relevant English language newspapers uncovered problems with report quality and timeliness. Third, capturing a wide enough selection of papers to overcome quality and availability problems resulted in unmanageably large numbers of search results, especially for articles relating to Liquid Crystal Displays. Considering two of the annual sources are published by firms also publishing relevant daily newspapers, focusing on the annual publications was a more efficient way to gather the same information.

Beyond these print based data sources, patent data were gathered, interviews were conduced, and conferences and trade shows attended. These data sources are discussed in more detail in separate sections below.

Supplementary Data – Patents

Patent data is useful to this research, as it comprises evidence reflecting past R&D efforts made by firms relating to the technologies in question. A stream of patents belonging to a specific display technology can be construed as evidence the firm in question has an R&D program in place focusing on that technology.

Although patent data is useful, care is required in its interpretation for a number of reasons. Patent laws differ by country, and therefore patents cannot be directly compared between different countries. For example, Numagami (1999) notes the legal definition of "discovery" differs in breadth between US and Japanese patent law. As a result, the same discovery will have more patents under Japanese patent law and fewer under US patent law (Numagami, 1999). Furthermore, patenting strategies also vary greatly by firms. In the course of reading and interviewing it became evident that some firms in this industry have relatively extreme approaches towards patenting. One firm, for instance, discouraged patenting because they felt they were more effective at protecting their intellectual property by keeping it secret. Another firm encouraged its development staff to patent as much as possible to increase income from patent licensing. Correct assignment of patents to the relevant display technology is another issue which will be discussed later.

Data on display patents came from the Derwent patent database following Eggers (2007), and examination of several sources of patent data including USPTO and Japanese Patent Office data. Derwent's classification system allows the layperson to search for and select patents related to relevant display technologies. Given the significant difficulties in separating and assigning patents, especially with regard to display technologies, this is a valuable attribute. An additional benefit of Derwent data is that it covers related patents in multiple countries worldwide. To enable suitable use of this data, preparation was required.

After selecting and downloading Derwent patent data relating to Liquid Crystal Displays, Plasma Display Panels, and Organic Light Emitting Diodes, the data was manipulated and reorganized to form a relational database using Microsoft Access. This database is capable of a variety of outputs, however the chief one for this research gives the number of patents by firm, year, and technology type. Japanese patent data was extracted from this database for use in this dissertation. United States patent data was also analyzed; however it was not used in this dissertation due to anomalies in the data that could not be resolved.

In addition to Derwent data, reports by KSR Limited (2003) and Techno Associates (2006) on flat panel display patenting in Japan were also collected. These reports will be discussed in more detail later where appropriate, however they warrant mention here relating to the question of how accurately patents are assigned to display technologies. Both reports are created by reputable research organizations in Japan, and both include the international patent codes included in their classification schemes. Comparison of the classification schemes used in the reports uncovered significant differences between the International Patent Codes (IPC) assigned to each flat panel technology (LCD, PDP, OLED) used by the different organizations. Some IPCs were also assigned to multiple display technologies. This was true even at the more detailed level of the IPCs. This was the case for Derwent classification as well as the classification systems used by the Japanese firms. This should not be a surprise as many of the patents have applications to more than one of these technologies. The most prominent example is the thin film transistor (TFT) related technology, which is used in both active matrix LCDs and also in active matrix OLEDs. The number of patents counted using Derwent data is higher than those shown in patent analyses by other firms. This is due to Derwent's broader classification of patents compared to the other analyses.

The issue of patents being assigned to multiple display technologies required the decision either to proceed with all of the patents, or to exclude those that were assigned across different technologies. The purpose of patent data analysis in this dissertation is to understand relative focus on the different technologies at the firm level. If a firm holds patents exclusively on a single technology, this is evidence the firm may not be holding options on other competing technologies. If the firm has a stream of patents over time for each technology, it appears they are developing R&D based real options on competing technologies. Including patents assignable to multiple technologies potentially blurs the picture. For example, a firm purely pursuing LCD technology might have patents that databases assign to OLED as well. Accordingly, those patents assigned to multiple technologies were excluded from the analysis. This exclusion reduced the total number of patents in the analysis by approximately 15%.

The Derwent data gathered was for LCD, OLED, and PDP. In retrospect, it would have been advantageous to have patent data on Field Emission Display technology, although it has not gathered as much attention as the other technologies. However as access to the Derwent database was no longer accessible, patents on FED were not included in this research. This represents a limitation to this research, however its impact is not large because other data sources used in this thesis provide non-patent related evidence of FED-related investments and developments.

Supplementary Data – Patent Licensing Agreements

The thesis proposal included gathering data on patent licensing agreements, however this data was not used in the final research. The decision to drop this data was made for two reasons: first, there are difficulties interpreting patent licensing agreements in terms of option-like investments. Second, reporting of patent licensing is spotty, therefore it is impossible to develop an accurate database. These are discussed in more detail below.

In the course of performing research, it became clear that patent licensing did not play the role expected at the proposal stage. In the proposal, licensing was considered to be a way for firms to obtain opportunity for entry while reducing the level of commitment required to the technology in question. Licensing was also thought to serve as a hedge against unforeseen development of alternative technologies which the firm did not want to develop. In other words, the proposal assumed that firms could use licensing to keep up-to-date on a technology trajectory without investing in R&D themselves. However, timeline data and interview data suggested this was not the case.

In the course of assembling the timeline data, firms were often found to conduct joint development projects, which were followed by licensing agreements between the partners. These patent agreements essentially allowed the firms to use the technology developed. Rather than representing a new option, therefore, license agreements appeared to represent option exercise in these cases.

To get a clearer picture, industry informants were asked questions about the role of licensing. As with patenting in general, firms' attitudes towards patent licensing vary a great deal. However, informants disagreed with the idea that licensing could be used as a low cost way to keep current with technology. Rather, they suggested licensing as a legal requirement that needed to be fulfilled to do something they already knew how to do. Accordingly, licensing cannot be assumed to include some aspect of technology transfer.

Availability of data relating to patent licensing agreements was also problematic. A search was unable to identify any databases covering patent license agreements in the flat panel displays and televisions. Several sources used in this research including annual serials, newspaper articles, and press releases mention license agreements, however their coverage is incomplete. For example, Thomson S.A. reported having over one thousand licensing agreements, however only a small handful of these could be identified through the other data sources.

There is little published empirical work on licensing (Anand & Khanna, 2000). Perhaps the difficulty of obtaining good data on patent licenses has contributed to this.

Supplementary Data – Interviews

As a part of data collection, semi-structured interviews with industry insiders were conducted in Japan. Additionally, several academic researchers in Japan who have performed research related to flat panel displays and consumer electronics were also interviewed. All interviews were performed in person and in Japanese.

Even though the researcher was bilingual in Japanese and had his own social network in Japan, arranging interviews with industry insiders was challenging.[3] Although great care was taken to explain to potential informants their rights and protections and a Japanese translation of the invitation letter and consent form was provided, many potential informants declined to participate because they considered the interview topic to be too sensitive. Although the number of interviews is therefore rather limited, the interview data gathered was of great value to this research.

Most of the informants agreeing to be interviewed stated requirements for participation. All but one participant refused audio recording of the conversation. Also, all but two of the participants had time limitations and also refused additional follow-on questions after the interview. Several steps were taken to increase the accuracy of the interview data given these restrictions. First, where suitable, charts and diagrams were created in advance, and these were modified in front of informants with their guidance. This allowed verification on the spot. Also, full interview notes were written up immediately after the interview when possible, and at the earliest possible time when not.

Although the number of interviews was limited, the informants interviewed had very relevant backgrounds and provided substantial insight to this study. Within the limits of the ethics agreement, the informants can be introduced as follows. Informants were with or recently retired from the following firms: Sharp, Hitachi, Panasonic, Sanyo, and Toshiba-Matsushita Display Technology. As is common in Japanese firms, informants had experience in a number of roles in different parts of the firm. As a group,

[3] It is worth noting that several Japanese academic researchers in the field I spoke with indicated they also had great difficulty obtaining access to informants.

they had managerial experience in the following: flat panel screen development, television set development, television / panel plant start up, and television set marketing.

Supplementary Data – Trade Shows and Conferences

In the process of planning and performing this research, the researcher attended two trade shows and conferences. These included seminars on display technology, business and investor's conference and trade show at the Society for Information Display's (SID) conference in Los Angeles during May of 2008, as well as presentations relating to the flat panel television industry, television technology, and image quality and trade show at Flat Panel International in Yokoyama, Japan during October, 2009.

These experiences were useful in building a better understanding of both the industry and the competing display technologies. Notes relating to specific data points were integrated with other data discussed above. A journal was also kept discussing experiences at these conferences.

This section has discussed the different data types used in this research. To be of use, this data had to be suitably organized and manipulated. The next section deals with quality and productivity issues relating to these activities.

Quality and Data Management

Descriptive validity, in other words, factual accuracy (Maxwell, 2002), or authenticity (Lincoln & Guba, 2002), is crucial in qualitative research studies such as this one. Furthermore, Miles and Huberman (1994) state that study management tends to be poor with lone researchers. Several steps were taken to assure data quality, provide transparency, and promote efficient use of time and energy. Procedures and databases to track and manage work progress were developed and applied (Marshall & Rossman, 2006). Database templates were developed and used to gather and input data from different sources in identical ways. These database templates included areas to note entries requiring further investigation or verification. Additionally, each entry has a location to specify source, and in cases where it is important such as quotations, the page of the source the entry is from.

With the exception of interview data, the end data used in analyses in this research is structured in a number of databases in Microsoft Excel. This way of managing data was chosen because it facilitated different sorting and data analysis. Related data types from different sources were integrated to form these databases. In all cases, the data contains records about specific sources used. Furthermore, the integrated data in these databases was cataloged to aid in search and ease of use. For an example of how data was managed, please see Appendix three which provides timeline data extracted from the larger database.

Study Scope

The section below discusses the scope of the study in terms of time frame, display technologies included, and focal firms.

Study Time Frame. This study covers the period 1990 to 2008. Earliest mass production of Active Matrix Liquid Crystal Displays began in the 1990-1991 period. In this period, mass produced flat panel displays were used in laptop and other smaller format applications, but usage in televisions was virtually nonexistent. LCD TV began to take off commercially in the period 2000 onward. Although the study focuses on 1990 to date, relevant historical data covering developments up to 1990 was captured as well. For reference, Eggers (2007) studied the period from 1965 to 2005, and Mathews' study (2005) covers 1990 to 2004.

Technologies. This research primarily focuses upon three flat panel display technologies that have been used in commercially available television sets, including LCD, PDP, and OLED and their sub-technologies. The timeline data also includes Field Emission Device technology, which has been a topic of R&D for many years but has yet to be commercialized, as well as Plasma Addressed Liquid Crystal, which never reached mass production but was developed with the intention of use in TV sets. Rear projection TV is another form of large screen Television although it is bulky and cannot be considered a flat panel TV technology. Several technological variants use Liquid Crystal based projection, while others use CRT based and DLP technologies. While rear projection is not a central focus of this study, events relating to rear projection TV were included in the data collection when available.

Efforts were made to ensure this research included all relevant flat panel display technologies. Appendix two provides a typology of flat panel display technologies. It serves as evidence of the thoroughness of the identification of relevant display technologies.

Focal firms. The focal firms in this research are large Japanese consumer television set producers. These firms had large worldwide market shares in the television set business prior to the arrival of flat panel technologies. From the perspective of consumer electronics companies, flat panel televisions are replacement products (Helfat & Raubitschek, 2000) for CRT based analog televisions, and therefore flat panel technologies represent strategic options (Raynor, 2007) to these firms. Meanwhile, opportunities in the flat panel television industry may represent a growth option (Raynor, 2007) for flat panel display manufacturers not previously in the television business.

The theory presented in the prior chapter is primarily about strategic options and not growth options, therefore the focus on existing television producers is suitable. Other reasons for focusing on these firms are that Japan was the location where these display technologies were developed to a level where they were practical in consumer products, and Japan was also the earliest consumer market for flat panel television sets. Finally, because the researcher speaks and reads Japanese local data were accessible and interviews were possible.

To build a thorough understanding of the industry development and technology options over time, data on the activities of three other groups of relevant Japanese firms was collected. One group was comprised of minor Japanese TV producers that did not have CRT production capacity or invest in flat panel production including Funai and JVC. Another group included firms that had significant involvement in developing flat panel display technologies but did not have major consumer television businesses, such as Fujitsu. Finally, Canon was included as it had publicized its intention to enter the consumer television set business and invested in display technology for this purpose, but failed to enter in the end.

In addition to the Japanese firms, data on other groups of firms was also collected. These firms included large CRT based TV producers such as Thomson and Philips in Europe, and major flat panel display and television producers in Korea including LG group and Samsung group. Although these were not focal firms in the study, having an understanding of their activities was important to building the overall picture.

There are several display producers in Taiwan, including firms such as AUO and CMO. Although data was gathered on these firms, they are not included in the analysis in this dissertation. These firms are not TV set producers. They have generally played a role in the more commoditized part of the market for LCDs such as those used in personal computing applications. If the purpose of this research had been to document the history of display panels they would surely need to be included. However, as the focus is on flat panel TV set manufacturers, their inclusion would not be particularly helpful in this research.

Table 2-3 below summarizes the firms in this study. For focal firms, detailed descriptions of the option-like investments and changes in these over time as well as performance is provided in firm level case studies in Chapter five. The same chapter includes simplified case studies for the non-focal firms. Data gathering approach and content did not differ between the focal and non-focal groups, however, some of the non-focal firms had limited coverage in the sources used.

Table 2-3: Firms Included in this Study

Focal TV Firms	Non-focal firms	
	Television set manufacturers	Flat panel firms
Hitachi Matsushita / Panasonic Mitsubishi Electric Pioneer Sanyo Sharp Sony Toshiba	Minor Japanese TV set manufacturers: Funai Electric JVC Non-Japanese TV manufacturers: LG Group Philips Samsung Group Thomson	Key developers of FP Technologies: Fujitsu NEC FP developer that failed to enter TV business: Canon

Chapter Conclusion

This chapter has introduced the study setting and reasons for its suitability for examining the theory introduced in Chapter one. It presented detailed descriptions of the data used, and how this data was managed. Finally, it clarified the scope of this study in terms of time, firms, and technologies.

The following chapter focuses on the display technologies TV set manufacturing firms held options on. The technologies are described and their historical technological trajectories presented.

CHAPTER THREE: FLAT PANEL DISPLAY TECHNOLOGY TYPES AND THEIR HISTORICAL DEVELOPMENT

This chapter presents background knowledge on the display technologies and their development pathways leading up to the development of the flat panel television industry. This background knowledge is important for understanding the nature of uncertainty faced. It is also necessary for interpreting the analysis performed in the subsequent chapters of this dissertation.

The characteristics of the competing display technologies vary greatly. Accordingly, the development pathways they traveled and uncertainties they faced also differed. Furthermore, suitability for the various non-TV display applications differed between the technologies. Some technologies were suitable for more applications – providing opportunity for further investment – than others. The technologies discussed in this chapter include those that have been commercially used in TV sets as well as some that have not but were thought to have potential to be used.

Introduction to Display Technologies for Flat Panel TV applications

This section describes the different display technologies competing for use in the flat panel TV application over the time period of the study. The intention here is to familiarize the reader sufficiently with the competing technologies so as to facilitate understanding of the detailed actions of the firms over the study period. Significant effort was made to ensure the study covered the relevant technologies. Appendix Two contains a typology of display technologies as further evidence of this effort.

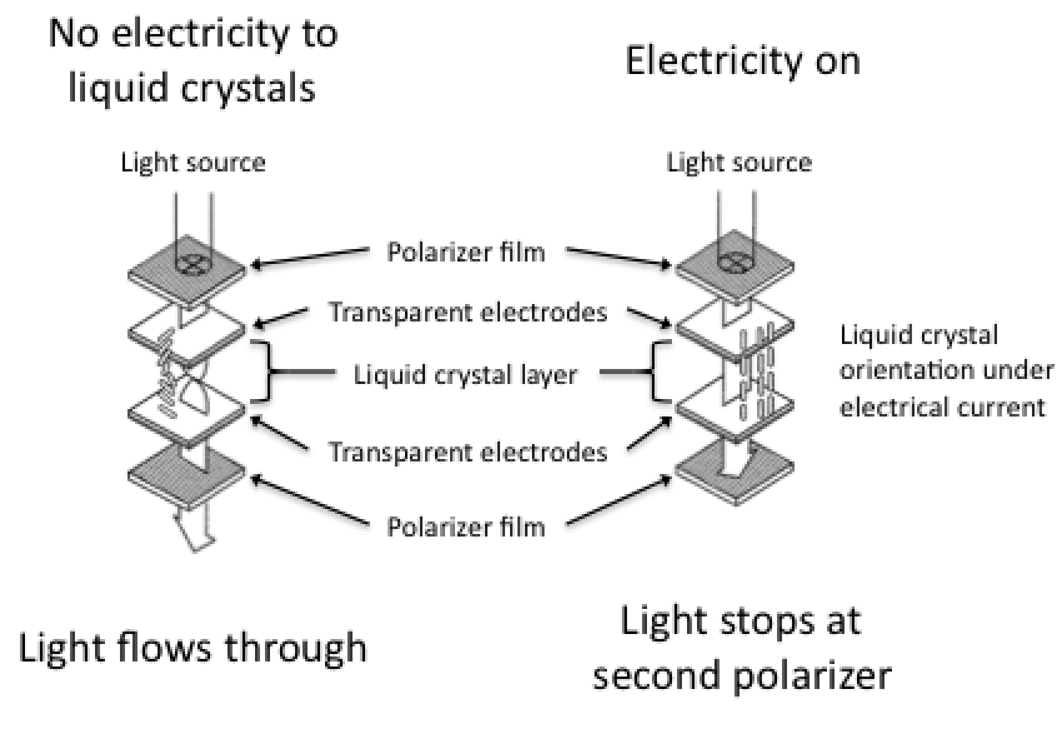
The technologies described in this section include: liquid crystal, plasma, organic EL, field emission display and plasma addressed liquid crystal. The most common of these is liquid crystal.

When used in a display, liquid crystal materials work like shutters controlling light flow. A white light source behind the liquid crystal shines through the liquid crystal layer and a number of filters that are layered on the display glass. Applying different levels of electricity to small areas of the crystals causes them to change their orientation, blocking or unblocking the light from shining through. Figure 3-1 depicts the general principle for the typically used twisted nematic liquid crystal mode.

In color LCD panels, pixels on the display are made up of different colored sub-pixels (typically, red, green, and blue), each of which has a color filter and an associated switch to control the liquid crystal shutter. Closing all of the shutters on the sub pixels results in the pixel becoming black. Leaving them all open results in white. These switches used to control the liquid crystal make up a matrix across the display.

Each LCD cell is addressed through a matrix, which can be active matrix (AM-LCD) or a passive matrix (PM-LCD). However, active matrix is required for higher quality, higher resolution applications. Passive matrix proved unsuitable for applications like TV. Thin Film Transistor (TFT) is the primary active matrix technology, although diodes can also be used for active matrix switching.

Figure 3-1: Diagram of Twisted Nematic Liquid Crystal Cells



Source: Based upon den Boer, 2005.

There are several sub-technologies belonging to TFT-LCD. These include: amorphous silicon (a-Si), low temperature poly-silicon (LTPS), and high temperature poly-silicon (HTPS). Amorphous Silicon is the predominant LCD technology today; it is used in flat panel televisions and a large variety of other applications. LTPS is capable of very high-resolution display, and has been used in high quality cell phones, cameras, and laptops. It has not been manufactured for very large screen applications. HTPS is also capable of very high-resolution display. HTPS are typically very small panels that are used in projection systems and near eye displays. With a few minor exceptions due to data availability issues, option-like investments in LCD are tracked at this sub-technology level in this dissertation.

Plasma display technology works in a way similar to florescent lighting. PDPs are made up of many sub-pixel cells, each containing electrical connectors, a gas, and a colored phosphor similar to those used in CRT displays. The color of the phosphor determines the color of the sub-pixel. When electricity flows, it causes the gas to become plasma, which in turn causes phosphors on the screen to glow. In order for the process to occur quickly enough to be useable in a TV, all of the cells need to receive a certain level of electricity even when they are dark. In the past, PDPs were developed using direct current and alternate current; however, direct current panels were found to have very short lifetimes, so this type was completely dropped by all firms in the industry.

Organic Electroluminescence (OLED) is a solid-state technology; electrical current is run to a cell containing OLED materials, which causes the cell to emit light. Color is achieved through one of two ways: white color OLED materials can be used with color filters, or red, blue, and green OLED materials may be used without filtration. One of the attractions of OLED to manufacturers has been its relative simplicity because it requires fewer layers than LCD and does not need a backlight. Like LCD, OLED cells are switched on and off by active or passive matrices. Active matrix is required for larger applications. OLED technology can be divided along the different kinds of OLED materials used: small molecule materials and large molecule materials. Kodak has key patents for small molecule and Cambridge Display Technology (CDT) has key patents for large molecules.

Field Emission Display (FED) is similar to having many tiny CRTs next to each other. Each pixel has its own electron gun (emitter), which is fired across a small vacuum to light a phosphor on the screen. A large number of emitter types have been developed by different firms interested in this technology. Many firms conducted R&D on this technology. Despite announcements that it would be used in television sets this has not happened.

Plasma Addressed Liquid Crystal (PALC) is another display technology briefly developed with the intention of being used in television sets. The general idea of the technology combined plasma and LCD. Plasma was used instead of TFT to drive the system and liquid crystals worked as shutters as with regular LCD panels. Development activities were limited to a small number of firms. Although PALC does not rank in the top potential flat panel television technologies in retrospect, it is of interest in that several firms did make option like investments in the technology.

This section has provided a brief introduction of the display technologies followed in this study. The section following considers the requirements for flat panel TV.

Potential Television Displays

There are a number of attributes of a display that make it more or less suitable for TV applications. These include: display size, image quality, energy requirements, lifespan, production requirements and production cost. These different requirements are considered below with regard to the major competing technologies. The bulk of this discussion focuses on three main competing technologies: LCD, PDP, and OLED. Each technology has moved along a different development trajectory and has faced different uncertainties over time.

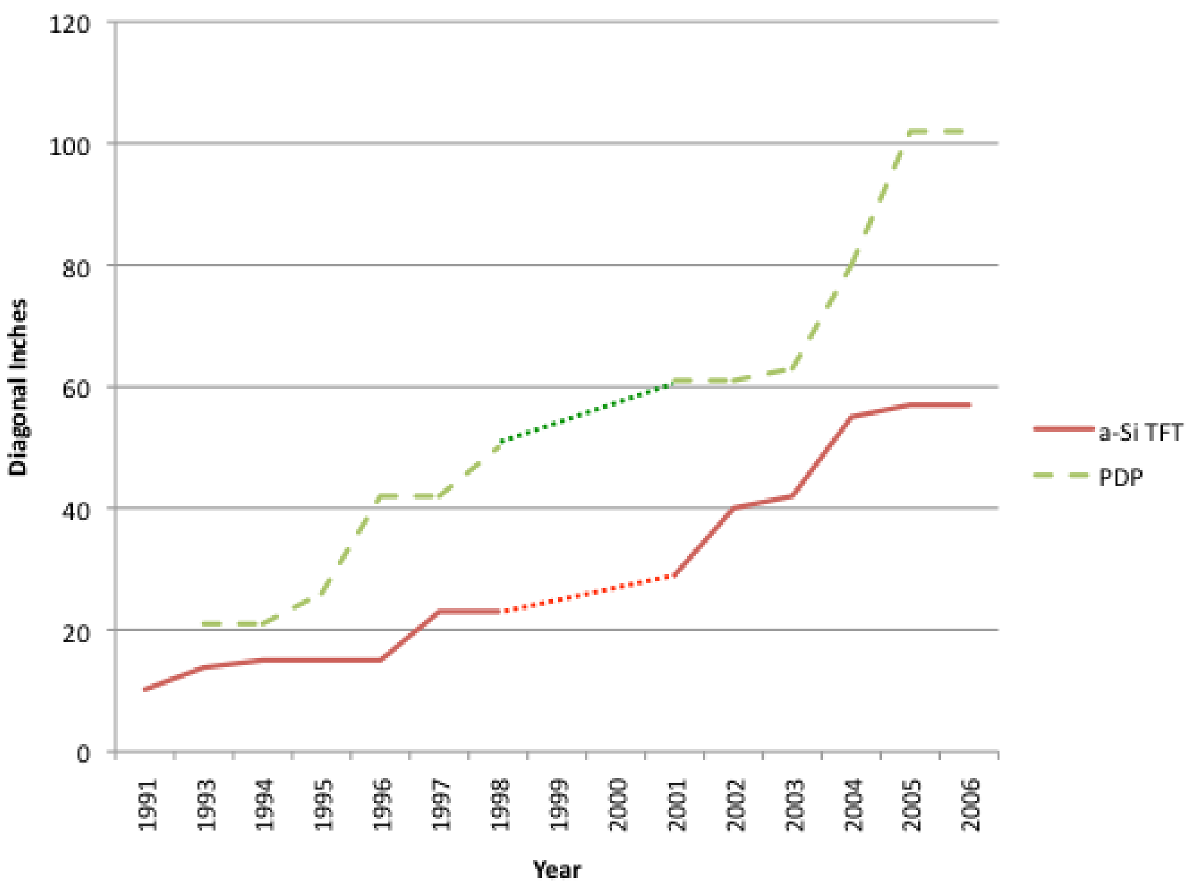
Data on specifications of flat panel displays was gathered as evidence of how the different display technologies changed over time with regard to the attributes discussed below. No single source carried panel specifications for the entire period, and there was a period of several years in the middle of the study where data was unavailable. The Nikkei BP series carried panel specifications for the years 1994 through 1995. The Fuji Chimera series listed panel specifications for the years 2001 through 2007. Additional observations outside of this time frame were available from these same sources in several instances, allowing some observations as early as 1991. Unfortunately, there is a gap in coverage between these sources for the years 1999 and 2000. In the charts below, years with no data are represented by dashed lines connecting the points where data was available. The entire database of panel specifications gathered here has over 2,800 records.

Display size. Television sets come in a variety of different sizes, however the main TV of the household tends to be a larger one in the living room of the house. Early TFT-LCDs were small and expensive. Limitations to LCD size were due to issues with production quality (larger screen = higher potential for defects) and limited size of early production equipment. Costs were also an issue. Only relatively recently has production of large LCD panels become feasible.

PDPs did not face the same size-related technological barriers as LCD and were produced in large sizes from early on. The situation with PDP was the opposite of LCD. It was difficult to make large LCDs, and difficult to make PDPs small. PDPs are comprised of many small cells each of which must hold a gas. It is more difficult to make small pockets than large. As a result, pixel size and display size started out large.

Chart 3-1 below depicts how the state of the art in terms of panel size changed over the years for LCD and PDP technologies. Early PDP TVs were released in the 1998-1999 timeframe, when the technology was already capably of sizes over 40 inches, twice the diagonal measure of the largest LCD panels at the time.

Chart 3-1: Largest LCD and PDP Panels by Year (Includes Prototypes)



Source: Nikkei BP, 1993-1997; Fuji Chimera, 2001-2007.

Commercial applications of OLED technology to date have been small. Although OLED technology should be scalable to large sizes, there appear to be issues with uniformity that surface with larger sizes.

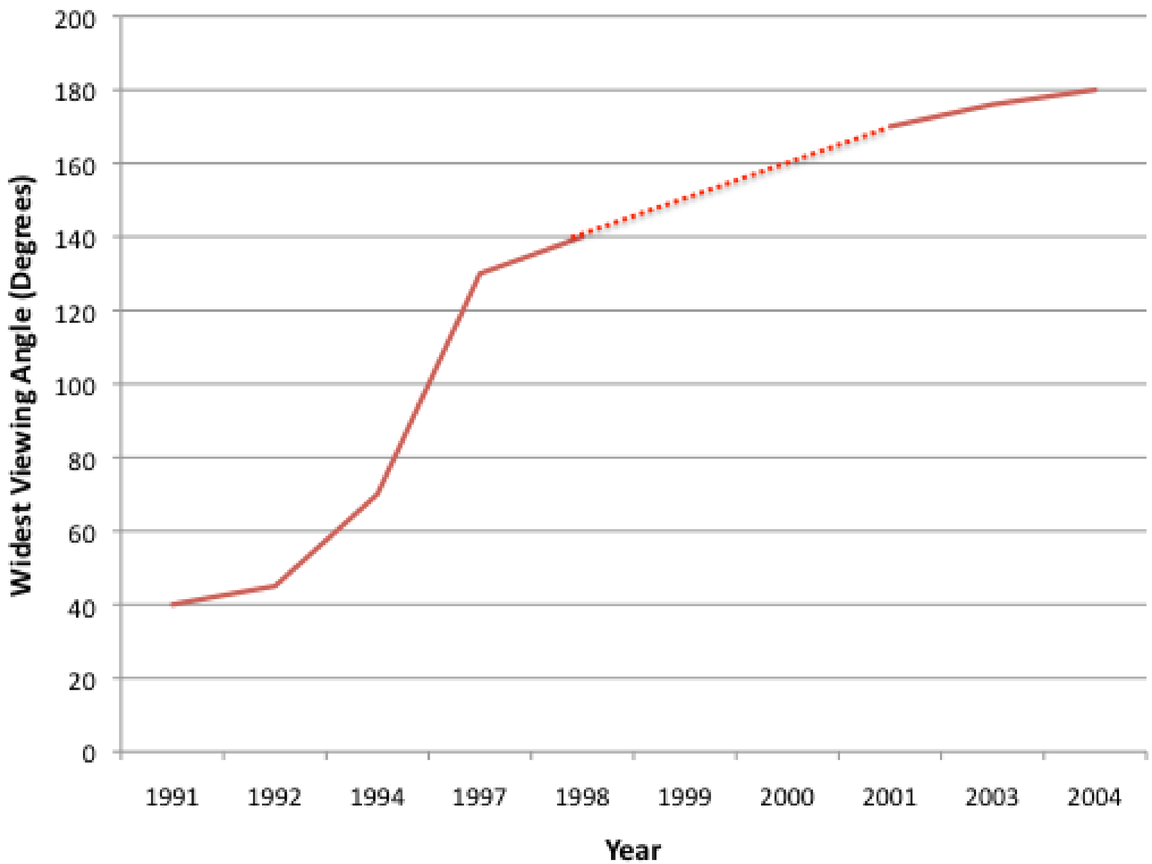
Image Quality. Experts on image quality for television displays typically look at contrast, quality of color and black levels, off axis visibility, reflections in the screen, and blurring (FPD International 2008 Forum Session P-22: "What High Quality Means for Each Type of FPD?" October 30, 2008: 15:00-18:00). Of these, contrast and color quality have improved in each of the technologies.

Black levels have been harder for LCD to achieve than the other technologies. Because Liquid Crystals act as shutters to allow or keep out light from the backlight, they do not readily create complete blacks. It is very difficult to keep some light from leaking through. Many incremental developments over the years have greatly increased the black level performance of LCDs. There was no particular turning point that can be identified as a breakthrough in contrast capability. PDP on the other hand has had very good black levels from an early stage in the development, as has OLED. While data exists on the panel contrast, it is not included here for two reasons. First, it does not necessarily address the black level, and second because contrast measurement methods used in the industry have been inconsistent, and interpretation of the data is difficult.

Early LCDs appeared washed out and had strange colors when viewed off the correct viewing angle. Although this was not a fatal flaw for some applications such as personal computing, it was considered to be a major problem for television use. Chart 3-2 below depicts the state of the art in LCD technology with regard to viewing angle over the period 1991 to 2004. Two major AM-LCD technologies have been developed to ameliorate this problem: In-Plane Switching (IPS), first successfully applied by Hitachi in 1996, and Multi-Domain Vertical Alignment (MVA), originally developed by Fujitsu in

1997. A number of variants have been developed by other firms based upon these technologies. Viewing angle has not been an issue with other display technologies.

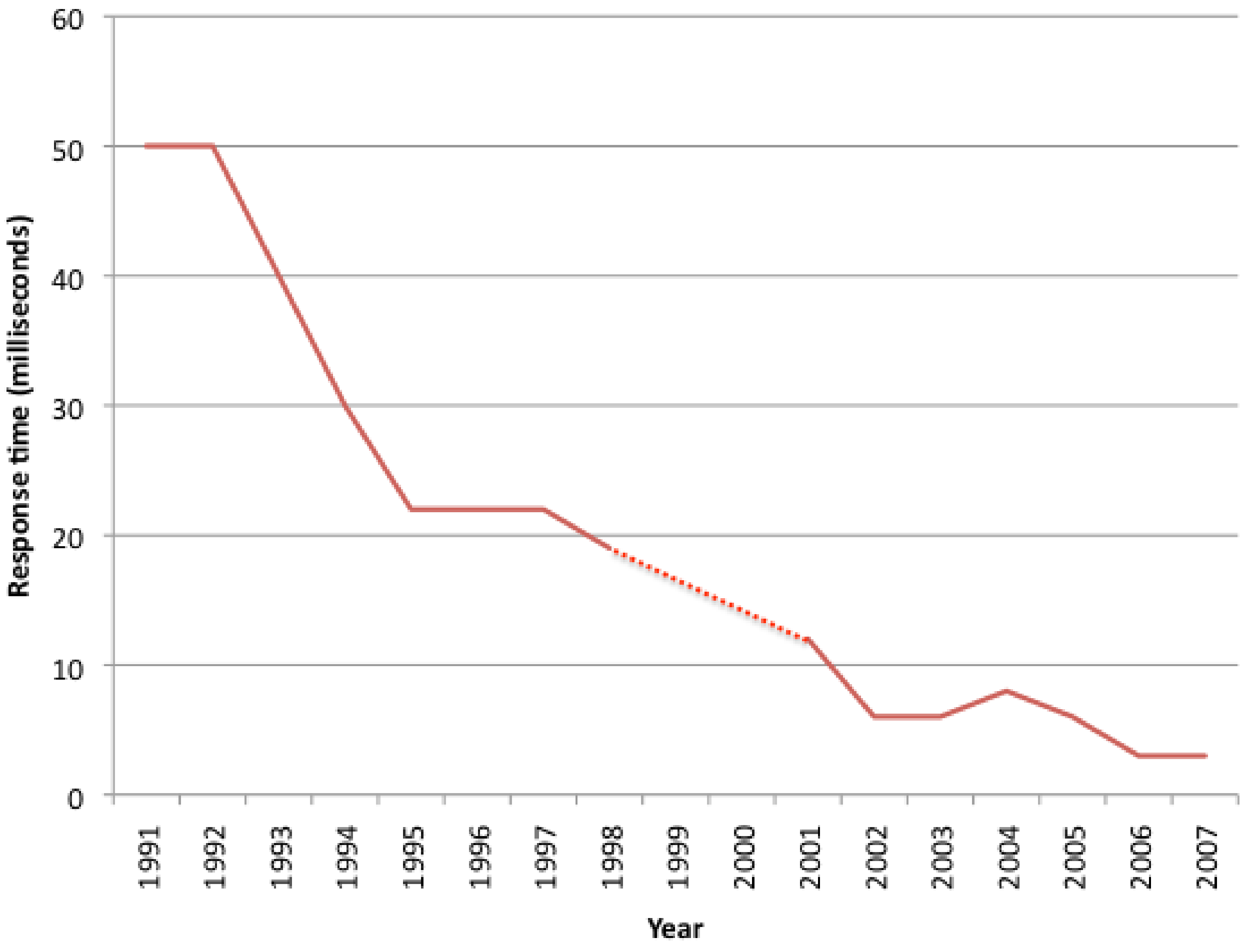
Chart 3-2: Maximum Viewing angle of LCD Panels



Source: Nikkei BP, 1994-1998; Fuji Chimera, 2001-2007.

Liquid crystals take time to react and change orientation after the electrical current is applied. Earlier LCD generations could not react quickly enough for moving pictures, resulting in a blur or trail behind parts of the image moving rapidly. As the case with viewing angle, this did not present a problem for many applications. For example, many computer users did not need displays to have fast reaction times. Chart 3-3 below shows how the reaction time of LCDs, measured in milliseconds, has improved over the study period. Although there is some difference of opinion, response time of 10ms or less is generally considered “good” for TV sets. Other display technologies discussed here did not have blurring issues.

Chart 3-3: Response Times of Fastest LCD Panels



Source: Nikkei BP, 1994-1998; Fuji Chimera, 2001-2007.

PDP has been prone to picking up reflections in certain lighting conditions. This issue appears to have been largely addressed through the application of filters on the PDP glass.

In the past, burn-in has been an issue in PDP and CRT technologies. Burn-in occurs when the same image is kept on screen for very long periods of time. Manufacturers have been able to largely eliminate this problem, and it was not really a major issue for consumer televisions because the same image did not remain on the screen for weeks at a time.

OLED is generally reported to have good characteristics with regard to picture quality aspects discussed here. However, OLED materials fade as they age, and this can have negative impact on color representation. Currently, the speed of degradation is considered to be a major problem with OLED.

There are other important aspects of picture quality that do not depend on the display but rather the electronics driving it. These include jerkiness in movie playback and digital compression artifacts. These aspects of the television performance are the result of image processing hardware and software and not the display itself and therefore are not discussed in detail here.

Energy Requirements. Energy usage is another area of display panel performance that matters to customers. OLED should generally require the least energy to run of these three technologies. PDP has had much higher energy requirements than the other technologies although it is improving. LCD requirements are in the middle. Operating the crystals does not require large amounts of power. Backlighting requires most of the power and approximately 90% of the light generated in the backlight unit is lost inside the set. Companies have been working on improved optical films, lower power backlight units using light emitting diodes instead of the conventional cold cathode fluorescent light (CCFL) units, and dynamic lighting which turns down the backlight in dark areas of the screen image, to reduce energy usage in LCDs.

Lifespan. Consumers have high expectations for how long a television display should last. Both LCD and PDP meet these expectations. PDPs have suffered from burn-in in the past, however this was mainly an issue when used to display relatively static images as in the case of displays used in train stations, for example. When used in normal TV viewing conditions, burn in should not have been a major problem reducing lifespan even with earlier models. The short lifespan of OLED materials, on the other hand, has probably been the primary reason why OLED display usage has not become widespread.

Production requirements. These technologies provide various challenges for the would-be manufacturer. LCD has a large number of stages in the production process. The cell, or sealed liquid crystal and thin film transistor matrix, must be produced under extreme clean conditions. This process is highly capital intensive. Current state of the art LCD fabs cost around $3 US billion to set up. The module assembly portion, where backlights and other electronics are attached to the cell to produce the LCD module, is highly labor intensive. It is not uncommon to see manufacturers divide the highly capital-intensive panel fabrication activities and the highly labor intensive module assembly activities into different locations.

PDPs are much less capital intensive than LCDs to produce (e.g., den Boer, 2005). The PDP production process has fewer steps than LCD and does not require extremely clean production areas.

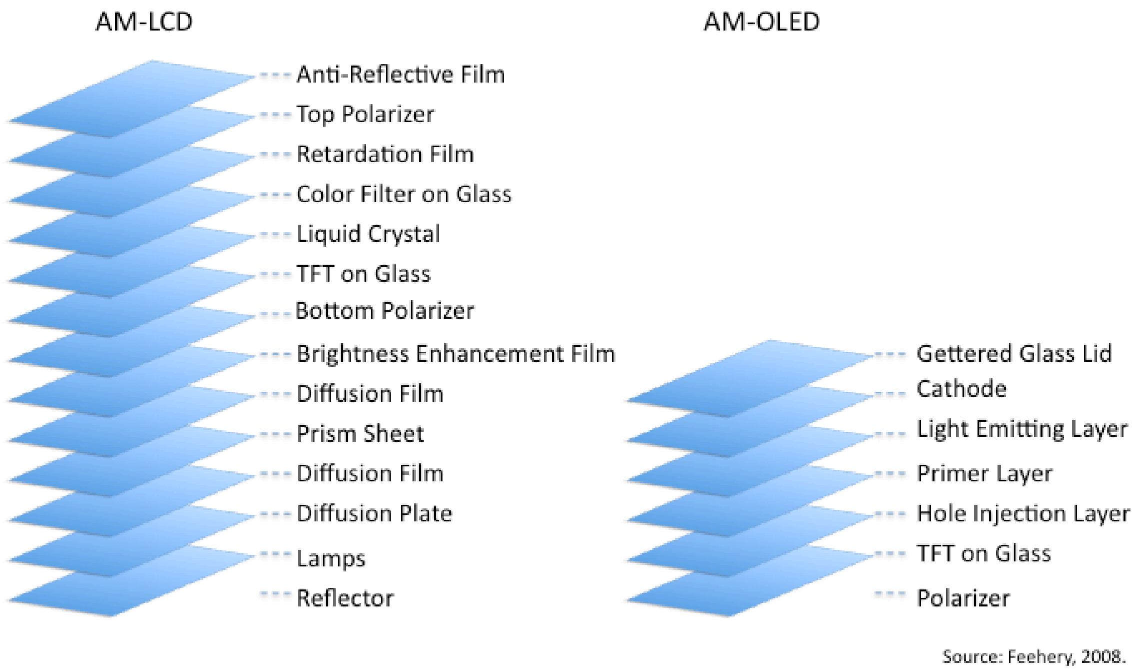
Like LCD, OLED production requires a clean room. There are competing production approaches including vacuum evaporation and printing which also relate to the kind of OLED materials being used. Which, if either, approach will become mainstream is uncertain at this time. However, OLED can be produced using LTPS and shares some steps with LCD. It is possible for existing LCD firms to do some pilot OLED production without major investment. As the number of steps is fewer however, in the future, plants specifically designed for OLED production may not require as much clean room space and therefore investment as conventional LCD plants.

Production Cost. Compared with the other technologies, LCD panels contain more expensive materials. High quality, thin glass substrates must be used and optical films and color filters are also relatively expensive. OLED has fewer layers than LCD, meaning that it requires fewer materials, and also fewer steps in the production process than are required for LCDs. Figure 3-2 depicts the different numbers of layers in OLED and LCD. Given the greater simplicity of OLED, many observers argue it should cost less than LCD to make if it reaches mass production.

The cost of the driving circuitry also needs to be included in the cost equation in order to compare between the technologies. PDP panels are cheaper to produce than LCDs, however, PDP driver circuits cost more because they have to be able to handle higher voltages than LCD drivers.

Over the years, LCDs have become cheaper to produce due to increases in yield and economies of scale available with the newest generation production facilities. In addition to general cost reductions over time, the cost of producing large panels, suitable for living room TV applications, has decreased dramatically. PDP production cost also appears to have gone down dramatically, however data on this is limited. As far as production cost for TV applications is concerned there is no clear winner between the two technologies. Amongst all of the technologies, experts suggest OLED could be the most cost effective if it ever reaches true mass production.

Figure 3-2: Layers in Active Matrix LCD and Active Matrix OLED Panels



FED and PALC as Television Displays

Both FED and PALC have also been considered as potential television displays.[4] However, interest has been less widespread than the three main technologies above. FED has been touted as providing high image quality, wide viewing angle, good brightness,

[4] See section “Introduction to Display Technologies for Flat Panel TV applications” for a description of these technologies.

ability to operate in harsh environments, and energy efficiency (Komoda, 2005). FED has yet to be introduced in a consumer product. Why it has not developed into a television product is not completely clear, although industry followers suggest it may have proven difficult or very expensive to mass produce (Iguchi, 2008). Prototypes of up to 55" have been announced (Fuji-Chimera, 2007) in the past, suggesting display size is not a barrier.

PALC was developed by a group of firms with the intention of using it as a television display in response to arguments LCD could not be produced in large enough sizes (Komoda, 2005). The technology is a hybrid of plasma and liquid crystal display, using plasma to function as an active matrix without using diodes or transistors (den Boer, 2005). Although originally touted as providing the best of Plasma and LCD, an informant said that PALC development was doomed from the beginning because it offered the *worst* of Plasma and LCD. PALC is arguably a failed technology in that development ceased. Sony released one TV model using PALC in 1996 (Sangyo Times, 1997; Sony web site[5]). The technology is complex and difficult to manufacture; in the end PALC was never mass-produced (den Boer, 2005). Industry followers suggest that manufacturing cost, and not problems with image quality, is the reason this technology was dropped.

Continued Competition and Uncertainty

[5] http://www.sony.co.jp/SonyInfo/News/Press_Archive/199609/96T-120/

The discussion above describes the pros and cons of the different display technologies that have been in the running to be used in flat panel television sets and how they have changed over time. Although the general observations stated here are commonly agreed upon in the industry, interpretation varies.

LCD has clearly become the most dominant of the technologies. It accounts for the largest production volume of any of the technologies and is used in a variety of applications including living room TV sets. However, debates by industry observers and insiders have been going on for many years and still continue. The Society for Information Display 2008 conference had an evening session to debate the topic, titled: "AMLCD World Domination: Does Anything Stand in the Way?" Participants were from firms specializing in each of the technologies, so much of the debate hinged upon the importance of different aspects, such as cost and lifespan. As far as overall picture quality is concerned, however, the general consensus seems to be that PDP is superior. Asakura Reiji, Vice Chairman of the society of Picture Quality Engineers stated: "All of the technologies have come a long way in terms of any measure of video quality; however, Plasma still stands out as the single display technology capable of producing an excellent picture" (paraphrased and translated from Japanese; FPD International 2008 Forum Session P-22: "What High Quality Means for Each Type of FPD?" October 30, 2008: 15:00-18:00).

The future place of OLED technology is particularly uncertain. Every year, industry insiders joke that OLED was described as "taking off" next year (Sorin, 2008). However, many industry participants have high hopes for OLED and think it may be superior in every way to the existing technologies if technological problems can be overcome.

Although the popularity of FED research appears to have decreased, there are still firms developing this technology. Its future use in TV set applications cannot be ruled out.

Development History of Flat Panel Display Technologies

Up until this point, this chapter has introduced the requirements for TV displays and the alternative flat panel display technologies that have competed or continue to compete for use in TV set applications. It has briefly considered how the technologies have or have not met these requirements over time. Below, the development histories of the technologies are presented. This allows the reader to get an understanding of the general time frames, firms involved, and applications each technology could be used for over the time it was being developed.

The display technologies discussed above have long and complicated histories. Not surprisingly, discoveries and breakthroughs occurred at different times, and not in parallel between the different technologies. Each technology faced unique uncertainties in its development and problems that had to be addressed before it could become useful. The display applications each has been used in differ, largely due to the different properties of the technology in question and the timing during which it was available. For instance, while LCD has been used in a large number of products from watches and calculators to car navigation systems, plasma display technology has not been used for such applications. The existence or lack of more easily achievable applications has, and continues to have, a number of implications. These include the potential for learning and therefore quality improvement and cost reduction over time, as well as the potential to decrease uncertainty relating to the display technology by applying it in multiple adjacent markets.

The different sections below each follow one of the display technologies. A timeline is later presented to allow comparison of the development between the different technologies over time.

LCD

The purpose of this section is to familiarize the reader with some of the key players, including several focal firms of this study, earlier on in LCD development. It also provides a look at how LCD technology was developed through applications before it became a TV display. LCD's development is long and detailed, however it is only briefly addressed here. Other sources cover the history of LCD development and the industry. Interested readers may consult Castellano's 2005 book "Liquid GOLD."

Liquid crystals were originally discovered in the 1800s but they were considered only as a scientific curiosity until the 1930s when a patent on a liquid crystal device was filed in the United Kingdom citing TV as one potential application (Castellano, 2005; Murtha et al., 2001). Although LCD R&D gained some government funding during World War II (Numagami, 1999), its potential as a viable display technology only became clear in the 1960s.

In 1968, RCA announced its liquid crystal display technology with much fanfare (Murtha et al., 2001). RCA suggested wall hanging flat panel TVs could be developed based upon the technology. A number of Japanese firms began R&D on LCDs in the 1960s and early 1970s.

As discussed in the section introducing LCD technology, it consists of a number of sub-technologies. Early applications used a relatively simple type called a segment LCD in products such as watches, clocks, and calculators. Sharp's introduction of the LC Mate EL-805 calculator with liquid crystal display in 1973 (Sangyo Times, 1993) is often mentioned as a key development in this era. The next step in LCD development was dot matrix display, which was introduced into products in the late 1970s. Though these displays could display some graphics, image quality was low.

In the quest for higher quality imaging, many firms began R&D on active matrix LCDs in the early 1980s. Canon, Fujitsu, IBM, Kyocera, Ricoh, Samsung, Sony, and Toshiba all began major research into TFT-LCD in the early 1980s (Castellano, 2005; Sangyo Times, 1990, 1992, 1993, 1994, 1997). The technology proved difficult to master.

Passive matrix STN-LCD technology was also developed in the 1980s. Although STN has much lower image quality, often suffering from a washed out look, it was relatively low cost to manufacture. Fujitsu, Sharp, Toshiba, Tottori Sangyo and others began producing STN-LCDs primarily for computer applications in the mid 1980s (Sangyo Times, 1992, 1993), although mass production by Japanese firms did not start until 1986 (Numagami, 1999). Sharp, Toshiba and Seiko Epson were amongst firms releasing laptops with color STN-LCD screens around the late 1980s (Nikkei BP, 2004 (Jitsumu-hen); Sangyo Times, 1992, 1993; Weber et al, 2008).

Fascination with television as an application is evident from these days. Even though display quality was poor, production costs were high, and screen size was small. Seiko-Epson commercialized the first LCD TV watch in 1982 (Aoyagi, 2000; Sango Times, 1993). In 1984, Seiko-Epson developed a 2.1" color TFT LCD TV (Nikkei BP, 2000 (FPD 2001)). The following year, Matsushita began selling a 3" LCD TV of its own (Sangyo Times, 1992). Sharp exhibited its first LCD TV prototype, also with a 3" screen, at Electronics Show in 1986 (Sangyo Times, 1993). NEC exhibited a 4.3" color LCD panel designed for television usage in 1988 (Sangyo Times, 1992).

Announcements of TFT prototypes and new products began growing in the late 1980s. However, mass production of TFT-LCD was challenging and did not start right away. Display Technologies Incorporated (a manufacturing Joint Venture between IBM and Toshiba), NEC, and Sharp each separately began mass production of TFT-LCDs in 1990-1991 (Murtha et al., 2001).

Large investments, scarcity, and low yields meant that these screens were very expensive, typically costing over $1000 US each at the time (Murtha et al., 2001); however, the new technology created possibilities for new and improved applications. NEC announced the world's first color TFT LCD laptop, the 9800 NC in 1991 (Sangyo Times, 1993). Car navigation systems and Pachinko games were other applications that began to grow around this time.

These new applications increased the diversity of markets for LCDs, however the laptop computer was by far the biggest application and had the most impact driving technology and manufacturing capability development. TFT-LCD was useful to the laptop application but the technology was not yet at a level suitable for other potentially large applications. One informant stated that he had taken early 8-inch class TFT panels to television set makers however they were not interested. The TV set manufacturers said the panels were too expensive, too small, and did not have good enough image quality to be relevant in televisions.

LCD continued to suffer from image quality problems at the time. The screens had narrow viewing angles and slow response times – these were fatal flaws for some applications but not for laptop usage. LCD technology was the only suitable technology for laptop displays at the time. Laptops required a lightweight, thin display, and preferably, low energy usage. Laptops were deigned to be used by one person at a time, therefore viewing angle was not important. Also, computers at the time lacked sufficient processing power to allow them to use video; hence, slow reaction time was also not a problem. TFT image quality was much better than the competing STN technology; STNs provided a lower cost laptop alternative while higher end laptops featured the more expensive, better looking TFT-LCD. Plasma screens had been used in laptops by Toshiba and Compaq, however plasma technology suffered from major drawbacks in comparison to LCD. First, plasma displays at the time were single color units. Second, the high energy requirements of plasma meant laptops with plasma displays could not run on battery power.

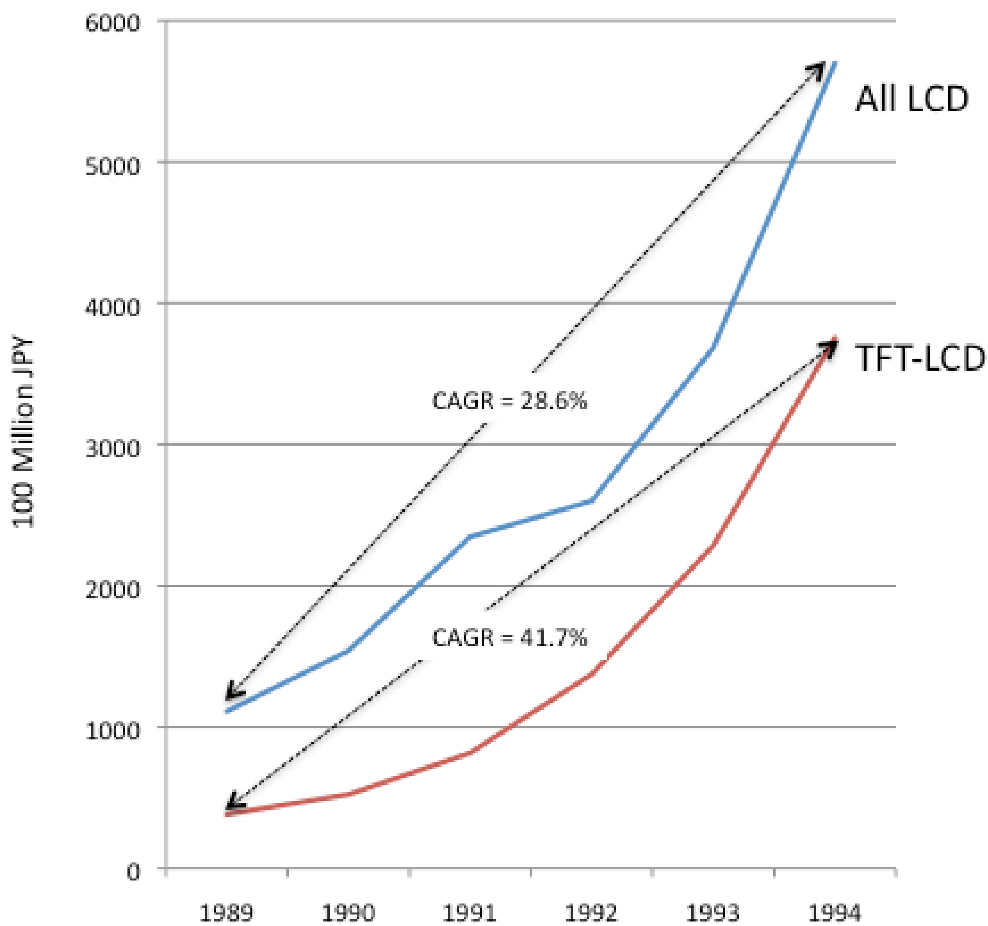
Around the time TFT-LCDs became available, computer processor speed was increasing dramatically, and computer software using graphical user interfaces (GUI), in particular Microsoft Windows 3.0, became available. These advances increased the relative attractiveness of higher quality active matrix displays.

Chart 3-4 below shows the growth of LCD production from 1989 to 1994 by six of the largest Japanese TFT-LCD producing firms at the time. Of the six firms, four firms were also laptop computer manufacturers, including Hitachi, NEC, Sharp, and Toshiba (Hitachiwebcafe.com site[6]), while Hoshiden and Sanyo sold the majority of their displays to third party manufacturers. Total LCD production included non-TFT panels such as STN panels as well as more basic passive matrix TN panels used in calculators, watches, and automotive applications. TFT production in 1989 was still quite limited; mass production facilities had yet to be built and yield ratios were very low.

The growth of both LCD and TFT-LCD was quite rapid over this period, especially when one considers that per unit prices were falling, therefore unit volume grew more quickly than the revenue based production shown in Chart 3-4. It is hard to gauge exactly how much of the TFT-LCD output was used in laptops, however there is no question that it was by far and away the largest single application of the technology during this time frame. Chart 3-5 below shows the production levels of displays manufactured in Japan during the period 1990-1992. Interestingly, LCD surpasses CRT around 1991, as TFT-LCD mass production was beginning.

[6] http://www.hitachiwebcafe.com/siryo_prius.htm

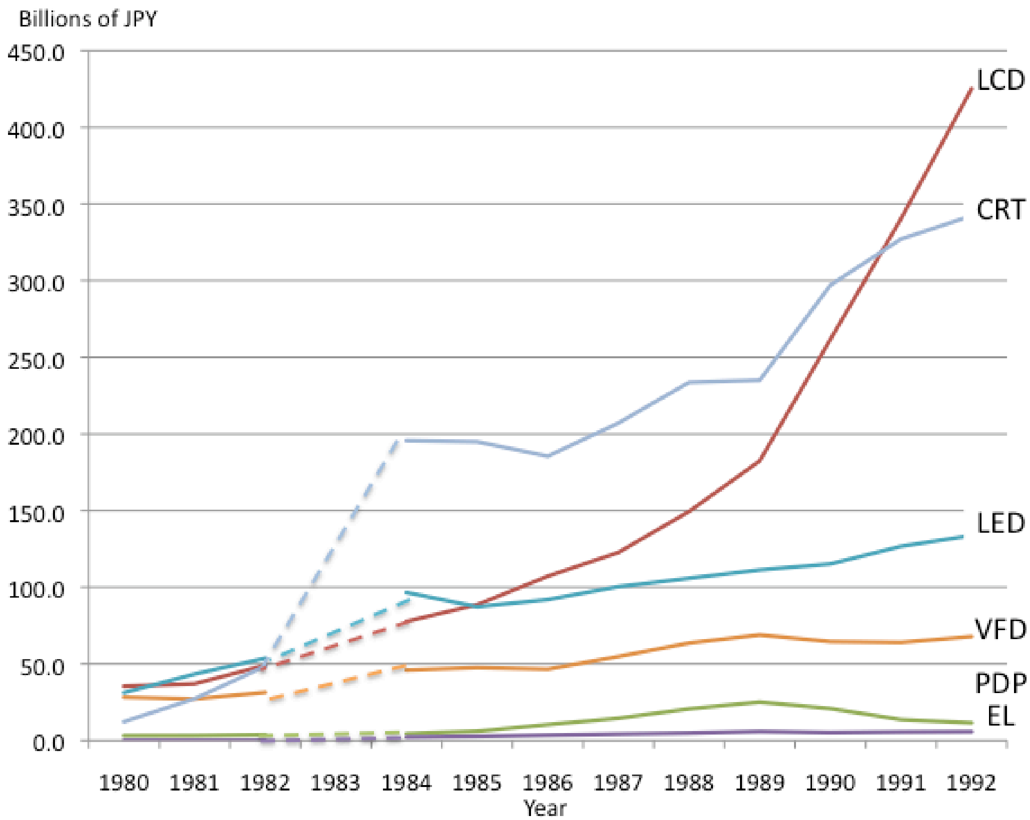
Chart 3-4: LCD Production by 6 Major Japanese Active Matrix LCD Firms



Note: Firms included are Hitachi, Hoshiden, NEC, Sanyo, Sharp, and Toshiba.

Source: based upon Nikkei BP, 2000. Missing TFT data estimated by author.

Chart 3-5: Total Japanese Domestic Display Production Value, by Display Technology Type (1980-1992)



Note: Data for 1983 is missing.
Source: Numagami, 1999 using data from Yano Keizai.

Growth

The number of LCD applications continued to grow as the quality increased and the cost decreased. Desktop computer monitors were another major application for LCD once the prices became reasonable and the display sizes increased. The average size of the panels used in many applications has also grown for similar reasons.

Ongoing incremental technological developments improved LCD technology in a number of ways, and two large technological breakthroughs occurring in the mid-1990s can be identified as largely eliminating the viewing angle problem faced by the technology. Hitachi was the first company able to produce commercial grade panels using In Plane Switching (IPS) mode in 1996 (Nikkei BP, 2004 (Jitsumu Hen)). Fujitsu developed a competing technology called Multi-domain Vertical Alignment (MVA), which it began mass-producing in 1997 (Sangyo Times, 1999). These technologies both substantially increased the viewing angle of LCDs, reducing uncertainty around LCD's suitability as a TV display.

Increasingly sophisticated, reliable, and large LCD production equipment is a major driver of these improvements. The better equipment has reduced the level of knowledge required for new entrants over time. There have been several waves of new firms entering the LCD production business, including a number of Korean firms around 1995, and Taiwanese firms around 1997. Firms in Mainland China have been increasing their TFT-LCD capabilities as well as of late.

Although the improved production equipment may have reduced costs and increased quality, the combination of the great expense of building an up-to-date LCD plant and the huge production capacity it entails has dramatically impacted the LCD industry. Matthews (2005) discussed the crystal cycle – a boom and bust cycle in the LCD industry similar to the cycle seen in the semiconductor industry.

Although a number of the flat panel display technologies have long development histories, color TFT-LCD was the first to be mass-produced. The impact of this is probably large as LCD had more time to reduce uncertainty related to its potential through ongoing technological improvements and increases in cost effectiveness. The

PDP development story, discussed below, did not offer as many similar opportunities for application in related markets.

PDP Development

Plasma technology is not as old as Liquid Crystals. PDPs were first developed at the University of Illinois in the 1960s (Kawamura, 2005; Weber et al., 2008). Following some initial developments, Burroughs, Fujitsu, IBM, and Philips began R&D on PDPs later in the decade (Nikkei BP, 1990). Although much of the early development occurred in the United States, there is surprisingly little written about its development in English.[7]

Nihon Hoso Kyokai (NHK), the Japanese state television broadcaster, began research on PDP as a potential next generation television display technology in 1971 (Weber et al., 2008). In the early 1970s, Fujitsu, IBM, Hitachi, Matsushita Electronics, Mitsubishi Electric, NEC, Oki Electric, and Owens Illinois begin producing PDPs in very small quantities. PDP faced a number of hurdles and some of the firms dropped the technology while many others had on-again off-again research programs.

Yano Keizai (1982) documents the state of the PDP business in 1982. Interestingly, a number of firms including Burroughs, Fujitsu, Matsushita Denshi Kogyo, NEC, Okatani Electric, Oki Electric, and Sanya Electronics made and sold PDPs that year (Yano Keizai, 1982). PDPs of this generation were single color, matrix displays typically used in public areas such as train stations.

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[7] Weber et al.'s (2008) account of PDP historical development is in Japanese.

Higher resolution displays useful in the computer industry did not arrive until later. IBM developed a 17" monochrome PDP with 968X758 resolution in 1983, and sold it to financial institutions (Murtha et al., 2001; Weber et al., 2008). In 1985, Matsushita Electronics began selling high resolution PDPs for laptop applications (Nikkei BP, 1990); however, difficulties in manufacturing the panels plagued the firm (Weber et al., 2008). Nonetheless, Toshiba began selling laptop computers with monochrome DC-PDP displays in 1986 (Nikkei BP, 1996). IBM concluded that PDP was not a suitable display technology for IT applications and exited in 1987 (Weber et al., 2008). It was the last major U.S. firm to exit.

Plasmaco, a start-up headed by Larry Weber, a leading researcher who had previously been a professor at the University of Illinois, began plasma development in 1987 (Murtha et al., 2001) using production equipment purchased from IBM (Weber et al., 2008). The firm played an important role in PDP technological development, however it never gained sufficient funding to build a mass production facility. Panasonic purchased the firm in 1996, and made it a subsidiary, retaining Weber (Murtha et al., 2001).

NHK established a PDP TV development program with industry players in 1994 with a plan to use the Nagano Winter Olympics in 1998 to publicly launch PDP-TV (Kawamura, 2005). By this point, a number of firms had developed promising color PDP technologies, but none were up to the standards required for consumer television. Several firms invested in first generation color PDP production plant and equipment in 1995, and began pilot production in 1996 (Nikkei BP, 1998, 2002 (Senryaku hen)). NHK's preferred technology, DC-PDP was used as planned to show the Nagano

Olympics in public locations, however the sets had to be replaced often as picture quality degraded rapidly (Weber et al., 2008). Following the Olympics, the NHK project ended and PDP players unanimously dropped DC-PDP and switched to AC-PDP (Weber et al., 2008). Because many of the players had been developing both versions, focusing on only one increased the speed of development. The new PDP TVs that resulted ushered in the age of flat panel television.

Unlike LCD, PDP was used in few applications prior to the introduction of PDP-TV. Those applications it was used in were either in specialized niche markets (e.g., train station displays, financial institutions), or they were short-lived (e.g., plasma displays were replaced by LCDs for use in portable computers several years after their introduction). These limited opportunities for PDP may have kept uncertainty high for some time, reducing firms' willingness to invest in the technology.

OLED Development

Organic Light Emitting Diode technology is much younger than the other display technologies discussed here. A technology related to OLED, Electroluminescence (EL) was under development as early as the 1940s (Johnstone, 1999). A number of firms, including Sharp, developed and produced EL. Some developed EL-TV prototypes, however interest in EL as a TV display dried up many years ago, and a detailed discussion of it is not included here.

OLED development began in the 1980s. OLED can be divided into two groups based upon the kinds of materials used: small particle materials and large particle materials. Kodak researchers Tang and Van Slyke published their research on small particle OLED technology in 1987 (Mori, 2008). Large particle materials were first developed by researchers at Cambridge University in the United Kingdom. Cambridge Display Technology (CDT), a spinout from Cambridge University was formed in 1992 to develop large particle OLED technologies (Sangyo Times, 2004).

Early developers of OLED entered in the late 1980s and early 1990s and include IBM, Idemitsu, Philips, Pioneer, and Sony (Nikkei BP, 2007 (FPD 2008 OLED)). Early OLED displays were single color or area color (i.e., the display had several sections with different colors in them) and were passive matrix. Tohoku Pioneer, a subsidiary of Pioneer, was the first firm to commercially use OLED, when it included one in a car radio in 1997 (Nikkei BP, 2007 (FPD 2008 OLED)).

The industry has gone through several attempts to move to full color active matrix OLED, but it has not been easy going. Pioneer began mass-producing Active Matrix OLED in 2004; however, it exited in 2005 (Sangyo Times, 2007). Sanyo and Kodak formed a joint venture to develop and produce OLED displays including passive and active matrix (Nikkan Kogyo Shimbun, February 5, 1999). This JV was dissolved after some degree of development success but limited production (Sangyo Times, 2007). Sony has produced OLEDs for some time, incorporating them in PDAs in 2005, a TV in 2007, and a personal music player in 2009 (Nikkei BP, 2004 (Jitsumu hen); Sony web site). A number of Taiwanese and Korean firms have begun mass production of PM-OLEDs, including Chi Mei Electroluminescence, RiT Display, LG, and Samsung. Currently, OLEDs are being produced in limited numbers. OLEDs are mainly used in cell phone and portable audio applications, where limited lifetime is not an issue because the displays are not turned on most of the time and because users tend to replace cell phones once every several years.

For the last several years, OLED technology has been the center of a lot of hype and OLED exhibits have been prominent at industry trade shows. Prototype announcements are not uncommon, and yet the technology has not been used in many consumer products. Given its significant cost disadvantage compared to LCD at this stage, it is not surprising that OLED has yet to be used in laptop applications.

OLED TV has been the goal of a number of firms, however this goal has been elusive. Sony has released the world's first OLED TV with an 11-inch diagonal 3 mm thick display in December of 2007 (Sony, 2007), and Kodak began selling a 3-inch OLED TV in Japan in March, 2008 (Akasaka, 2008). A number of other firms have stated they plan to begin producing OLED TV models, however these have not as yet become reality.

OLED has been used in a number of applications through its development, however the number of applications is lower than LCD. OLED is directly competing with LCD in these applications. With the exception of TV, OLED has been chosen primarily for applications where its limited lifespan will not be a problem, such as cell phones, mp3 players, and car stereos.

FED Development

FED has a long history even though it has not yet found its way into commercially available consumer products. The field emission phenomenon was first described in a patent in 1921 (Komoda, 2005). In 1968, a researcher at SRI International in the United States, C.A. Spindt began developing an emitter type that was subsequently commonly used in FEDs. Although this was a significant achievement, the technology did not receive much attention until 1986 when the French Laboratory LETI (Le Laboratoire d'Electronique de Technologie et d'Instrumentation) announced a breakthrough 6" FED. Around this same time, Canon, Candescent (U.S.), Futaba Electronics, Motorola, and Sony began R&D into FED (Sangyo Times, 1999, 2000, 2006; Nikkei BP, 2000). A number of other firms have performed FED research since that time, but many of the research efforts appear to be small. Sony and Canon (and its joint venture partner Toshiba) had relatively larger efforts compared to the other firms. Sony announced a 13.2" color FED prototype in 2001, but later in 2006 moved the development efforts to a separate venture company (Nikkei BP, 2001 (Senryaku hen): Nikkei BP, 2007 (Shijo hen); Sangyo Times, 2005). Canon and Toshiba formed several joint ventures to develop and mass-produce SED, a variant of FED technology, with the intention of using it as a TV display. The Joint Venture announced a number of prototypes including a 36-inch prototype in 2004, and a 55-inch in 2006 (Fuji-Chimera, 2007; Nikkei BP, 2004 (Senryaku hen)). However, the JV was later disbanded, apparently for legal reasons. A mass production facility was never built. Futaba Electronics, a specialty display maker not included in the target firm group, is the only firm to be producing FED displays at this time. Its focus has been on small FEDs using the most conventional variants of the technology. It is unclear what applications these displays are currently used for.

Comparing Development Pathways

The display technologies discussed in this chapter all had different development trajectories and have been used in different applications. Figure 3-3 below depicts major developments relating to each display technology over time, to allow comparison of the relative stages each was at over time. For additional comparison, a short development timeline is provided in Table 3-1 at the end of this chapter. It is worth noting that amongst the different potential TV displays discussed, color TFT-LCD was the first to be mass-produced. The impact of this is probably large as LCD had more time to improve its characteristics and reduce its cost before other entrants arrived.

The applications the different display technologies have been used in differ and have developed over time. Figure 3-4 below depicts the applications each technology was used in over their development. These applications have provided opportunities for firms to generate revenues justifying further investment in R&D as well as production capabilities. This has, in some cases, provided enough resources for the technologies to be developed to the point they can increase the scope of applications they are useful in, either through improved performance or decreased cost.

LCD, for instance, had disadvantages including blurriness and narrow viewing angle that made it unattractive for numerous potential applications in earlier stages, however its use in laptop computers gave manufacturers time and resources to improve the technology to the point where it had much better video characteristics. Improvements in the production methods not only increased quality, they also reduced cost and opened the way to development of larger production scale.

Compared with LCD, competing display technologies had fewer, lower volume applications. PDP, for example, had some early applications, however these were all small niches such as stock price displays in financial institutions; mass production was not feasible for the applications it could handle prior to its development as a potential TV display.

Chapter Summary and Conclusions

This chapter provided background on the technologies and their development histories. In presenting the development of the display technologies over time, it described the technological uncertainty due to the competition between multiple display technologies for TV and other applications, and how this changed over time. Additionally, it provided a basic understanding of the relevant display technologies. Some degree of familiarity with the technologies, their similarities and differences, and their abbreviations is needed for interpreting the firm level case studies and subsequent analyses presented in Chapters five through seven.

Each of the display technologies discussed faced a different set of uncertainties over its development. These uncertainties included those regarding performance improvements required for use in different applications, uncertainties relating to cost reduction potential, and uncertainties due to competing display technologies. The following chapter discusses the television industry and the development of flat panel television.

Figure 3-3: Development of Display Technologies Over Time

	Pre-1960	1960s	1970s	1980s	1990s	2000s
LCD	Liquid Crystal discovery	RCA announcement Early LCD development	First segment and dot matrix LCD products	STN-LCD introduced TFT-LCD development	TFT-LCD mass production start IPS, MVA dev. Early LCD TV Introduction	Growth in LCD size, cost competitiveness
PDP		U of Illinois paper Early PDP development	NHK research start Small volume production for specialized applications	PDP portable computers	Nagano Olympics public display Color PDP mass production start PDP TV introduced	
OLED				Kodak publication Early OLED development	CDT established First commercial PM-OLED product	First OLED TVs
FED	Field emission patent	Spindt emitter developed		LETI prototype FED Early development		FED / SED prototypes Futaba enters production
PALC					PALC R&D begins	PALC R&D ends

Sources: Developed by Castellano, 2005; Fuji Chimera, 2001; Futaba web site; Komoda, 2005; Mori, 2008; Murtha et al., 2001; Numagami, 1999; Sangyo Times, 1995, 2002, 2005, Sony web site.

Figure 3-4: Application of Flat Panel Display Technologies Over Time

Application

	1970s	1980s	1990s	2000s
LCD	Calculator, Watch	Laptop, PDA, Word Processor	GPS, Avionics, Games, TV	HDTV
PDP	Financial Industry, POS	Portable computer		HDTV
OLED				Digital Camera, Cell phone, Car Audio, MP3, HDTV

Sources: Saccocio, 1994; Murtha et al., 2001; Nishikubo, 2006; Sorin, 2008; www.old-computers.com, 2008

Table 3-1: Display Technology Development Timeline

Year	LCD	PDP	OLED	FED	PALC	Other	Event
1888	X						Liquid crystals discovered (Murtha et al., 2001).
1920	X						First thin film transistor patent filed (Numagami, 1999).
1921				X			First patent on field emission phenomenon (Komoda, 2005).
1940s			X			X	EL research at Sylvania (Johnstone, 1999).
1960	X						RCA demostrates liquid crystal became opaque when current passed through (Murtha et al., 2001).
1964		X					University of Illinois researchers first publish work on PDP (Weber et al., 2008).
1965			X			X	First working EL display prototype (Johnstone, 1999).
1968	X						RCA announces liquid crystal display technolog (Murtha et al., 2001).
1968				X			Spint emitter developed (Komoda, 2005).
Late 1960s	X						Citizen, Hoshiden, Matsushita Electric Industry, NEC and Hitachi begin work on LCD development (Numagami, 1999; Sangyo Times, 1995; Sangyo Times, 2005).
Late 1960s		X					Burroughs, Fujitsu, IBM, Philips begin PDP development (Nikkei BP, 1990).
1970	X						Sharp licenses LCD technology from RCA (Sangyo Times, 1992).
Early 1970s		X					Fujitsu, IBM, Hitachi, Matsushita Electronics, Mitsubishi Electric, NEC, Oki Electric, and Owens Illinois begin producing PDPs in very small quantities (Kawamura, 2005; Weber et al, 2008).
1970s			X			X	Mitsubishi, Panasonic, Sharp perform EL research (Nikkei BP, 1990; Numagami, 1999; Television Academy, 1974)
1971		X					Japanese State Broadcaster NHK begins PDP research as potential next generation TV (Weber et al., 2008).
1973	X						Sharp intorduces LCD Mate EL-805 calculator using LCD display (Sangyo Times, 1994).
1974	X						RCA sells off LCD production facility, exits LCD altogether (Murtha et al., 2001).
1975	X						Hitachi, Asahi Glass and Dainippon Paint announce prototype dot matrix LCD (Numagami, 1999).

Table 3-1: Display Technology Development Timeline (Continued)

Year	LCD	PDP	OLED	FED	PALC	Other	Event
1980	X						Hitachi files for patents relating to LTPS (Nikkei BP, 1999).
Early 1980s	X						Canon, Fujitsu, IBM, Kyocera, Panasonic, Ricoh, Samsung, Sanyo, Seiko-Epson, Sony, Ricoh, and Toshiba all began major research into TFT LCD in the early 1980s (Castellano, 2005; Sangyo Times, 1990, 1992, 1994, 1995, 1997).
1982	X						Seiko Epson commercializes first LCD TV watch (Aoyagi, 2000).
1983		X					IBM develops and begins selling 17" monocrhome PDP (Weber et al., 2008).
1984	X						Hitachib builds prototype TFT-LCD line (Sangyo Times, 2000).
1984	X						Seiko Epson develops 2.1" color TFT LCD TV (Nikkei BP, 2001).
1985	X						Panasonic begins selling 3" LCD TV (Sangyo Times, 1992).
1985		X					Panasonic begins selling PDPs for portable computers (Nikkei BP, 1990).
1986	X						Sharp releases first word processor using LCD display (Sangyo Times, 2001).
1986				X			French laboratory develops 6" prototype FED (Komoda, 2005).
1986		X					Toshiba begins selling laptop computers with single color DC-PDPs (Nikkei BP, 1998).
1986-1989				X			Futaba Electronics, Sony, Candescent, Canon, Motorola and Toshiba begin FED R&D (Nikkei BP, 2001; Sangyo Times, 1999, 2006).
1987		X					IBM is last major U.S. firm to exit PDPs (Weber et al., 2008).
1987		X					Plasmaco, a U.S. based startup headed by a researcher from University of Illinois, begins plasma development (Murtha et al., 2001).
1987			X				Kodak researchers publish research on small particle OLED technology (Mori, 2008).
1988	X						NEC exhibits 4.3" color LCD panel for TV applications (Sangyo Times, 1992).

Table 3-1: Display Technology Development Timeline (Continued)

Year	LCD	PDP	OLED	FED	PALC	Other	Event
1990					X		Techtronix develops PALC technology (Fuji Chimera, 2001).
1990-1991	X						Display Technologies Incorporated (manufacturing Joint Venture between IBM and Toshiba), NEC, and Sharp each separately begin mass producing TFT-LCDs (Murtha et al., 2001).
1991	X						NEC announces world's first color TFT-LCD laptop (Santyo Times, 1994).
1992					X		Sony licenses PALC technology from Techtronix (Fuji Chimera, 2001).
1994		X					NHK establishes PDP-TV development program with industry players (Kawamura, 2005).
1995					X		Sony develops 25" PALC panel with 768X448 resolution for TV applications (Nikkei Bp, 1996).
1995	X						Sharp's Window line of LCD TVs becomes unexpected hit. Sets come in 8.4" and 10.4" sized (Sangyo Times, 1996).
1996		X					Panasonic buys Plasmaco for its PDP technology (Murtha et al., 2001).
1996		X					Pilot production of color PDP begins in Japan (Nikkei BP, 2003 (Senryakuhen)).
1996					X		Sony plans to begin selling 25" Plasmatron color TV, model PZ-2500; prices is 900K Yen (Sangyo Times, 1997).
1997					X		Sony, Sharp, and Philips agree to joint development of PALC technology (Sangyo Times, 1999)
1997					X		Sony, Sharp, and Philips successfully develop prototype 42" PALC with wide viewing angle (Sangyo Times, 1999).
1997			X				Tohoku Pioneer produced first comercial OLED displays (Nikkei BP, 2008 (FPD 2008 OLED)).
1998		X					DC-PDP TVs fail in NHK public viewing areas for Nagano Olympics (Weber et al., 2008).
1998		X					Following Nagano Olympics, all PDP manufacturers drop DC-PDP (Weber et al, 2008).
1998-9		X					Several PDP mass production plants come on line in Japan.
1999					X		Contract to cooperate on PALC ends, Philips does not renew. Sony and Sharp continue cooperating on PALC development (Sangyo Times, 2000).

Table 3-1: Display Technology Development Timeline (continued)

Year	LCD	PDP	OLED	FED	PALC	Other	Event
2001				X			Sony and Candescent announce 13.2" color FED prototype (Sangyo Times, 2005).
2001					X		Sharp decides not to produce PALC displays because they were not convinced of the superiority of the display and there were difficulties encountered regarding developing mass production capability for PALC (Sangyo Times, 2002).
2004				X			Canon and Toshiba announce 36" SED prototype (Nikkei BP, 2005 (Senryaku Hen)).
2005			X				Sony AM-OLED PDA (Nikkei BP, 2005 (Jitsumu Hen)).
2006				X			Canon and Toshiba announce 55" SED prototype (Fuji-Chimera, 2007).
2007			X				Sony AM-OLED TV (Sony Web Site).
2009			X				Sony AM-OLED mp3 player (Sony Web Site).

CHAPTER FOUR: THE FLAT PANEL TELEVISION INDUSTRY

The previous chapter introduced display technologies competing for use in the flat panel television industry. In addition to providing a technological background, it also provided a basis for understanding the nature of technological uncertainty present in that competition. This chapter discusses the television set manufacturing industry and its evolution. The general industry background of industry and firms in it is meant to aid interpretation of the analysis in subsequent chapters of this dissertation. It provides evidence market needs uncertainty was relatively low in this industry during the study period.

The TV set manufacturing industry is large and global in nature. The Japanese TV set manufacturers that are the focal firms of this investigation have played a major role in the industry for many years. This chapter begins by establishing a general background of the industry and Japanese firms in it. It then looks at its evolution at the industry level, including drivers of change such as the digitalization of television.

Japan's Early Television Industry

The television set industry had a complex beginning, involving many people and organizations. A full discussion of the early developments is beyond the scope of this research, however some discussion of Japanese firms studied is warranted in order to establish the length and extent of their involvement with the industry.

Although early developments relating to television sets go back into the 19th century, it took many years for television technology to develop to the point it was practical and for broadcasts to begin. Early examples of TV sets can be found, but TV sets only became widely owned in the 1950s and 1960s. In the United States, for instance, less than 10% of households had TV sets at the beginning of the 1950s, but by the end of the decade, number was over 80% (www.tvhistory.tv[8]).

Many of the Japanese firms in the television industry have long histories with television and related technologies, as shown in Table 4-1, below. A number of Japanese firms, including Toshiba, Panasonic, and Sharp, were active in black and white TV in the 1950s.   The first color CRT was first developed by RCA in 1956, but Toshiba was quick to catch up, building one in 1959 (Nikkei BP, 2004 (Senryaku hen); Nikkei BP, 2007 (OLED hen)). Several of the firms introduced color TVs in 1960. Sony refused to use the shadow-mask color CRT technology that was adopted by the other manufacturers; after a failed earlier attempt, Sony successfully developed Trinitron CRT technology in 1968 (Jojima et al, 2006).

[8] http://www.tvhistory.tv/Annual_TV_Households_50-78.JPG

Table 4-1: Events in Japanese TV development up to 1970

Year	Firm	Event
1897		Braun invents the CRT in Germany (Weber et al, 2008).
1924	Toshiba	Toshiba successfully develops its first CRT prototype (Menzawa et al, 2008).
1925		J. Baird of the United Kingdom is first to send tv image through cable (Hashimoto, 1994).
1937	General	TV broadcasting begins in the U.K. (Weber et al, 2008).
1950	Toshiba	Toshiba beings R&D on television sets (Toshiba web site).
1952	Panasonic	Panasonic (MEI) develops 17" black and white TV set (Panasonic Web Site).
1952	Sharp	Sharp begins selling TV sets (Nikkei BP, 2007 (Gyoukai Bunseki Hen)).
1952	Toshiba	Toshiba develops Japan's first TV broadcasting equipment (Menzawa et al, 2008).
1953		Commericial TV transmission begins in Japan (Toshiba web site).
1953	Sharp	Sharp is first company in Japan to mass produce television sets (Miyamoto, 2007).
1953	Toshiba	Toshiba begins TV assembly (Hashimoto, 1994).
1955	JVC	JVC begins TV assembly (Hashimoto, 1994).
1955	Panasonic	Panasonic (MEI) begins TV assembly (Hashimoto, 1994).
1955	Mitsubishi	Mitsubishi Electric begins TV assembly (Hashimoto, 1994).
1955	Sanyo	Sanyo begins TV assembly (Hashimoto, 1994).
1956	Hitachi	Hitachi begins TV assembly (Hashimoto, 1994).
1956	RCA	RCA develops first color CRT (Nikkei BP, 2008 (OLED Hen)).
1959	Toshiba	Toshiba builds its first color CRT (Nikkei BP, 2006 (Strategy Hen)).
1959	Toshiba	Toshiba develops Japan's first transistor TV (Menzawa et al, 2008).
1960		Color TV transmission begins in Japan (Weber et al, 2008).
1960	JVC	JVC introduces its first color TV set (JVC Web Site).
1960	Sharp	Sharp introduces its first color TV set (Sharp Web Site).
1960	Panasonic	Panasonic (MEI) develops its first color TV set, using a 21" CRT it (MEW) produced (Panasonic Web Site).
1960	Sony	Sony introduces world's first transistor TV set (Jojima et al., 2006).
1960	Toshiba	Toshiba announces first Japanese-made color TV models. One of the two models featured the first commericaly Japanese made CRT (Toshiba web site).
1965	Hitachi	Hitachi develops its first color CRT (Hitachi Web Site).
1968	Sony	Sony introduces the color trinitron. Sony had failed at earlier attempts to develop color CRT not using shadow mask (Jojima et al., 2006).

Note to event timeline: Panasonic was formerly known as Matsushita. MEI and MEW belonged to the Matsushita Group. Matsushita Electric Industry (MEI) was the central firm in the group; Matsushita Electric Works (MEW) was a Joint Venture with Philips making picture tubes, formed in 1952 and dissolved in 2001.

Some of the television set manufacturers had a CRT production capability, but a number did not. CRT production was capital intensive. Many firms considered the CRT to be a key device, i.e., one that gave the maker opportunities for differentiation or cost leadership, in the television business. However, a number of firms never made the investment. JVC, Pioneer, Sanyo, and Sharp did not develop their own CRT production capability[9].

The coming of color TV in the 1960s was a major technological change, however the combination of CRT technology and analog broadcasting remained stable until the late 1990s. There were some technological developments relating to television, but most of the new technologies had to do with components connected to the television, such as set top boxes, video recorders and players.

Other Players in the TV Set Industry

Korean firms Samsung and LG have invested in flat panel technologies and have grown their standing in the television business over the last ten years. Korean firms had historic relationships with Japanese firms, including joint ventures and technology transfers. Samsung and NEC established Samsung SDI as a joint venture to produce

[9] Source: In person anonymous interviews, dates: November 4, 2008; March 19, 27, 2009.

CRTs in 1969 (Sangyo Times, 2002). LG and Hitachi set up a similar Joint Venture in 1974 (Sangyo Times, 2002).

These firms began LCD R&D efforts many years behind their Japanese counterparts, and entered into TFT-LCD production after the market had begun to grow through the laptop computer application. Samsung began R&D on LCDs in 1984 and LG in 1987 (Sangyo Times, 1994). Samsung built a TFT-LCD pilot line in 1991 and its first mass LCD production line in 1993 (Sangyo Times, 1994). LG began mass-producing TFT-LCDs for laptops in 1995 (Sangyo Times, 1995).

Samsung and LG have grown to become two of the largest LCD producers. Samsung has grown to become respected for its advance display research and development capabilities, technological prowess in manufacturing flat panel displays, and financial strength that has allowed it to make bold investments in LCD manufacturing facilities. Both firms were also CRT-TV producers and their progression of product applications has been similar to that of other firms in the industry.

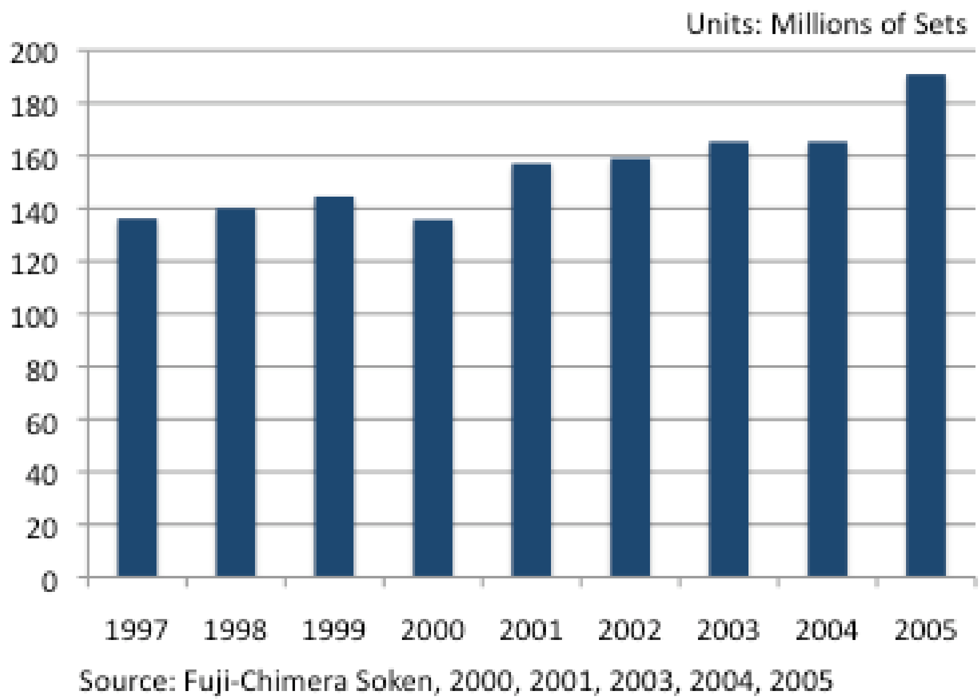
Taiwan is home to a number of large LCD producers. Taiwanese firms gained their initial LCD capabilities primarily through technology transfers with Japanese firms. Most of the Taiwanese LCD producers are related to computer manufacturers. Unlike many of the Korean and Japanese firms, these producers do not belong to groups with well-known consumer electronics companies. However, their panels are used by a number of TV set manufacturers including famous companies and others.

Several European firms also have long TV set development and production histories. Two have long been major global players: Philips and Thomson. Philips has long been involved with Asian firms. Matsushita Electronic Works, for instance, was set up as a Joint Venture between Philips and Matsushita to produce CRTs in 1952. Philips later entered into joint ventures on LCD with Hoshiden and LG. Thomson is a French company that purchased the consumer electronics businesses of RCA and GE from General Electric in 1987 (Dow Jones News Service, 1987). In 2004, it set up a joint venture with Chinese firm TCL, and moved its television manufacturing operations to the new firm TTE (Chiu, 2004). Since then Thomson has reduced its stake in the joint venture and is reducing its involvement with consumer electronics in general (Palenchar & Smith, 2007). Both firms had large worldwide market shares in the past, but have been reducing their exposure to consumer television markets more recently.

Changes in the Television Set Industry

The Television set industry experienced only minor, gradual change between the introduction of color TV in the 1960s and the late 1990s when digitalization and new display technologies came onto the scene. There were many years of growth in the industry with no discontinuous technological change during this period. With increasing incomes in much of the world and improvements in production methods, the relative cost of televisions went down for consumers worldwide over the period. Chart 4-1 below depicts the size of the global TV set market. In 1997, the global market was nearly 140 million sets.

Chart 4-1: Global TV Set Market



The following sections introduce two drivers of technological change in the television set industry: the arrival of new display technologies and the digitalization of content. LCDs were used in television applications prior to PDPs. In the process of describing PDP development, the previous chapter covered the entrance of PDP into television, which was the primary reason for developing color PDP to begin with. Although many had considered LCD to be an attractive display technology for television, its entrance was gradual due to technological limitations such as display size, and also due to its high cost. After presenting the background behind introduction of LCD technology to TV sets, the discussion moves on to consider the digitalization of content and the industry.

Early LCD TVs

A number of firms developing LCD technology produced small, portable LCD based televisions in the 1980s and 1990s. These TVs attracted attention, but never represented a large percentage of the market. Table 4-2, below, lists some of the early LCD TV product development and introductions. A number of the firms making these early models, namely Casio, Citizen, and Seiko-Epson, were not television set producers prior to their entry into this segment. The products up until the late 1980s were very small, and intended for personal use only. Beginning in the late 1980s, slightly larger sets intended for use in automobiles started to be introduced.

Readers familiar with electronics of this time period may ask: Where was Sony? Interestingly, Sony released a small portable black and white TV in 1982, but it was based upon CRT technology (Sony web site[10]). Color LCD models were not made by Sony until around 1990.

Sharp's 1995 introduction of the "Window" LCD-TV arguably marks the first LCD-TV that could be considered to be competitive with CRT-TVs in terms of size. Its introduction was also important because it demonstrated consumer needs for flat panel television sets. Sharp's initial production run of 28 thousand sets sold out in less than three months (Nikkei BP, 1995). Sharp introduced 10.4" and 13" models in 1996, and moved up to a 20" model in 1999 (Nikkei BP, 1996; Sangyo Times, 1995; Sangyo Times, 2000). The 10.4" model had a price tag of 170,000 yen when introduced (Nikkei BP, 1996). Assuming an exchange rate of 110 yen to the U.S. dollar, this would be the

[10] http://news.sel.sony.com/en/corporate_information/company_of_firsts

equivalent of $1545 U.S. (calculated based upon average exchange rate data from the Bank of Japan web site).

Table 4-2: Early LCD TV Developments and Product Introductions

Year	Firm	Event
1982	Seiko Epson	Seiko commercializes World's first LCD TV wristwatch (Aoyagi, 2000).
1983	Seiko Epson	Seiko Epson develops a 2.14" color TFT-LCD TV (Nihon Gakujitsu Shinkokai, 1989 in Numagami, 1999).
1983	Casio	Casio introduces TV-10 with a 2.7" B&W LCD display; Casio's first LCD TV (Casio Web Page).
1984	Seiko Epson	Seiko-Epson begins sales of portable color TFT-LCD TV (Aoyagi, 2000).
1985	Panasonic	Panasonic (MEI) begins selling a 3" portable LCD TV (Sangyo Times 1994; Numagami 1999)
1985	Casio	Casio introduces TV-1000, protable color LCD TV with passive matrix-LCD (Casio Web Page).
1985	Citizen	Citizen Watch Company introduces a 2.2" color LCD TV (Sangyo Times, 1995; Roberts, 1986)
1986	Sharp	Sharp shows 3" color TFT-LCD TV at Electronics Show in Japan (Sangyo Times, 1994).
1987	Sharp	Sharp begins mass production of 3" color TFT-LCD TV (Sangyo Times, 1994).
1988	NEC	NEC develops 4.3" LCD panel for portable TV applications.
1988	Sharp	Sharp begins mass production of 4" color TFT-LCD TV (Sangyo Times, 1994).
1989	Panasonic	Panasonic (MEI) begins shipping 5" display for in-car TV applications(Sangyo Times, 1992).
1995	Seiko Epson	Seiko Epson releases 5.6" color LCD TV for auto applications (Sangyo Times, 1995).
1995	Sharp	Sharp introduces "Window" LCD TV. Window came in 8.4" and 10.4" sizes (Sangyo Times, 1996).

Around this same time period, flat screen CRTs were also coming on the market. These screens had a flat face, but were still based upon the bulky CRT design. The picture quality of the flat screen CRTs was considered to be better than conventional CRTs. Although a number of manufacturers made these products, Sony's 32" high resolution "Wega" branded models introduced in 1997 define this type best (Sony Web Site[11]; In person anonymous interview, March 27, 2009). Wega was a hit; competitors introduced similar models in 1998, including Panasonic's "Gao" and Toshiba's "Face" (In person anonymous interview, March 27, 2009; Toshiba Web Site[12]).

Digitalization of Television

The industry began to change in the late 1990s as plasma TVs entered the market and LCD TVs, which, although expensive, were starting to have screen sizes large enough to be more practical. Changes in the industry went beyond the display technology. Standards were changing, and the broadcast technology used was moving from analog to digital.

Although interest in high definition TV was not new -- NHK began research on high definition television in 1964 (Kawamura, 2005) -- efforts to develop new high definition standards did not bear fruit unit the 1990s. The development and evolution of the new high definition standard was a complex series of events, which others have written about in depth and is beyond the scope of this research. What is relevant is that standards were eventually agreed upon, and a transition to digital broadcasting is taking place worldwide.

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[11] http://www.sony.co.jp/SonyInfo/CorporateInfo/History/sonyhistory-c.html

[12] http://www.toshiba.co.jp/regza/ctv/36hd3z.htm

The beginning of the transition to digital television fits the same general time frame that flat panel technologies were starting to be used in home televisions. The first exhibits of the high definition standard televisions at CES (Consumer Electronics Show) were in 1998 (Consumer Electronics Association web site[13]). This timing is close to early introduction of plasma televisions. The digital technology did not require the new flat panel displays; it could also be used with CRT displays. However, the new flat panel displays may have made the digital technology more attractive to consumers.

The transition to digital television will continue for some time. According to Izumiya et al. (2005), most countries are expected to switch from analog to digital broadcasting (often referred to as digital TV or DTV) between 2006 and 2012. Over the air digital broadcasting is currently available in many countries. Within the next several years, many countries will discontinue analog broadcasting to free up the frequency range for other uses. Analog broadcasting ceased in the US in 2009 and in Canada and Japan will end in 2011 (Canada's Office of Consumer Affairs, 2008; Japan Ministry of Internal Affairs and Communications, 2008; United States Federal Communications Commission, 2008).

While this change is a substantial one, it has been so gradual, and standards decided so far in advance of their implementation, that it does not appear to have substantially influenced uncertainty levels. If anything, the switch to digital has increased interest in new, flat panel, high definition televisions, increasing the size of the replacement market.

[13] http://www.ce.org/Press/CEA_Pubs/928.asp

The shift towards a digital format had a major impact on the technological capabilities required to compete in television sets. Developing and producing analog sets required detail orientation and some degree of learning based upon trial and error. For example, changing the location of wiring inside an analog CRT-TV could impact picture quality. This is not true for digital. In other words, although analog products can be tweaked to perform better through adjustments in the production process and design without changing the parts and materials used, digital products generally cannot – they either work or do not. The change to digital has reduced the barrier to entry into TV assembly (Nikkei Business, 2009). On the other hand, value creation has moved from assembly of the set to production of the devices that go into it (Osada, 2006). Relevant devices include displays as well as other items such as digital signal processors.

If there is a change in uncertainty levels due to the adoption of digital technologies, it would be from the new potential that non-TV set producing firms with strong digital capabilities may enter the market. This is discussed below.

Potential for "Standardized" Digital TV Platform, New Entrants

Several new entrants have begun selling television sets that were not evident before the change to digital and flat panel sets. Information technology firms make up one group of these entrants. For example, Nikkei BP (2003 (Senryaku hen)) announced planned entry into digital television markets by Dell and Microsoft. Another group of entrants is comprised of start-up firms using contract manufacturers in Asia to produce at a low cost using off of the shelf components. Vizio is a well-known example of this type.

For a further example, please see the sidebar – “Nikkei Business compares two LCD TVs,” below.

Several firms provide standardized solutions including standardized digital TV platforms and HDTV reference designs that allow firms with little TV experience to enter the business (Nikkei BP, 2004 (Jitsumu hen)). Although several informants dismissed these kinds of standardized approaches as being unsuitable for TV sets, the long-term impact of these efforts is unclear.

Sidebar: Nikkei Business Compares two LCD TVs

Nikkei Business (May 18, 2009) compared two 32-inch LCD TVs: one from Sony, and one sold by Dynaconnective, a Japanese start-up firm and produced by a contract manufacturer in Asia. The Sony was priced at 119,800 yen and the Dynaconnective at 49,800 yen. An expert on picture quality was called in and commented that an average household TV user would not be able to discern the difference in picture quality between the two sets. The sets were then dismantled to compare their insides. The Sony was made with fewer, custom-made printed circuit boards using proprietary Sony technologies. The Dynaconnective was made with off-the-shelf parts. The quality of design and manufacturing was much higher on the Sony model than on the Dynaconnective model, however, the magazine staff had to disassemble the televisions to document the real differences.

Introduction of Flat Panel TV Brands

The switch from analog, CRT based television to digital, flat panel based television has been a dramatic one. A number of TV set manufacturers have attempted to reinvent their TV set brand image in order to achieve a better position through the transition. Sharp became the first to introduce a full line-up of flat panel televisions when it launched its' "Aquos" brand in 1998. Sharp's branding campaign was both different and effective in the Japanese market. Sharp had hired outside designers to create a product that was fresh and visually appealing – not just a box. The firm also hired a Japanese actress many women looked to as a role model, Sanae Yoshinaga, to emphasize the appeal to women purchasers (In person anonymous interview, March 19, 2009; Sharp web site[14]).

Since this time, other companies have followed suit, creating their own flat panel television brands. Hitachi started using the "Woo" brand in Japan in 2001 (Hitachi web site[15]). Panasonic introduced its flat panel brand "Viera" in 2003 (Weber et al., 2008). Panasonic has managed to pull off a number of feats with this brand. In 2005, for instance, Panasonic implemented it "ichiya-jo" product introduction strategy (Ichiya-jo translates as a fortress built overnight). The firm replaced its entire line of Viera models with a new line, changing all of the TV sales displays throughout Japan virtually overnight. The company shipped 22,000 TVs in three days (Osada, 2006).

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[14] http://www.sharp.co.jp/products/cm/tv/tv143.html

[15] http://www.hitachi.co.jp/New/cnews/2002/1017/index.html

Sony eliminated its "Wega" TV brand in 2005 and replaced it with a new flat panel TV brand "Bravia" (Nikkei BP, 2005 (Jitsumu hen)). Toshiba announced its new brand, "Regza," in 2006 (Toshiba web site[16]).

In terms of options and commitments, these new brands may be considered to be customer needs commitments. These branding efforts are costly and non-reversible in nature. In particular, Panasonic and Sony invested large amounts of money into globally coordinated marketing and product release campaigns, which are especially expensive and difficult to coordinate.

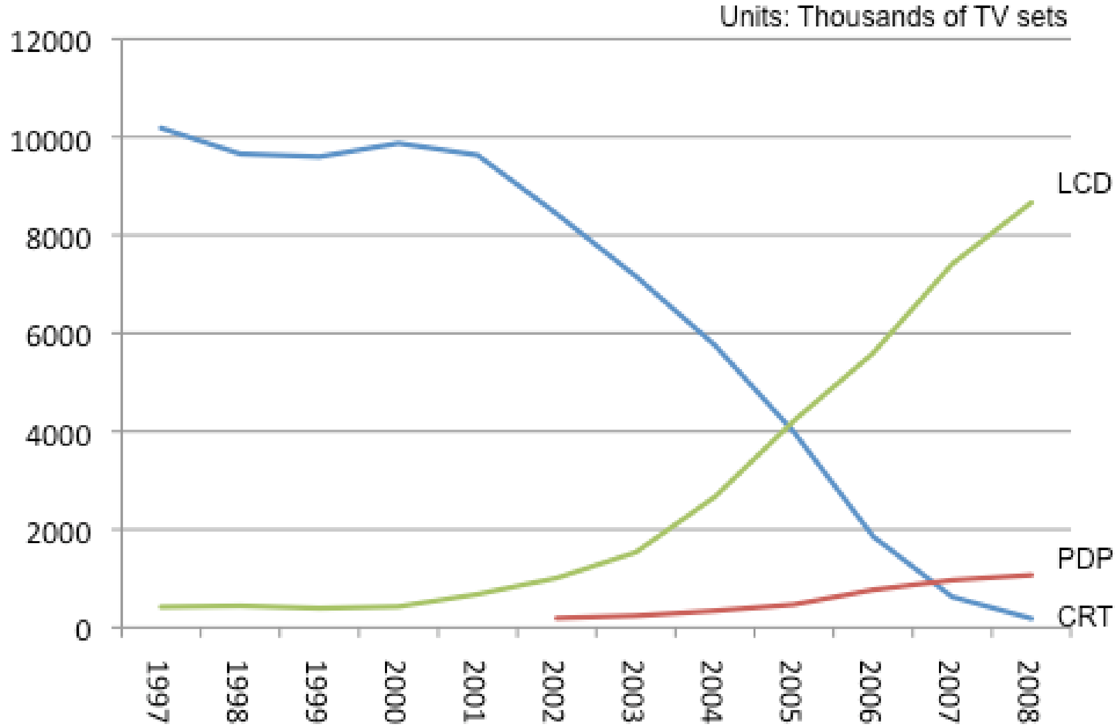
Growth of Flat Panel Television and Demise of the CRT in Japan

The Japanese market was an early mover to flat screen televisions. Chart 4-2 depicts the domestic shipments of TV sets in Japan based upon data from the Japanese Electronics and Information Technology Industries Association. According to this source, LCD-TV surpassed CRT-TV shipments in 2005. PDP TV shipments were not tracked separately by JEITA until 2002. There were PDP units shipped and sold in Japan prior to this date, however this data source did not capture earlier shipments.

Although sales of flat panel TVs have surpassed those of CRT TVs, replacing all CRT-TVs will still take time. As Chart 4-3 depicts, as of 2005, fewer than 30% of all Japanese households had flat panel televisions.

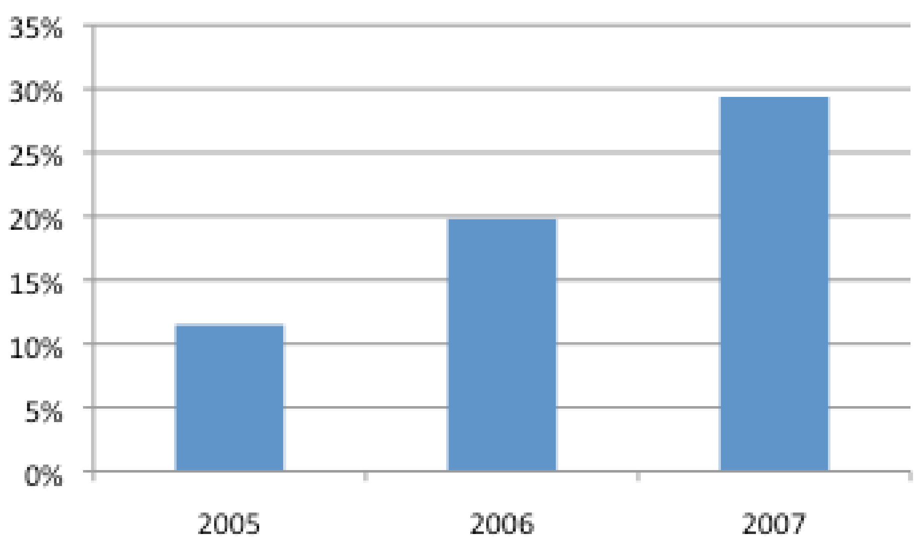
[16] http://www.toshiba.co.jp/about/press/2006_02/pr_j2101.html

Chart 4-2: Japanese Domestic Shipments of TV Sets by Display Type



Source: www.jeita.or.jp

Chart 4-3: Household penetration of Flat Panel television in Japan



Source: Rikku, 2008.

Japanese manufacturers of CRTs were faced with falling prices and volumes. They all stopped producing CRTs in Japan by 2006, and many stopped all CRT production on a worldwide basis. It is difficult to accurately track withdrawal from CRT; although data on currently operating LCD and PDP plants is available, equivalent data is not available for CRT. However, a number of events documented in the course of gathering other data are suggestive of the withdrawal, as shown in Table 4-3 below.

Table 4-3: Withdrawal from CRT-TV by Japanese Firms

Year	Event
1998	Sharp proclaims it will have only flat panels in its television line-up by the year 2005 (Murtha et al, 2001).
1999	NEC closes its CRT business (Nikkei BP, 2001).
2002	Sony's deputy president of its home network company proclaims CRTs will be history in 10 years (Jojima et al., 2006).
2002	Hitachi's US subsidiary ends production and sale of direct view CRT TVs (Sangyo Times, 2002).
2005	Panasonic and Sharp introduce their final CRT TV products for the Japanese market (Fuji Chimera, 2007 (Digital AV Market)).
2006	No CRT production remains in Japan - all remaining production has been moved overseas (Fuji Chimera, 2007 (Digital AV Market)).

Worldwide market trends

The television markets in other countries have experienced, or are in the process of experiencing, similar changes to Japan although the timeline is different. Chart 4-4 below tracks actual unit sales of CRT, LCD, and PDP TV sets from 2000 to 2006.

Chart 4-4: Worldwide TV set Market (2000 – 2006)

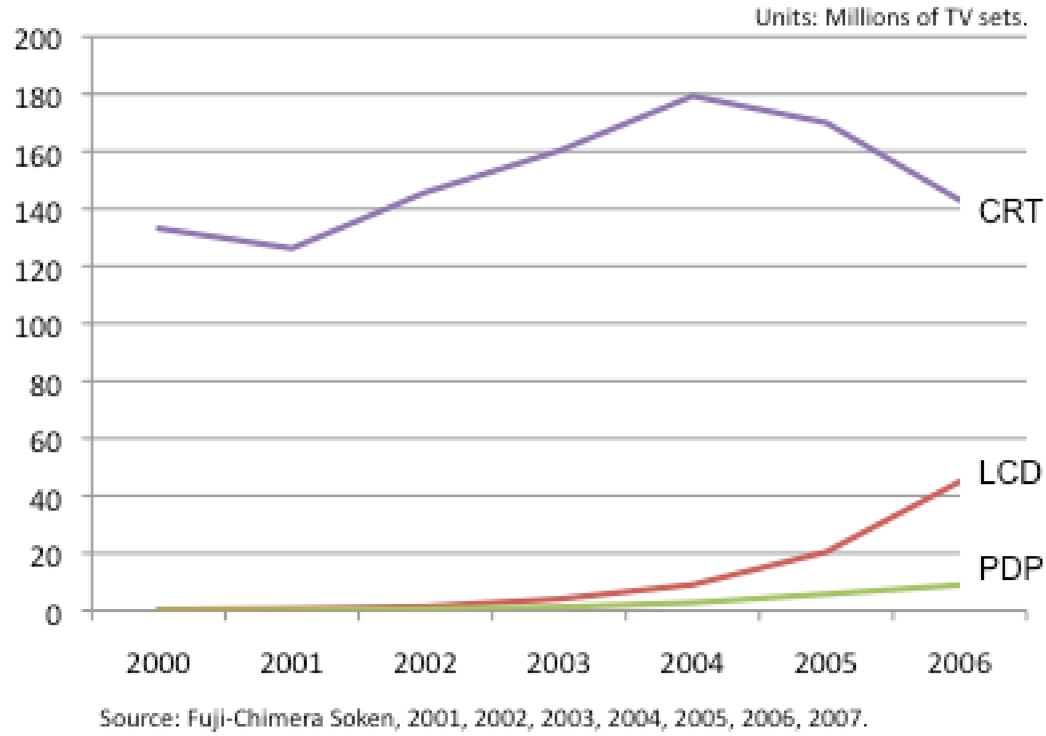
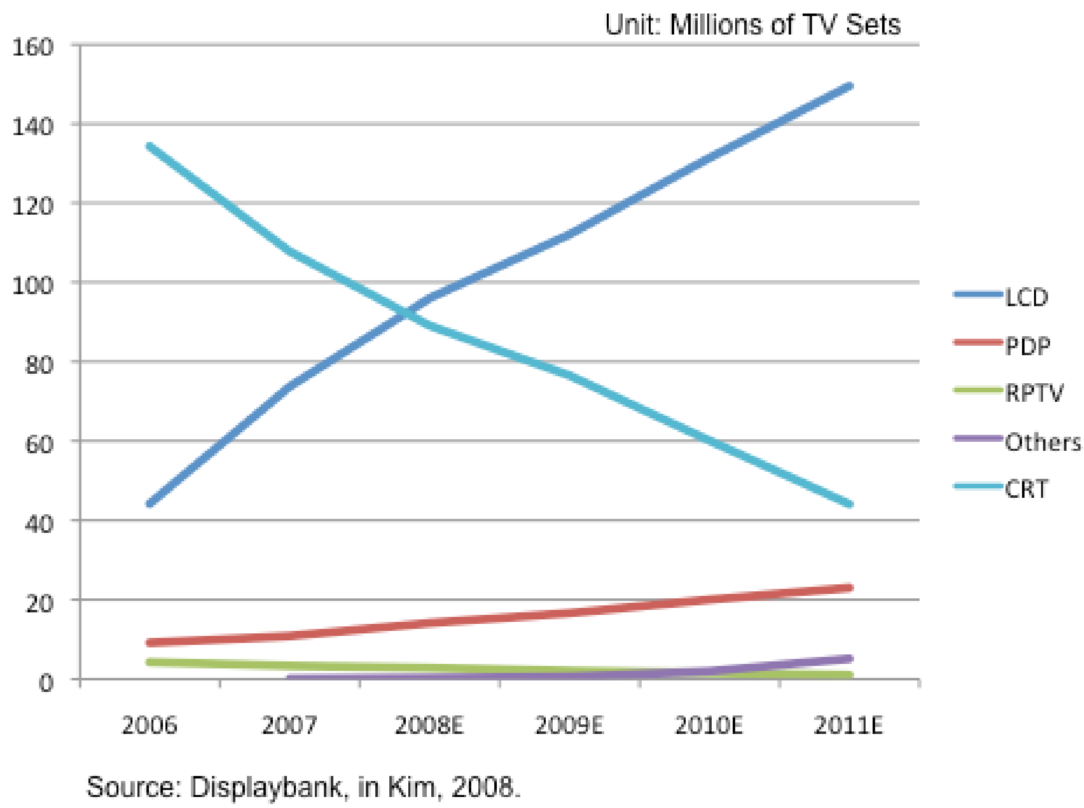


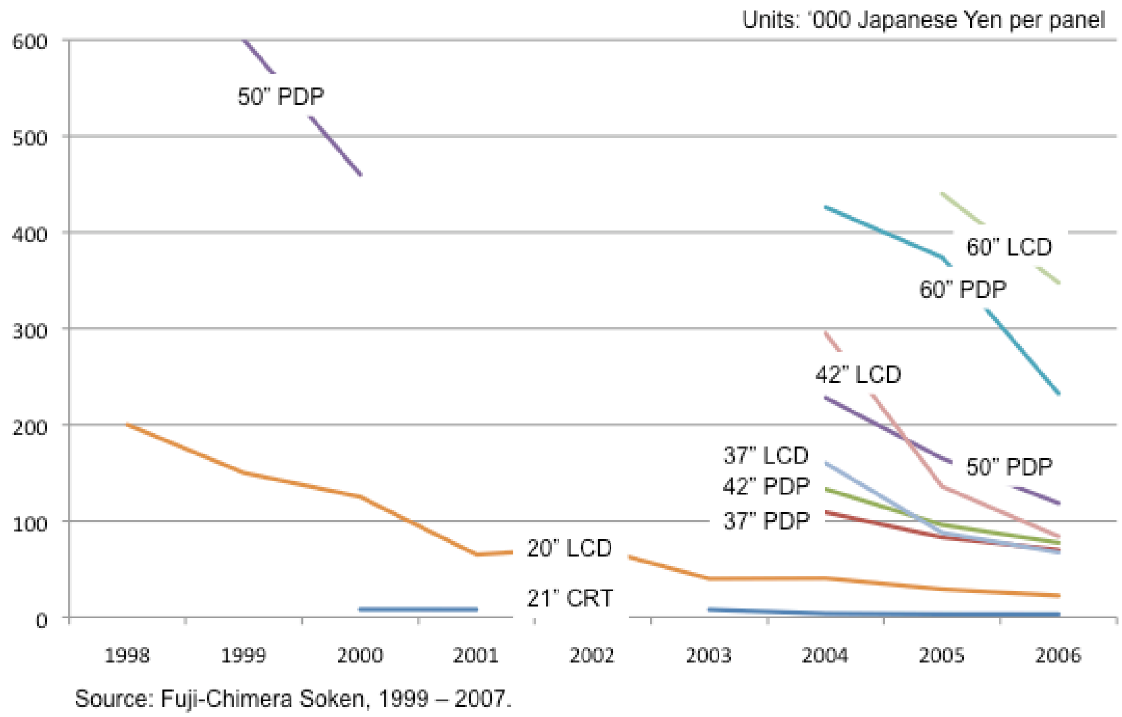
Chart 4-5, below, suggests LCD-TV surpassed CRT-TV production worldwide, in terms of unit volume in 2008. This projection was forecast prior to the current economic downturn; however, the general trends remain in-tact, even if the timing or volume have changed to some degree.

Chart 4-5: Worldwide TV market forecast



Behind the growth in flat panel television has been dramatic reduction in panel costs. Chart 4-6 shows the average prices of TV display modules from 1998 to 2006. Price reduction over the period has been dramatic. For example, 50” PDP prices for 2006 were roughly one-fifth their price in 1999.

Chart 4-6: Average TV Module Prices (1998 – 2006)



TV Set Industry – Chapter Summary and Conclusion

This chapter has discussed the TV set industry over time and the position of the focal firms in it. The TV industry was characterized by predictable growth prior to the introduction of flat panel TV and digitalization, two large technological changes in the industry occurring since the late 1990s. The Japanese TV set producers that are the focal firms of this study were active in the industry for many years and continue to play a large role in it. European TV set producers have been on a downward trend for some time, while Korean TV set manufacturers have been growing and taking a more prominent place in the industry for some time. The global market for TV sets in general is very large and has been growing. Many firms have considered the flat panel TV market attractive due to its large size and relatively well-understood demand. Indeed, the very large potential market size for flat panel TVs may have reduced firms' perceptions of uncertainty relating to investing in technologies to participate in this market.

The growing TV set market size as measured in unit volume has been accompanied by dramatic decreases in TV set and panel prices. Replacement demand for flat panel TVs has been and continues to be large. The following chapter performs firm level analysis of display technology options developed and held by the firm and subsequent performance in general and in the TV set industry.

CHAPTER FIVE: FIRM LEVEL ANALYSIS

This chapter presents firm level case studies of option-like investments by the target firms listed in the methodology section. These firm-level studies provide the key data for considering central questions of this thesis, "Do firms create and hold technology options under uncertainty?" and "How do firms holding options on multiple technologies perform compared with those making commitments to single technologies in the face of technological uncertainty?"

Evidence of investment in technology options by each firm is examined over time to identify patterns at the firm level. This evidence is considered in terms of a ladder of option-like investments ranging from low cost investments that are far from the market to large investments that are close to the market. As part of each case study, performance is also examined. Before moving on to the case study analysis, the option ladder is discussed in more detail.

Brief Chapter Summary

The analysis in this chapter finds target firms developed multiple display technologies. While most firms developed and maintained technology options in parallel, Canon stood out for developing in serial, dropping one before beginning the next.

As flat panel TV volume started to grow, the top tier incumbent Japanese TV producers Panasonic and Sony initially lost market share as competitors introduced more and better flat panel TVs. However, these top tier firms later regained their former place in the industry. Several second and third tier Japanese TV firms, including Hitachi, Mitsubishi, Pioneer, and Sharp, attempted to improve their position in the TV set industry through investments in flat panel technologies. Sharp was the only firm able to realize a durable improvement in performance over the longer term.

Option Ladder

Flat panel display technology options can be placed along a spectrum of different cost and flexibility tradeoffs, as previously discussed in Chapter One. The set of options along this spectrum can be considered in terms of an options ladder (See Figure 1-2, page 25).

Option types range in cost and the proximity towards market entry afforded. Options far from the market typically offer flexibility at low cost. For example, the cost of stopping a small R&D project will be lower than the cost of shutting down a mass production plant. Furthermore, technological progress gained through R&D offers the firm flexibility by providing the opportunity to move higher up the ladder at a later time. Firms not holding such options in R&D cannot easily leapfrog into a higher level on the ladder without either pursuing their own R&D program to the point it bears fruit or buying outside expertise and licensing requisite patents.

The higher rungs of the ladder represent increasingly commitment-like investments and market entry. These investments are much more expensive and difficult to reverse than those on lower rungs. For example, building a cutting edge LCD plant currently costs billions of US dollars (e.g., Samsung, 2006; Sharp, 2008). While there is a market for some used LCD facilities, there is no developed market for the larger and newer plants (FPD 2008 International Trade Show).

Intermediate ladder rungs each bring the firm closer to the market, but also increase investment costs. Some of the costs may be impossible to know in advance, and are not symmetrical between firms. For instance, prototyping is generally not extremely expensive, however one informant commented his firm had spent approximately one million dollars per PDP prototype it produced during early stages of development. Compared with building a plant this may not represent a large investment, but it is costly for a stage still far from the market. Asymmetry of costs at this stage can occur due to difference in resource bundles held by the firms in question. The cost of setting up a small LCD prototyping line will be lower for firms already possessing usable existing clean room space than for those needing to build it, for example.

Role of Cooperation in Reducing Investment, Increasing Reversibility

Firms may increase flexibility and reduce investments required by cooperating with other organizations. They may do so at different levels of development. Toshiba and IBM established an R&D JV in 1986 (Murtha et al, 2001), and later incorporated a separate JV entity, Display Technology Incorporated in 1989 for the purpose of manufacturing TFT-LCDs (Sangyo Times, 1992). Fujitsu Hitachi Plasma Display Limited, on the other hand, is an example of a JV that included development, production, and sales from the beginning (Business Wire, 1998; Sangyo Times, 2000).

Informant Input Regarding the Option Ladder

In the interview process, informants' direct experience in development and market entry were shown the option ladder and asked for general feedback. They were also asked if options levels or key investments were missing. Informants expressed general agreement with the model; several provided additional input. One informant emphasized the importance of making customer needs commitments when moving to higher levels on the ladder. He cited the need for display panel producers to develop relationships with other TV set manufacturers to sell excess display production volume, and also emphasized the idea that firms integrating TV set and panel production should invest sufficiently in marketing at the end consumer level. Both types of marketing activities have costs, but each reduces the market uncertainty of the investment in panel production. Another informant emphasized the importance of management decision-making styles in higher-level investments in follow-on options. A further informant from a panel producing joint venture added context to this point when he noted that the venture partners had previously made different investment decisions while facing the same uncertainty and despite having similar display technology capabilities.

Options ladders and Firm-Level case analysis

In the analysis below, evidence of each firm's display technology options over time are presented graphically. This is achieved by placing the options ladder on the vertical axis and time on the horizontal axis of a chart for each firm. The option ladder figure emphasize rises and falls in options levels over time; evidence of continued investment at the same level (e.g., continuing prototypes over time) is not included due to space limitations. Option levels are tracked over time using historical evidence. Base data, including citations, resides in a timeline developed for each firm. The complete historical timelines for each firm are included as an appendix due to their length and detail.

Ladder figures are color-coded, and have been formatted to be interpretable in gray-scale reproduction through inclusion of different shaped markers for each color. Generally, related technologies are coded in the same colors. Liquid crystal technologies, including a-Si, LTPS, HTPS, LCOS, FLCD and are all coded blue, for example. These technologies should be considered to represent different, but related, options. The more colors on the chart, generally speaking, the broader the technologies developed by the firm. Options on competing technologies are present only when more than one technology is developed or utilized at or around the same time. A firm that develops, discards, and then chooses another technology is not developing options on competing technologies. Instead it is choosing to abandon an existing option in favor of building a new one.

Other firm level data presented in this chapter includes Japanese patent data, panel production volume, and production lines in operation. Data on panel production and production lines is limited to available years, and is intended as a reference of scale and commitment levels over time for each firm. Patent data reflects R&D investments by firms studied. Japanese patent data was chosen because of Japan's important role in developing the technologies and because of data quality. Patent data gathered is divided into LCD, PDP, and OLED. Additional limitations exist with regard to the panel data used. Please refer to the methodology section for further information.

Performance data examined below includes financial performance, market share, and entry/exit. Many of the target firms are large, diversified companies. Detailed long-term line-of-business financial performance data is limited due to periodic reorganization of the firms in question as well as changes to the contents of existing sectors in financial reports.

The firm level studies below include the focal firms, Japanese TV set manufacturers, in addition to other relevant TV manufacturers, and IT related firms. Focal firms are the major Japanese TV set manufacturers. They are presented in order of which tier they belonged to when CRT-TV was still predominant. Panasonic and Sony were at the top tier, with the greatest market share. A middle tier included Hitachi, Mitsubishi, and Toshiba. These firms had their own CRT production capabilities and considerable experience in TV sets, but lagged behind Sony and Panasonic in market share. The third tier consists of Pioneer, Sanyo, and Sharp. These firms did not have their own CRT production capabilities and therefore had to rely on supplies from competitors. They had relatively low market shares (In person anonymous interviews, Dates: November 4, 2008; March 19, 27, 2009; In person interview with Tsuyoshi Numagami, March 13, 2009).

Abbreviated analysis of several groups of non-focal firms follows the section on the focal firms. These include other Japanese TV set manufacturers, Funai Electric and JVC, Korean firms producing TV sets and display panels, LG and Samsung, and Europe-based TV set producers Philips and Thomson. Abbreviated analysis of IT firms Fujitsu and NEC is also included as these firms played an important role in development of flat panel technologies. Canon is of interest because it developed flat panel technologies but did not enter the market and therefore is also included in this analysis.

Firm Level Analysis – Tier One Focal Firms

Panasonic

Panasonic Electric Industry, formerly known as Matsushita Electric Industry, is the central company in the Panasonic group, a diversified Japanese conglomerate. Display development and production is centralized through Panasonic Electric Industry and includes several production joint ventures: Matsushita Plasma Display (With Toray Corporation), Toshiba Matsushita Display Technology (focusing on small displays; consolidating with Toshiba), IPS Alpha Technology (TV use LCD panels), and Matsushita Toshiba Picture Display Co. (CRTs). In the past, Panasonic's display related activities were less centralized; display development and production was pursued by several Panasonic group companies in a way that was not always coordinated. Panasonic Electronics (Matsushita Denshi) was a joint venture between Panasonic and Philips, started in the 1950s to produce CRTs. The JV was involved with early DC-PDP development, but was later dissolved and integrated with Panasonic Electric Industry. Panasonic Electric Works has also been involved with FED development; however the focus on FED was more as a lighting source than as a display technology.

Panasonic has a long involvement with display technologies, including LCD, PDP, FED, and OLED. In addition to producing DC-PDPs used in early attempts at PDP-TV in the 1990s, Panasonic group company Panasonic Denshi had also been a major producer of single color PDPs in the late 1980s and early 1990s, including those used in portable computers in the 1980s such as those made by Toshiba (Weber et al., 2008). At the same time Panasonic invested in LCD production lines for use in its own products as early as 1985 (Sangyo Times, 1993).

Panasonic has considerable experience with LCD technology, however it decided to focus on PDP as the main display technology it uses for TV sets. It is the largest Japanese TV maker to put a strong emphasis on PDP. Korean firms LG and Samsung are also large PDP producers, however in addition to PDP TVs, they have LCDs in similar size ranges. Panasonic, on the other hand, has a dividing line between LCD and PDP TVs based upon size. The reasons Panasonic chose its PDP focus are suitability for large size applications, visual quality, and investment efficiency. Panasonic was interested in selling the main TV in the house – the large one typically found in the living room. PDP was suitable for large displays from a relatively early stage, whereas LCD technology took years to mature to the level it could be used in large displays. Panasonic believes emissive displays like PDP and CRT provide a more comfortable viewing experience than LCD.[1] At the same time, PDP plant investment requirements were much lower than those for LCD for a comparable size and production volume.

Panasonic has strong operational capabilities in addition to planning involving target market shares. Given the firm's capabilities and size it can change markets and impact technology adoption. Panasonic managers do not dismiss such options.[2]

Panasonic has a long history as a major player in Television sets. It began TV set production in 1955 (Hiramoto, 1994). For many years, Panasonic held the number one or two positions in TV set market share in Japan, with Sony being its primary adversary.

Evidence of Option-like investments

[1] In person anonymous interview: March 27, 2009.
[2] In person anonymous interview: March 27, 2009.

Panasonic assembled and maintained a number of display technology options. At one time or another it has held options on EL, FED, FLCD, OLED, PDP, and a-Si as well as LTPS LCD technologies. Panasonic appears to have some continuity of R&D investment even in the technologies it produces; EL activities do not appear to have been large, but they continued for a number of years (see Figure 5-1). Similarly FED development activities also continued for some time. Another feature of Panasonic's technology options is that the time frames over which investments were made are largely overlapping. PDP and LCD technologies were not at the same option levels until the late 1990s, however investment had been ongoing in both for some time prior to that point, just at different option levels. This can also be seen in the patent data (see Chart 5-1).

Panasonic's use of joint ventures is also of interest from an options standpoint. According to industry press, Panasonic's PDP joint venture was undertaken because of unique technological capabilities of its partner Toray, a Japanese firm in the chemical industry. Toray represented an opportunity to enter the market more quickly and effectively than Panasonic trying to replicate the technology on its own. Panasonic's joint venture activities with Toshiba, on the other hand, have a very different flavor. Generally, these joint ventures were used to integrate overlapping production capabilities between the two firms (See Figures 5-2, 5-3 for changes to Panasonic's production capacity through this joint venture). Over time, the two firms changed their stakes in the different JVs, with control of the CRT JV going to Panasonic and control of the LCD JV to Toshiba. As a result, Panasonic exited small LCD and Toshiba exited CRT. In essence, Panasonic and Toshiba used these to gradually re-arrange their capabilities rather than to decrease risk.

Finally, one way that Panasonic differs from most of its Japanese competitors is its willingness to make large commitments. This can be seen in its willingness to buy capabilities from other firms (or buy the other firm itself). Panasonic's controlling stake in IPS Alpha serves as an example. This investment comes at a point where technological uncertainty has waned, but it still faces large uncertainty with regard to future flat panel prices. Interviewees suggested that Panasonic uses its market power and branding to decrease the overall uncertainty it faces (In person personal interviews, dates: March 19, 27, 2009). This appears to allow the company to comfortably make commitments when other firms cannot.

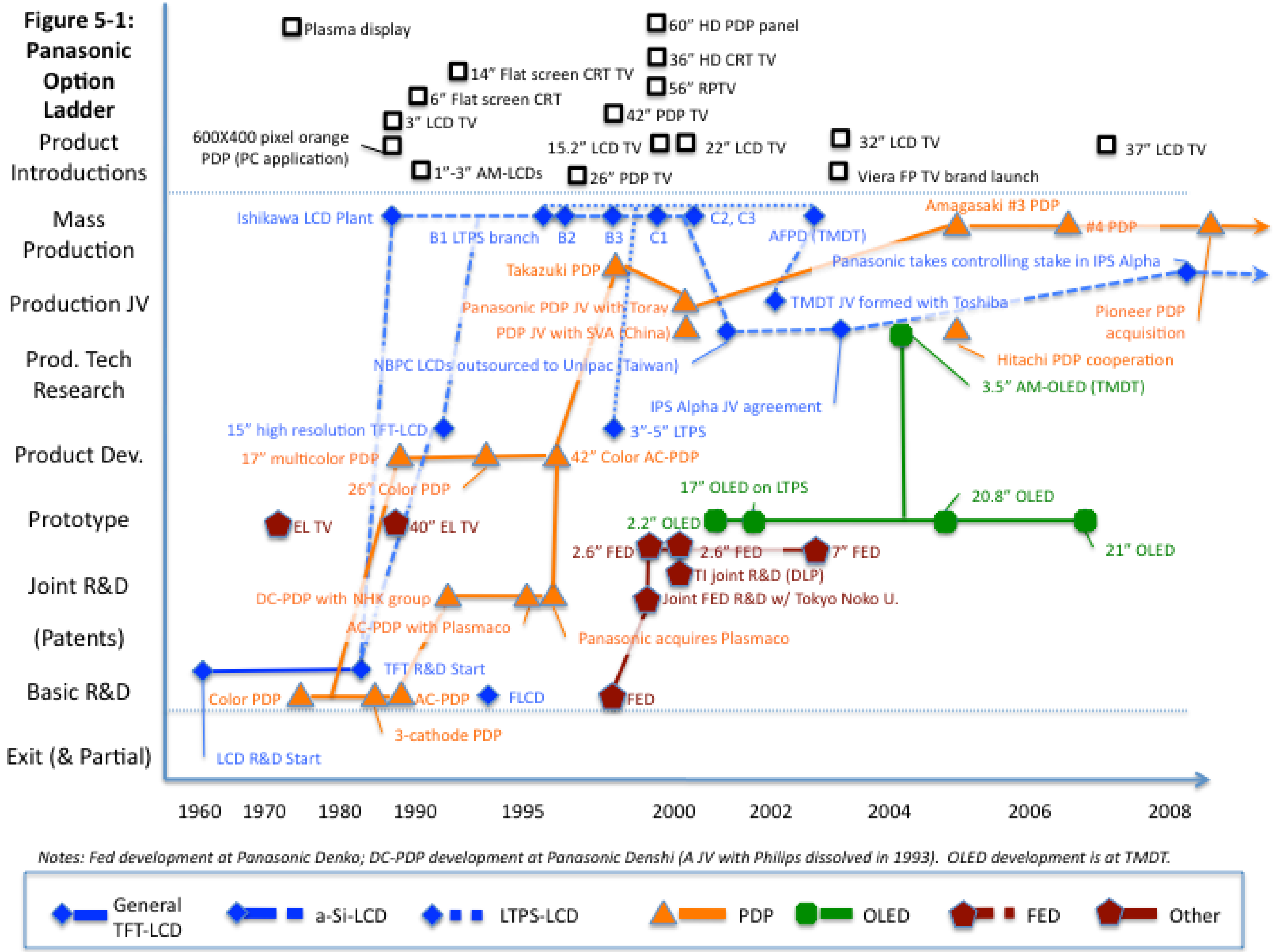
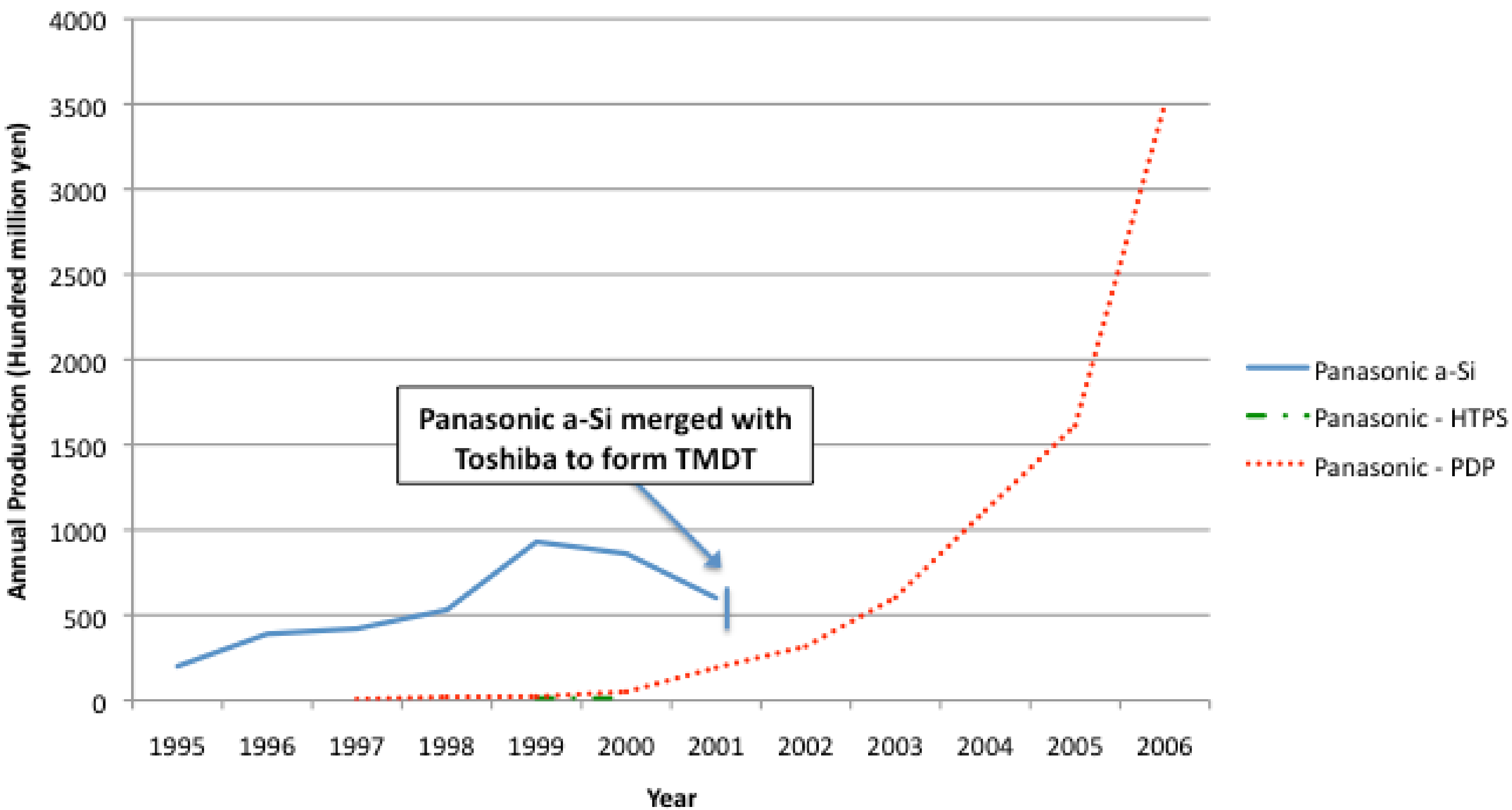


Figure 5-1: Panasonic Option Ladder

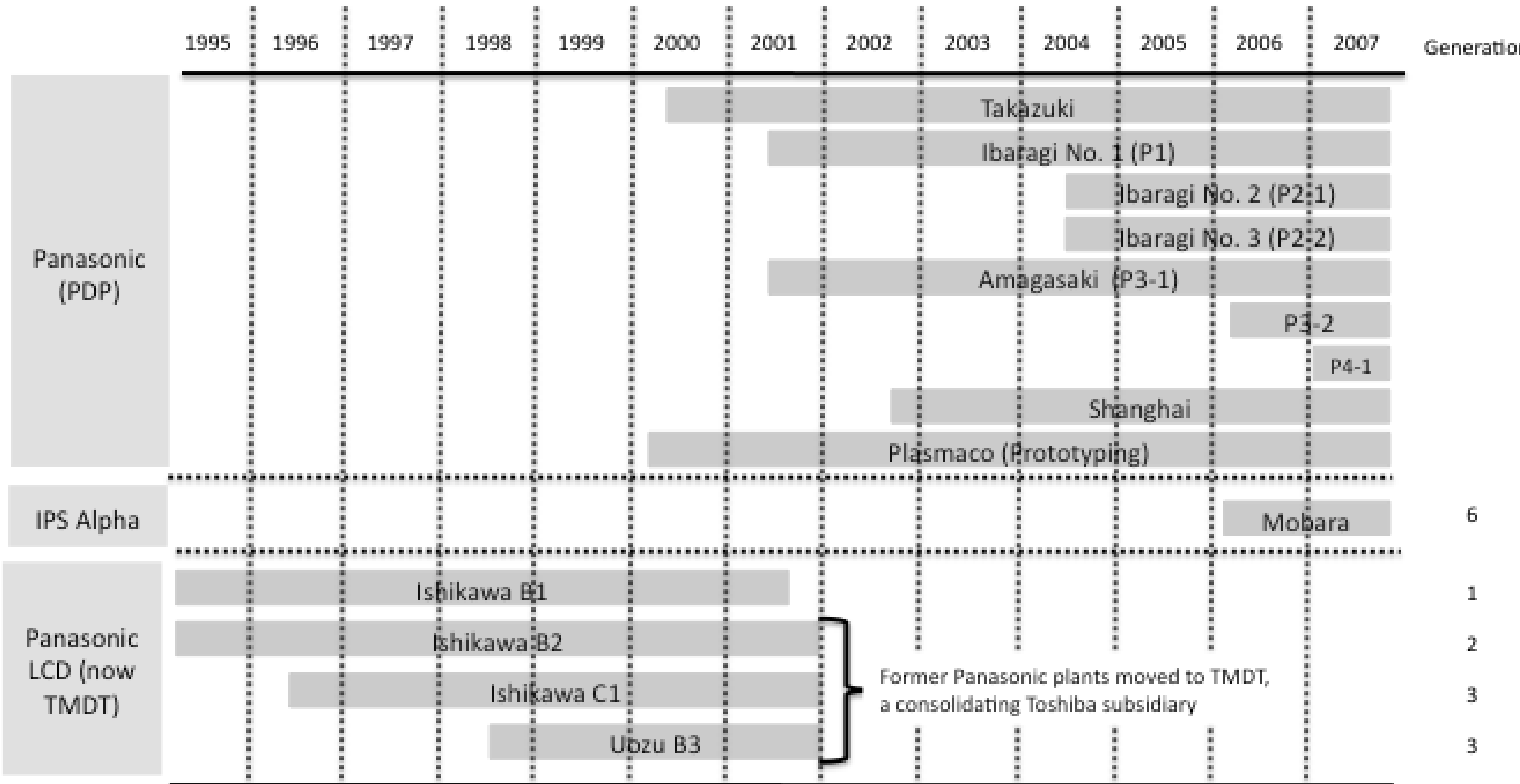
Notes: Fed development at Panasonic Denko; DC-PDP development at Panasonic Denshi (A JV with Philips dissolved in 1993). OLED development is at TMDT.

Figure 5-2: Panasonic Display Panel Production Volume and Production Lines



Note: LTPS and OLED production values were zero. Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Figure 5-3: Panasonic Production Lines



Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-1: Panasonic Patents

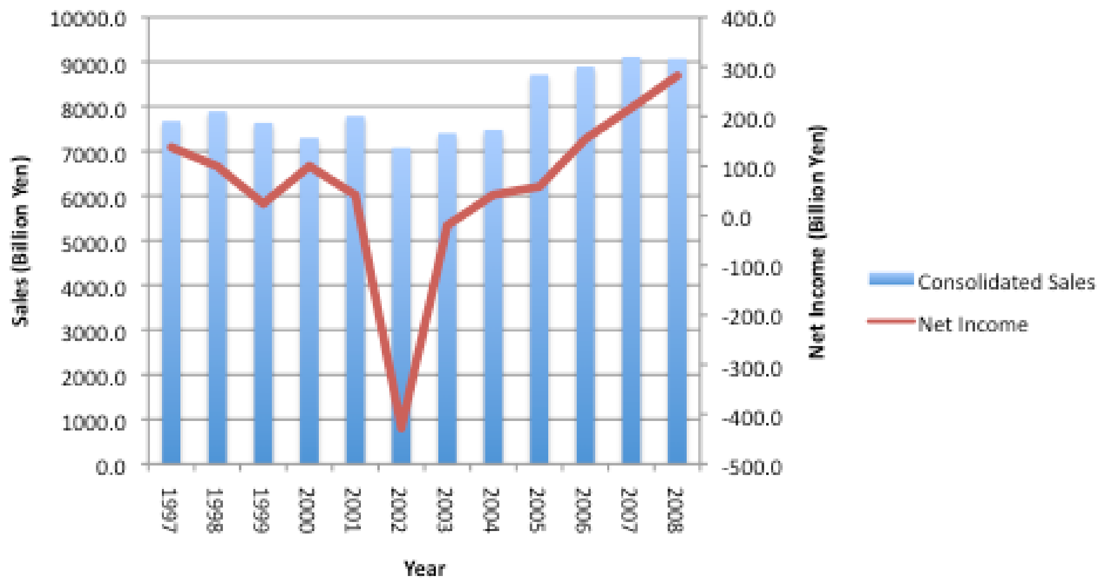
Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Panasonic's Performance

Panasonic had high market share in television sets before flat panel technologies began to represent a significant portion of the market. Fuji Chimera (1999) estimated Panasonic's worldwide TV market share for all technologies at 8.4%, in second place behind Sony. For a period, Panasonic lost market share to first movers in PDP and LCD. For example, Panasonic held 9% of the Japanese LCD TV market in 2002 – when Sharp held 54% (Nikkei BP, 2003 (Senryaku hen)). Panasonic was listed in 4th place for Japanese PDP TV shipments in the 4th quarter of 2002 with 13% of total, behind Hitachi, Pioneer, and Sony (Nikkei BP, 2004 (Bunseki hen)). Although hardly a late mover, it took Panasonic time to regain market share. The reason for this is not clear; perhaps Panasonic's prior successes in CRT TV slowed its movement into flat panel TVs. In the late 1990s, Panasonic introduced a flat screen (not flat panel) CRT TV series. Although not as successful as a competing flat screen TV introduced earlier by Sony, this product line may have distracted Panasonic. In any case, Panasonic has been able to turn around its market share. By 2005, Techno Associates Research (2006) listed Panasonic as the leading PDP TV in worldwide share with 26%. Its LCD TV share is less impressive, but this too has improved (Chunichisha, 2008). As of the time of writing, Panasonic had regained its position in the industry.

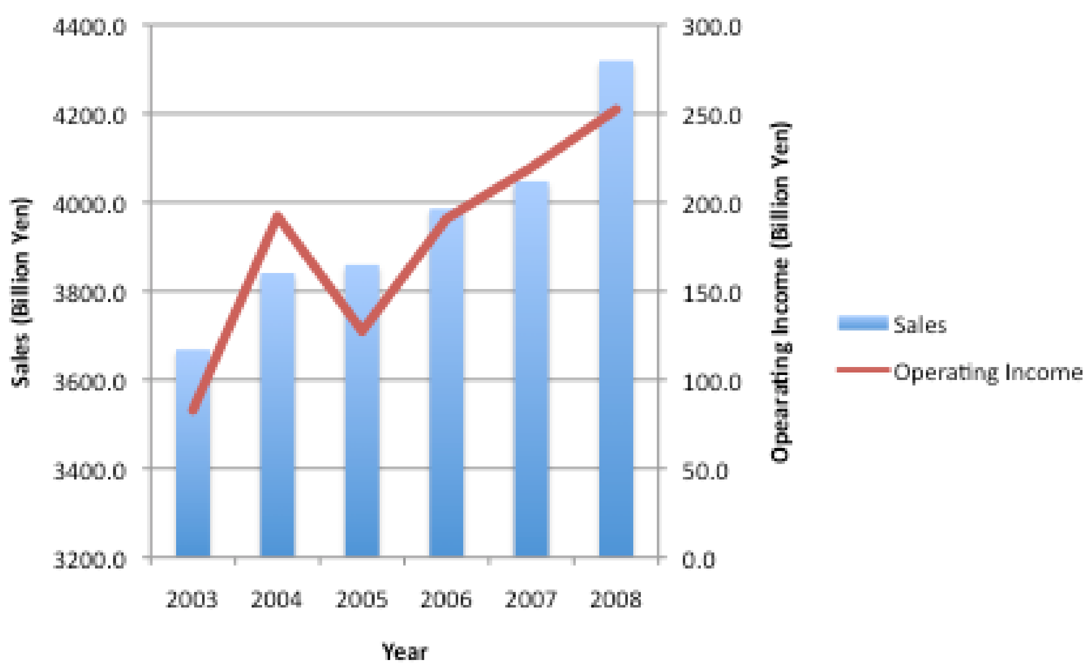
Panasonic's financial performance shows growth in revenue and profits. This is true both for the consolidated data as well as for the Panasonic AVC Networks sector that includes the TV business (See Charts 5-2 an 5-3). Taken together with the market share evidence, one can see that Panasonic has recovered from the period it faltered. Not only has it regained its strength in the TV set market, it has achieved strong financial performance as well.

Chart 5-2: Panasonic Sales and Net Income



Source: Panasonic annual reports

Chart 5-3: Panasonic AVC Networks, sales and operating income



Source: Panasonic annual reports

Sony

Sony has a long history of leadership in the TV set industry. For many years, Sony and Panasonic have battled for top position in the Japanese TV market. Whereas Panasonic's approach has typically emphasized efficient production of products that were "good enough" for its target consumers, Sony emphasized unique, innovative products.

Sony was not an early mover in TV sets, but nonetheless has a long history of technological achievements in the industry. Sony developed the world's first transistor TV in 1960 (Jojima et al., 2006). Unsatisfied with the shadow mask technology used by others in color picture tubes, Sony developed its own color CRT technology. Although an earlier attempt at development failed, in 1968 Sony introduced the color Trinitron (Jojima et al., 2006). The Trinitron display was a key technology Sony used to develop and maintain a strong, differentiated market position based upon superior image quality. Arguably, the success of the Trinitron has shaped the approach Sony has taken in subsequent display development efforts. Interviewees stated that Sony had developed extremely high standards for display quality in television sets – these standards made it difficult for the firm to accept display technologies such as LCD they considered to exhibit inferior image quality (In person anonymous interview, March 18, 2009; In person interview with Tsuyoshi Numagami, March 13, 2009). LCD TV has been a disruptive technology from Sony's standpoint. Informants and industry insiders commented that Sony's strong position with Trinitron-based CRT TVs slowed its switch to flat panel televisions.

Sony has performed research on a large number of display technologies, including PDP, LCD, FED, PALC, OLED, and MEMS (similar to Texas Instruments' DLP technology), as shown in Figure 5-4 below. TFT-LCD development included a-Si, LTPS and HTPS varieties. With the exception of FED, Sony used each display technology in at least one consumer product. However, Sony's in house production capability was limited to HTPS and OLED, and through joint venture, LTPS (Figure 5-5). Although Sony developed many varieties of display technologies, the firm was slow to switch from CRT TV to FP TV. Also, the company did not invest in its own a-Si TFT production capability, but relied on JVs with major producers including Samsung and Sharp, while procuring addition TFT-LCD panels from other producers.

Evidence of Option-like Investments

Sony developed broad options on a number of different display technologies. Evidence suggests investments in a number of these technologies were option-like in that they were low cost ways to increase Sony's flexibility. For example, Sony performed basic research on PDP, PALC, and FED without building mass production capabilities for any. Sony also increased flexibility and managed costs through joint R&D efforts (in the cases of FED, PALC, and OLED) and through participation in production joint ventures. For a-Si production, Sony partnered with Samsung in S-LCD, and is partnering with Sharp at a new Generation 10 plant in Sakai, Japan. Sony initially outsourced LTPS production to Sanyo, and later formed a joint venture to produce LTPS with Toyota Loom. It plans to take over Toyota's stake in the venture.

Figure 5-4: Sony Option Ladder

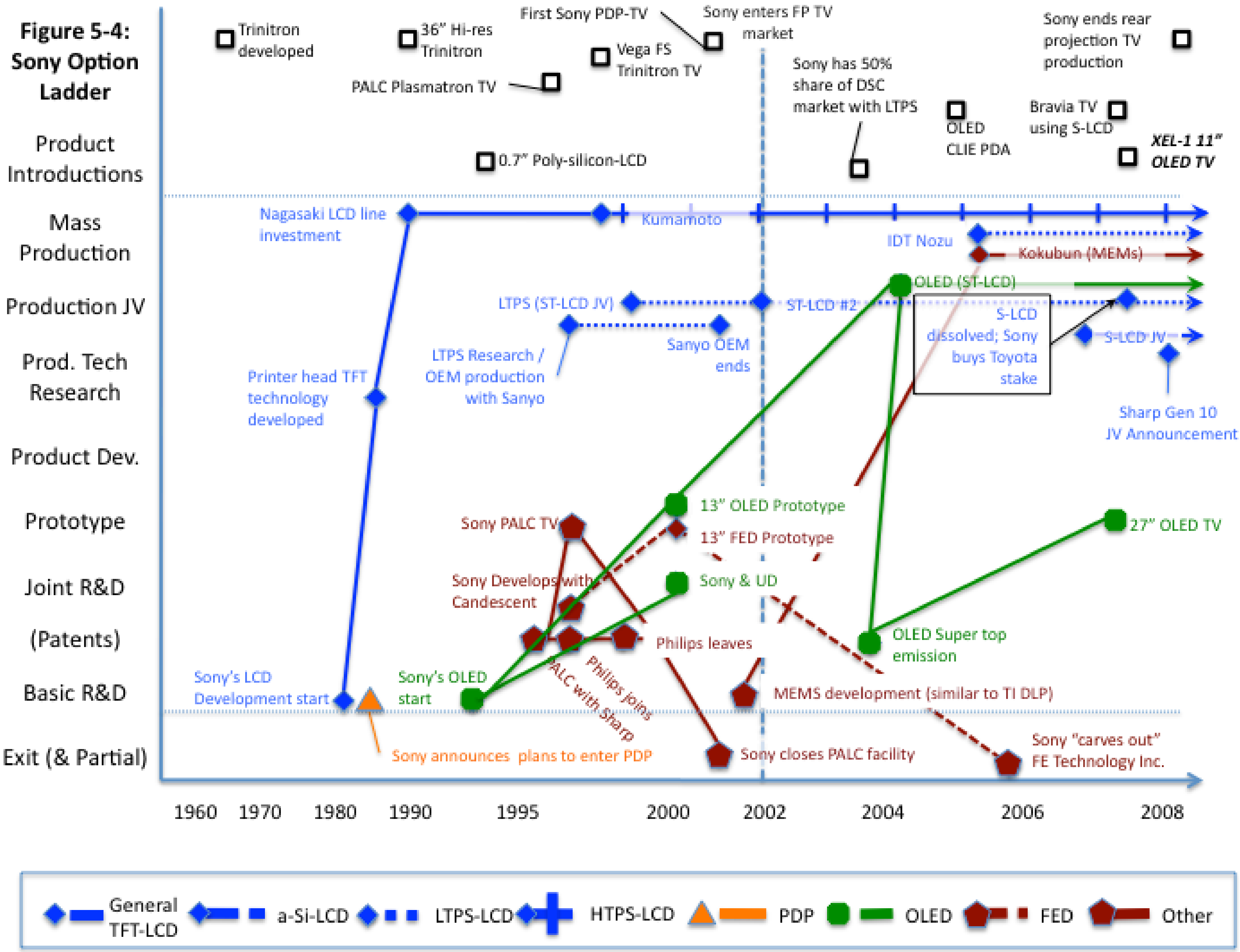
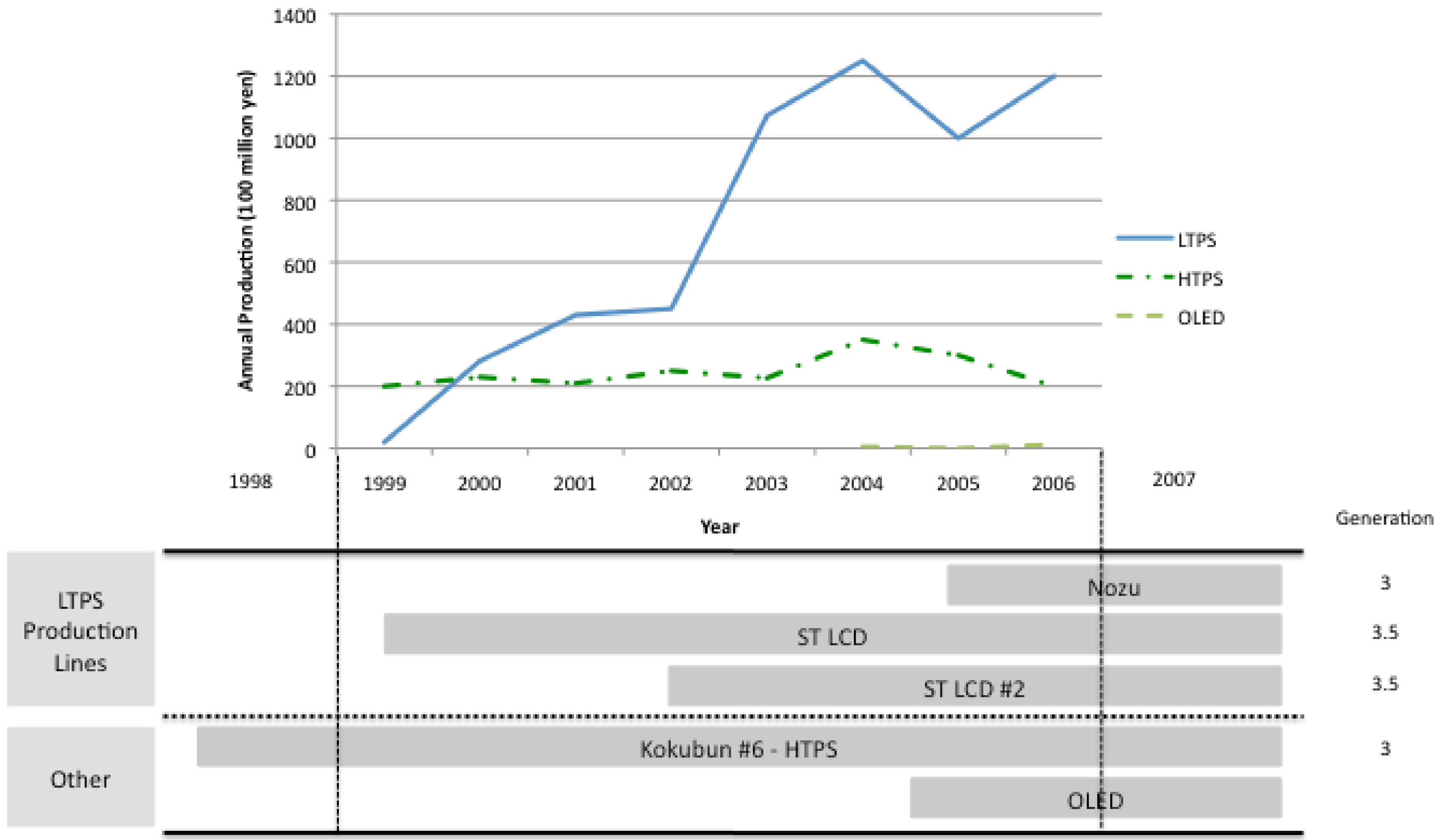


Figure 5-5: Sony Display Panel Production Volume and Production Lines



Notes: (1) PDP, a-Si values were zero. (2) no data available on MEMs.

Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-4: Sony Patents

Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Sony's activities relating to PALC, PDP, FED, and OLED represented investments in options on alternative display technologies.[3] The timing of Sony's development activities on these technologies exhibits substantial overlap. Furthermore, they coincide with breakthroughs by other firms in PDP as large flat panel displays become more feasible in the mid to late 1990s. Although Sony appears to have had

[3] After Sony's PALC activities ended, Sangyo Times (2003) reported that Sony was focusing on OLED and FED as candidates for "Post Trinitron" displays in 2002.

limited PDP-related R&D, they did have some PDP patenting activity (see Chart 5-4 above).

In LCD, Sony's activities focused upon LTPS and HTPS, as shown by Sony's annual panel production and production line charts in Figure 5-5 above. HTPS was used in some rear projection TVs, and LTPS in smaller direct view displays including notebook computers. It appears that Sony has some experience with a-Si design, although it has never invested in its own a-Si production capability. HTPS did not require major new production capability because it can be produced at a modified semiconductor facility. LTPS required new investment. As mentioned earlier, Sony reduced commitment by forming a JV with Toyota Loom to produce LTPS.

Sony's exit from FED also exhibits some option-like characteristics. Sony decided to move FED technology development outside of the firm after announcing a number of prototypes. In 2006, FE Technologies was formed as a venture company with Sony's FED development capability and ownership split between Sony and an external fund. Sony reserved the right to purchase back the fund's stake within a predetermined time period (Fuji Chimera, 2007; Sangyo Times, 2007). In other words, Sony retained an option on the technology with an expiration date.

Although Sony developed and maintained a number of different display technology options, it did not fully exercise these options. In fact, industry insiders note how Sony fell behind competitors when flat panel TV began to grow (e.g., Jojima et al., 2006; In person interview with Tsuyoshi Numagami, March 13, 2009). Although Sony had developed portable TVs with LCDs (and some using miniature CRTs as well), it announced developing its first 15" LCD TV in 1999, and began selling it in 2001. To put this in perspective, Sharp started selling its Window line of LCD TVs in 1995, and released a 20" model in 1999 (Nikkei BP, 1995; Sangyo Times, 2000). In PDP TV, it is a similar story; Sony entered PDP TV in 2001 with a 42" model, 2 to 3 years after early movers had entered into PDP mass production.

The success of Sony's flat screen (not flat panel) Wega brand CRT TV introduced 1997[4] is often mentioned as a factor in delaying Sony's entry into flat panel TV. The Wega TVs were popular, and allowed Sony to charge a premium over other CRT sets – Compared with the prices of similar sized TVs, Wega TVs were priced twice as high in Japan and 5 times as high in the U.S. market. Another factor often mentioned as a reason for Sony's late entry is the size of investment required to build a cutting edge a-Si LCD plant. Sony's investments in semiconductor capacity for Play Station Two (PS2) production may have reduced its appetite for additional big-ticket plants. The timing and scale of these investments agree with this: over the period 1999-2000, Sony invested over 200 billion yen in PS2 related semiconductor plant and equipment (Sony, 2000).

Sony's Performance

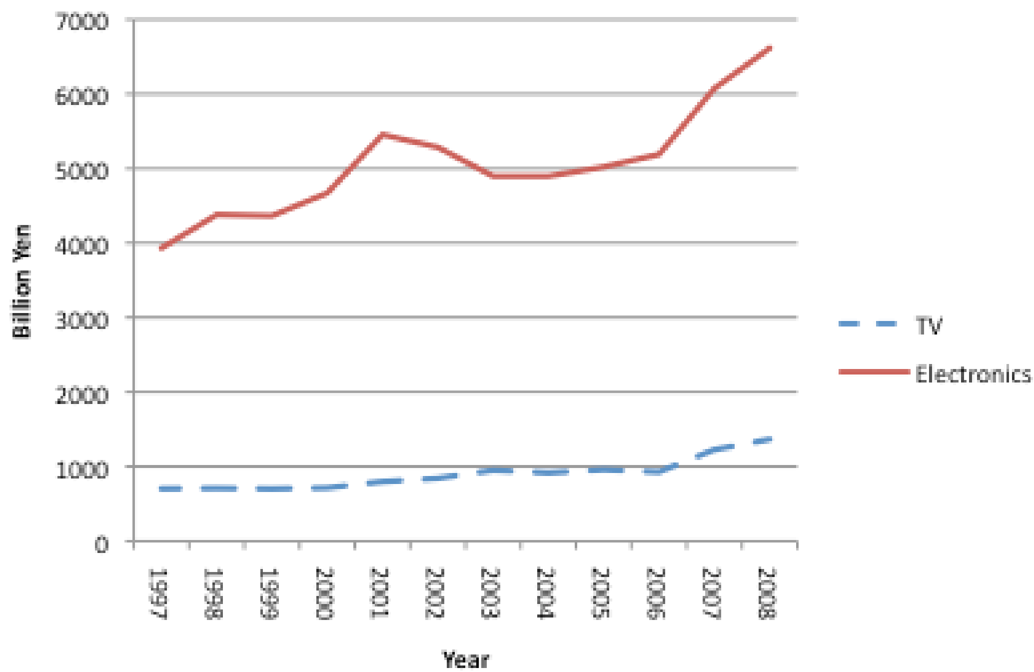
Sony had leading market share in CRT TVs before flat panel TV started to grow. Although Sony's market share declined for a number of years as the flat panel TV market was growing, it appears that Sony caught back up in terms of world wide unit market share as of 2007, and was neck-and-neck with Sharp in LCD TVs in Japan in the same time frame (Chunichisha, 2008; Rikku, 2008). Without a-Si production capability of its own, Sony's flat panel TVs used LCDs and PDPs supplied by other display producers

[4] See http://www.sony.co.jp/SonyInfo/CorporateInfo/History/sonyhistory-c.html

and the S-LCD joint venture with Samsung. Sony maintains relatively high price points compared to many other brands (Nikkei Business, May 18, 2009), so it does not appear that Sony is "buying" market share. Television related revenues have been growing as shown in Chart 5-5 below. It is worth noting that Sony did well in rear projection market share, taking first place in 1998 and staying at the top through 2005, the last year which data is available (Fuji Chimera, 1999, 2003, 2004, 2005).

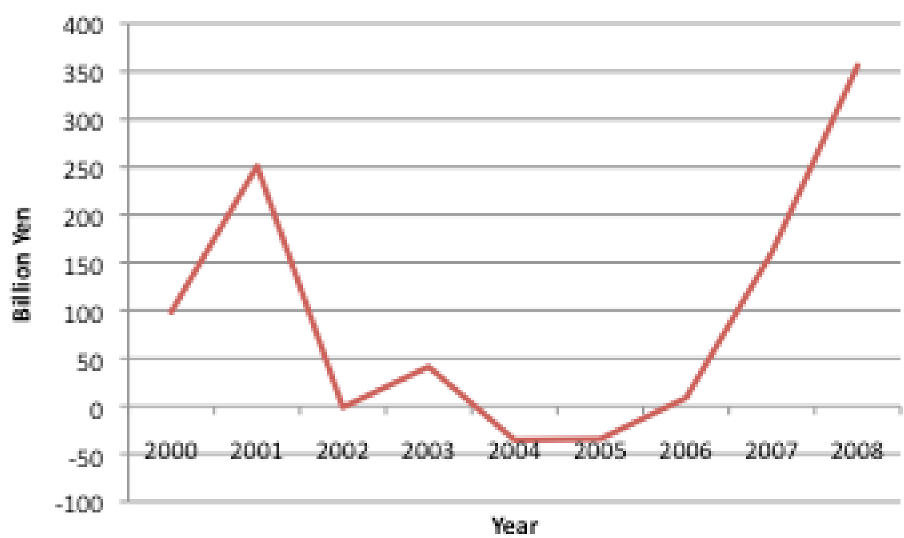
Sony has been reported to have poor profitability in its TV business (e.g., Nikkei BP, 2005 (Jitsumu hen)), on the other hand, the Electronics Sector to which Sony's TV business belongs has recently been exhibiting improved operating income (See Chart 5-6, below). Altogether, Sony appears to have suffered some performance decline due to being late to switch from CRT to flat panel TVs; there is evidence some of its competitors made inroads in market share for some time. However, after a number of years, evidence suggests the firm has been able to return to higher performance again.

Chart 5-5: Sony Electronics Sector and Television Revenues



Source: Sony Annual Reports.

Chart 5-6: Sony Electronics Sector Operating Income



Note: Electronics sector does not include Sony's game business.
Source: Sony Annual Reports.

Firm Level Analysis – Tier Two Focal Firms

Hitachi

Hitachi is large, highly diversified firm known as a technological powerhouse. Japanese observers consider the firm to have top-notch technological development capabilities but accompanied by a bureaucratic management culture.

Hitachi has long been involved with the consumer television set market. The firm began producing TV sets in 1956 (Hiramoto, 1994). It also started LCD development early. Although its first formally announced project began in 1971, it was performing R&D prior to that time (Numagami, 1999).

Along the progression of LCD technology, Hitachi was at or near the forefront of development from the 1970s until around the year 2002, when the firm stopped investing in new plants on its own. Hitachi frequently supplied other firms with LCD panels for use in products applications it didn't make itself (e.g., watches and calculators) as well as applications it did not have major market share in (e.g., laptops). Hitachi invented and holds patents on In Plane Switching (IPS) mode for LCD; this technology has a strong reputation based on its wide viewing angle and speed (See Chapter three for further detail on IPS). It is preferred by numerous Japanese television set producers.

In addition to being a key player in LCD, Hitachi was also an early developer of PDP, beginning R&D in 1970 and developing grayscale PDP technology in 1973 (Hitachi web site[5]; Weber et al., 2008). It entered PDP TV at an early date as well.

5 http://www.hitachi.co.jp/New/cnews/9808/0820.html

Unlike most other firms, Hitachi invested in both PDP production and LCD production. Hitachi built its PDP production through a JV with Fujitsu, and built its LCD production capability on its own (this capability was later moved to a JV). Although highly respected for its technology in both cases, an informant from a competing firm suggested Hitachi did not invest enough in building production for either PDP or LCD, and as a consequence was unable to fully exploit its capability in either.

In addition to PDP and a-Si LCD, Hitachi has performed R&D on a wide variety of other display technologies including LTPS LCD, LCOS, FLCD, OLED, FED and DLP. Although not all of these could be considered suitable for television applications, this still indicates Hitachi's portfolio of technology options was broad and included many competing technologies.

Evidence of Option-like investments

Hitachi started basic R&D into LCDs and PDPs around the same time, as shown in the Hitachi option ladder in Figure 5-6 below. However, in the case of LCD, Hitachi invested in a rapid series of increasingly expensive higher commitment options, beginning TFT-LCD production early on compared to other firms (see the following chapter for timing comparison between firms). The company then paused for a number of years before investing in the more expensive, higher volume production lines.

PDP efforts at Hitachi, on the other hand, exhibited a long period of limited and inconsistent investment in basic R&D, followed by a series of larger investments, including establishment of production under the FHP JV with Fujitsu. Although the options paths Hitachi followed for LCD and PDP were very different, by the time the flat panel TV market was becoming significant Hitachi had considerable positions in both LCD and PDP technologies. Investments in PDP were primarily aimed at TV applications, although Hitachi also sold PDP monitors. Early LCD production was not focused on TVs, with the exception of the IPS Alpha JV and its generation 6 line (see Hitachi Panel Production and Lines, Figure 5-7).

In addition to a-Si LCD and PDP display technologies, Hitachi also invested in LTPS and LCOS. LTPS LCDs are more difficult to produce than a-Si at the same time they offer more opportunities to differentiate. Japanese firms have invested in this technology to insulate themselves from swings in the crystal cycle for a-Si LCD. Investment in LTPS was a way for Hitachi to increase the option value on existing LCD production infrastructure up to the fifth generation.[6] Hitachi produced CRT based RP TVs; LCOS can be considered a way to continue inside the RP TV space with an improved display technology, thereby increasing the value of past investments in RP TV production and distribution.

Hitachi's OLED efforts are limited to R&D and do not exhibit high levels of investment. Although on the increase, Hitachi's OLED patent output is much lower than that for LCD (see Chart 5-7). Recently, the cost of Hitachi's OLED development has been reduced through moving the effort to a joint venture. Given the suitability of LTPS production for use in AM-OLEDs, this effort may increase the option value of existing LTPS production capabilities.

[6] Subsequent generations are not suitable for LTPS adaptation. Source: In person interview with Tsuyoshi Numagami, March 13, 2009.

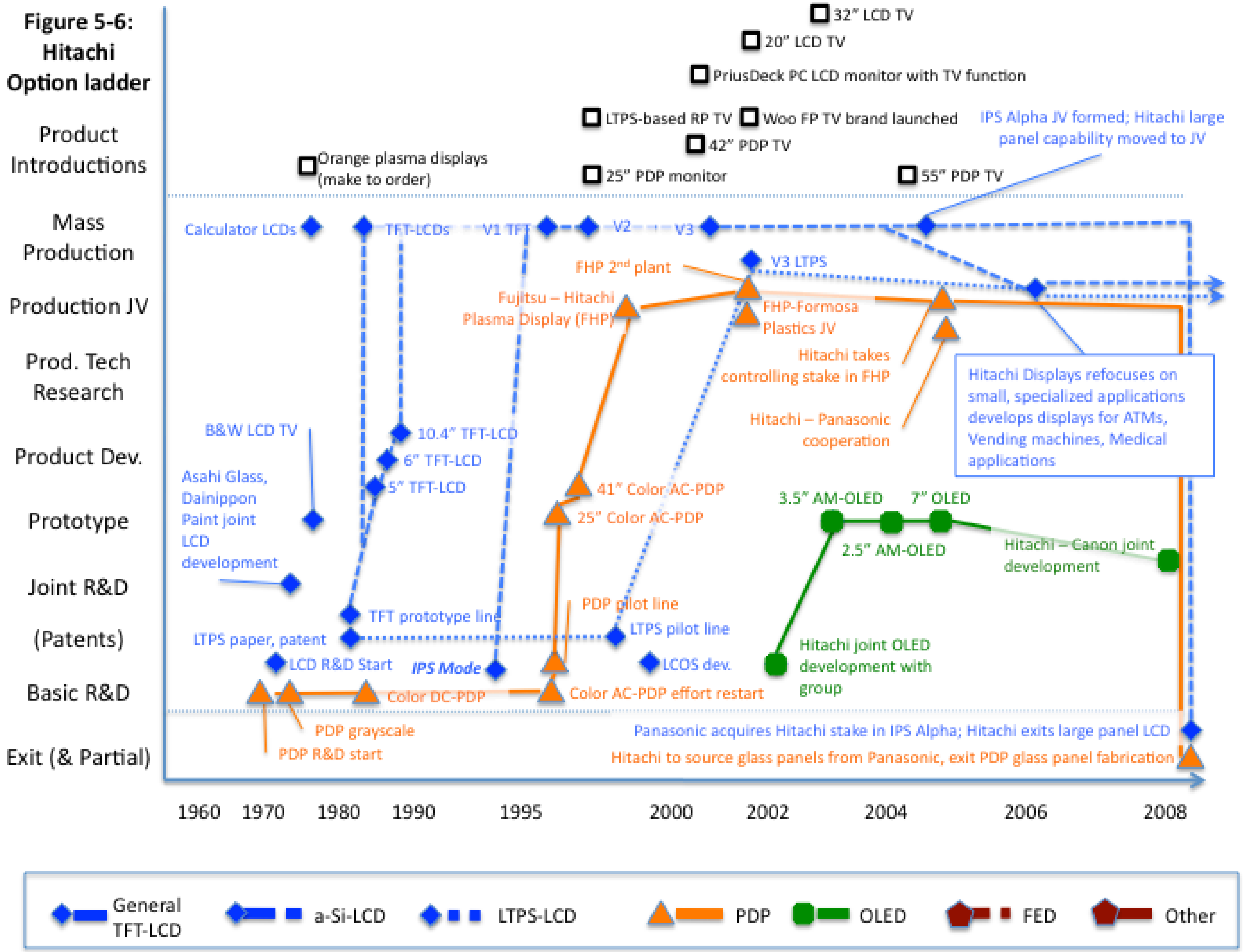
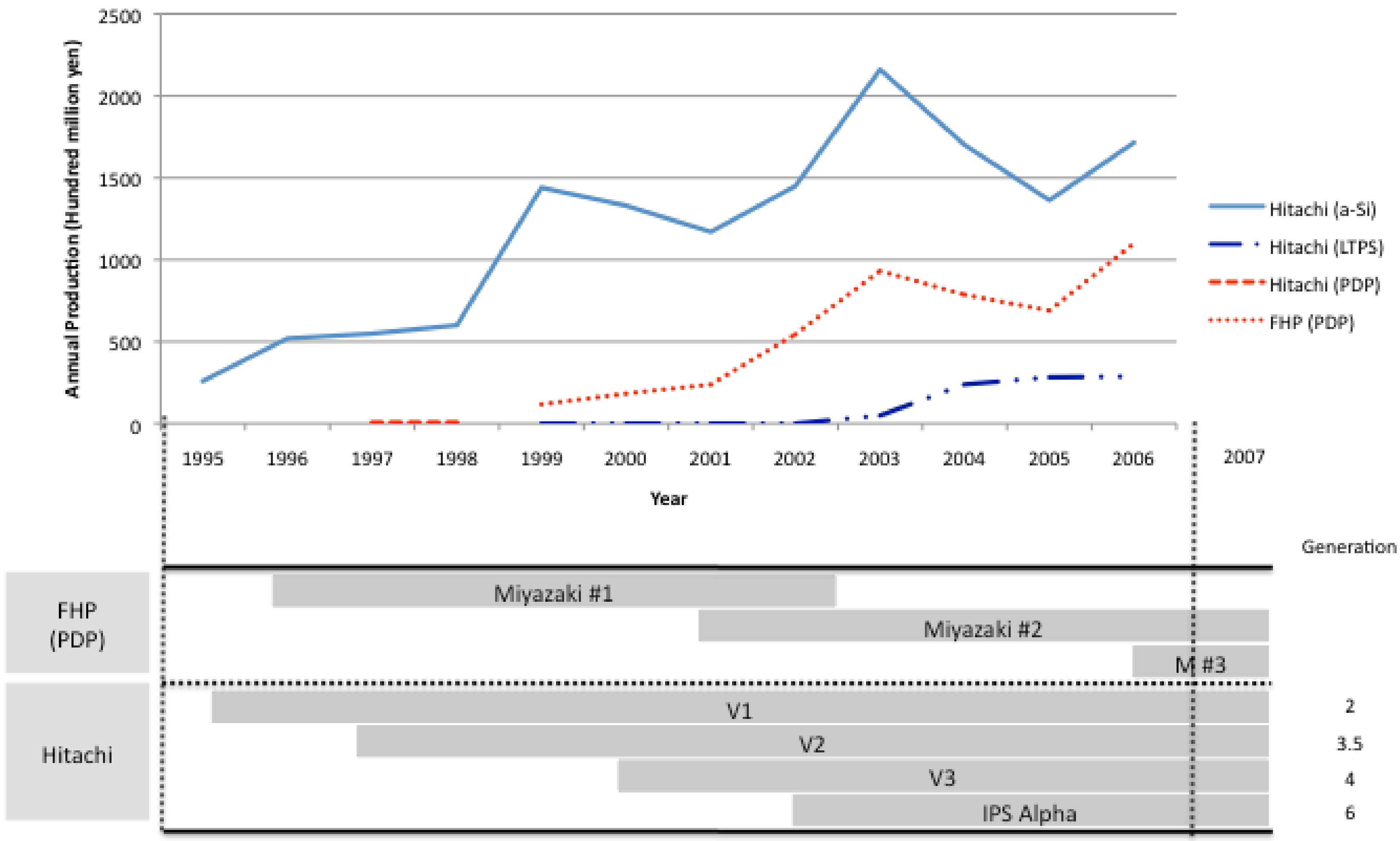


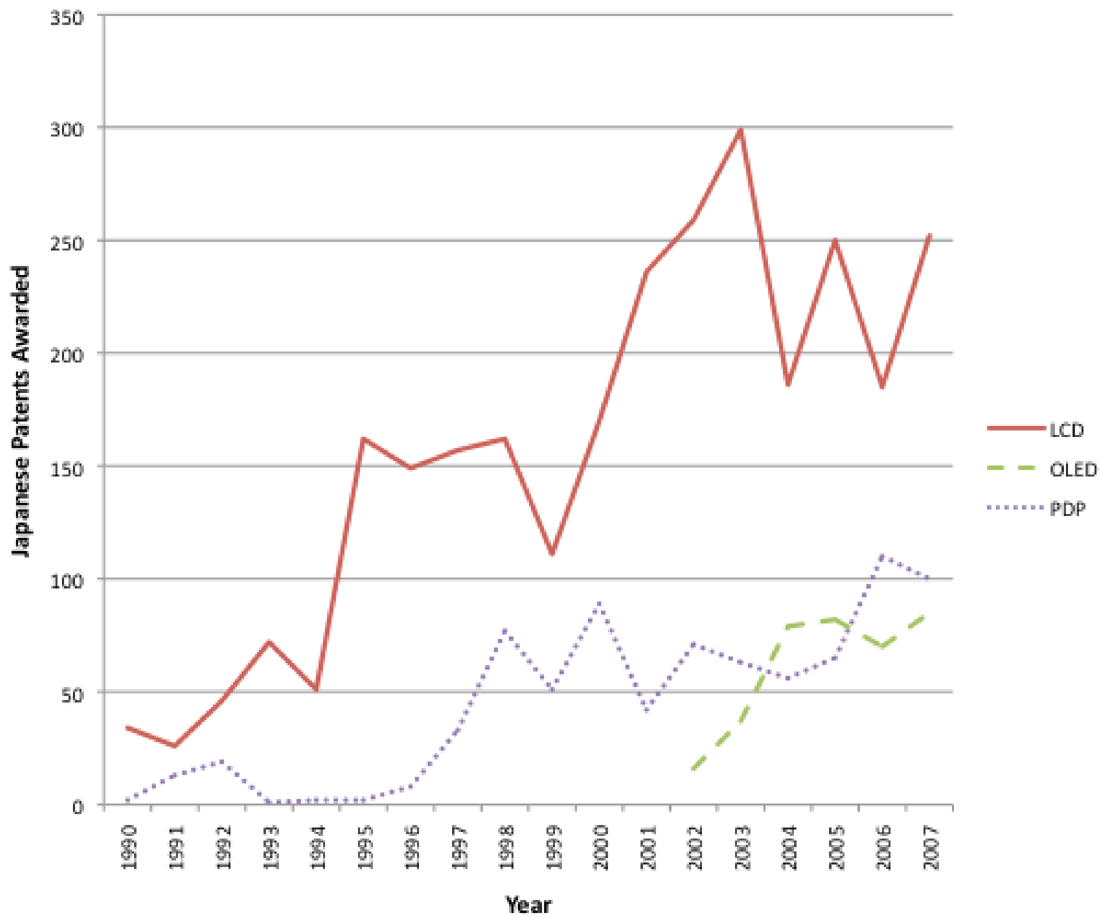
Figure 5-6: Hitachi Option ladder
Product Introductions
Mass Production
Production JV
Prod. Tech Research
Product Dev.
Prototype
Joint R&D
(Patents)
Basic R&D
Exit (& Partial)
32" LCD TV
20" LCD TV
PriusDeck PC LCD monitor with TV function
LTPS-based RP TV
Woo FP TV brand launched
IPS Alpha JV formed; Hitachi large panel capability moved to JV
42" PDP TV
Orange plasma displays (make to order)
25" PDP monitor
55" PDP TV
Calculator LCDs
TFT-LCDs
V1 TFT
V2
V3
V3 LTPS
FHP 2nd plant
Fujitsu – Hitachi Plasma Display (FHP)
FHP-Formosa Plastics JV
Hitachi takes controlling stake in FHP
Hitachi – Panasonic cooperation
Hitachi Displays refocuses on small, specialized applications develops displays for ATMs, Vending machines, Medical applications
B&W LCD TV
10.4" TFT-LCD
6" TFT-LCD
5" TFT-LCD
Asahi Glass, Dainippon Paint joint LCD development
41" Color AC-PDP
25" Color AC-PDP
3.5" AM-OLED
7" OLED
2.5" AM-OLED
Hitachi – Canon joint development
TFT prototype line
PDP pilot line
LTPS paper, patent
LTPS pilot line
LCD R&D Start
IPS Mode
LCOS dev.
Hitachi joint OLED development with group
Color DC-PDP
Color AC-PDP effort restart
PDP grayscale
PDP R&D start
Panasonic acquires Hitachi stake in IPS Alpha; Hitachi exits large panel LCD
Hitachi to source glass panels from Panasonic, exit PDP glass panel fabrication
1960
1970
1980
1990
1995
2000
2002
2004
2006
2008
General TFT-LCD
a-Si-LCD
LTPS-LCD
PDP
OLED
FED
Other

Figure 5-7: Hitachi Display Panel Production Volume and Production Lines



Note: HTPS and OLED production values were zero.   Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-7: Hitachi Patents



Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Hitachi's Performance

Hitachi's technological developments have been impressive, however performance in terms of TV set market share and financial returns have not been strong. In the period from 2000 to 2004, Hitachi's LCD development and production organization lost money every year except for 2003 (Sangyo Times, 2002-2005; Nikkei BP, 2004 (Jitsumu hen)). Perhaps as a result, Hitachi has been slowly and methodically exiting LCD production. In 2005, Hitachi formed the joint venture IPS Alpha together with Panasonic and Toshiba to develop and build large TFT-LCDs, starting with a new generation 6 production line to be built at Hitachi's Mobara plant. Following the formation of the joint venture, Hitachi Displays, Hitachi's remaining LCD organization, refocused its strategy on smaller and more specialized displays. Hitachi reduced its stake in IPS Alpha over time; in 2008 Panasonic purchased Hitachi's remaining stake and made IPS Alpha a consolidated subsidiary. Hitachi Displays also took some outside investment and became a joint venture with Canon and Panasonic in 2008.

Evidence regarding FHP's performance is less clear. Hitachi bought part of Fujitsu's stake of FHP in 2005, making it a consolidating subsidiary. However, the firm slowed investment into PDP and through cooperative arrangements with Panasonic in 2008 began sourcing the glass panels from outside (Hitachi still attaches filters and electronics to the glass panel to complete the PDP module). Although Hitachi has not formally announced exit of PDP production altogether, Showa Shell (energy) is considering buying the facility where FHP's PDP plant is located because some of the equipment can be used in manufacture of photovoltaic cells (Hitachi web site[7]; Japan Consumer Electronics Scan, 2009).

To summarize the evidence above, Hitachi has dramatically reduced its exposure to LCD and PDP production, exiting the most capital-intensive portions of large display production in both cases. Chart 5-8, below, shows operating income for Hitachi's Electronic Devices sector, including displays, and Digital Media & Consumer Products sector, including TVs. Poor performance in televisions is reported to be a major factor in the performance of the Digital Media & Consumer Products sector. Hitachi's TV

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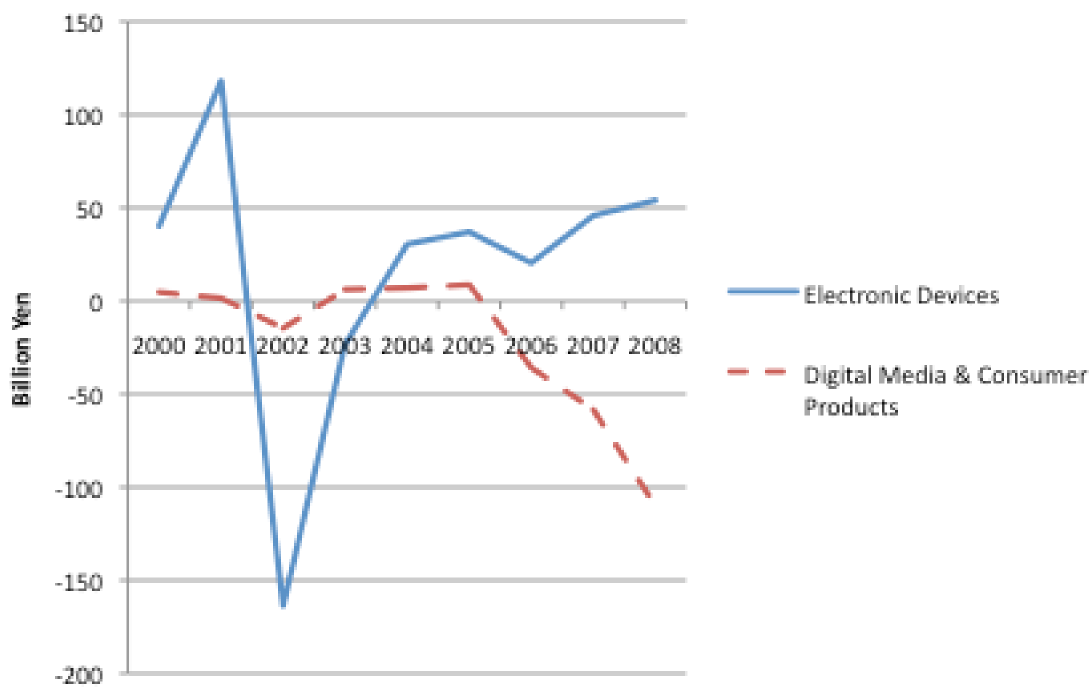
7 http://www.hitachi.co.jp/New/cnews/month/2009/04/0401a.html

business is reported to have been a money loser since around 2005. Analysts suggest the firm may exit the business altogether, although the company has denied having any intention of exiting (Yamaguchi, 2009).

Chart 5-8: Operating Income of Relevant Hitachi Sectors



Source: Hitachi Annual Reports

Hitachi does not have high market share in the TV market. It was not a top selling brand in the CRT TV market, and has not developed a strong position in LCD TV (e.g., Rikku, 2008). In comparison, Hitachi has a much stronger position in the Japanese PDP TV market. In 2003, Hitachi captured 35% of the Japanese PDP TV market by sales revenue, making it the leader (Rikku, 2008). Since then, Panasonic has grown its share dramatically, and Hitachi's has fallen somewhat despite the fact that two other companies exited PDP TV. In the period 2004-2007, Hitachi's Japanese domestic PDP TV share was between 25-30% in unit and revenue measures (Nikkei Report, 2006, 2007, 2008; Fuji Chimera, 2005, 2006, 2007 (Digital AV equipment marketing survey)). Given that the market for LCD TVs has grown several times faster than that for PDP TV, this translates to a decline in overall TV market share. In terms of unit share in the global television market including all display technology types, Hitachi's PDP sales are below 1% for every year which data was available (Fuji Chimera, 1999 – 2007).

Mitsubishi Electric

Mitsubishi Electric has a long involvement with LCD. It formed a joint venture called Optrex with Asahi Glass to produce passive matrix LCDs in 1979 (Sangyo Times, 1992). Later it established a separate joint venture, Advanced Display (ADI), for active matrix LCD development and production (Sangyo Times, 1992). In addition to a-Si LCD, Mitsubishi also developed and produced LTPS through ADI.

Mitsubishi's PDP involvement is also long. Evidence of basic PDP R&D by Mitsubishi dates back to 1973 (Weber et al., 2008). It began producing PDPs in 1997 (Fuji Chimera, 2000), and shipping PDP monitors the same year (Nikkei BP, 1997). However it rapidly about faced, ceasing PDP production in 1998, and later exiting the market (Sangyo Times, 1999; Deutsche Bank, March 11, 2004).

Mitsubishi also made smaller investments in EL and OLED. Mitsubishi developed a prototype EL TV in the 1970s (Numagami, 1999), however there is no evidence of continued R&D in this area. Similarly, the firm has been involved with joint

OLED R&D (Sangyo Times, 2004), but this did not lead to further development of an OLED capability.

Evidence of Option-like investments

Mitsubishi developed and held options in levels up to and including production for LCD (a-Si and LTPS) and PDP (See Figures 5-8 and 5-9). Mitsubishi invested in brief, option like development of EL without follow-on investments. Evidence on its development in OLED is mixed. Although Mitsubishi has participated in OLED R&D, aside from some patenting data (see Chart 5-9), there is no evidence of output or additional investment. Mitsubishi may be maintaining a low-cost option on the technology.

Mitsubishi invested in production capabilities on PDP and a-Si and LTPS LCD display technologies. Mitsubishi's involvement with a-Si was long term and was concurrent with development of other display technologies. However, the timing of investments in other display technologies were more serial in nature. Mitsubishi built PDP production and rapidly exited; after that it entered LTPS and again exited within several years. Its option pattern differs from that of other companies in that it maintained a-Si production for a long period of time on the one hand, while it tried and discarded other technologies one at a time.

Figure 5-8: Mitsubishi Option Ladder

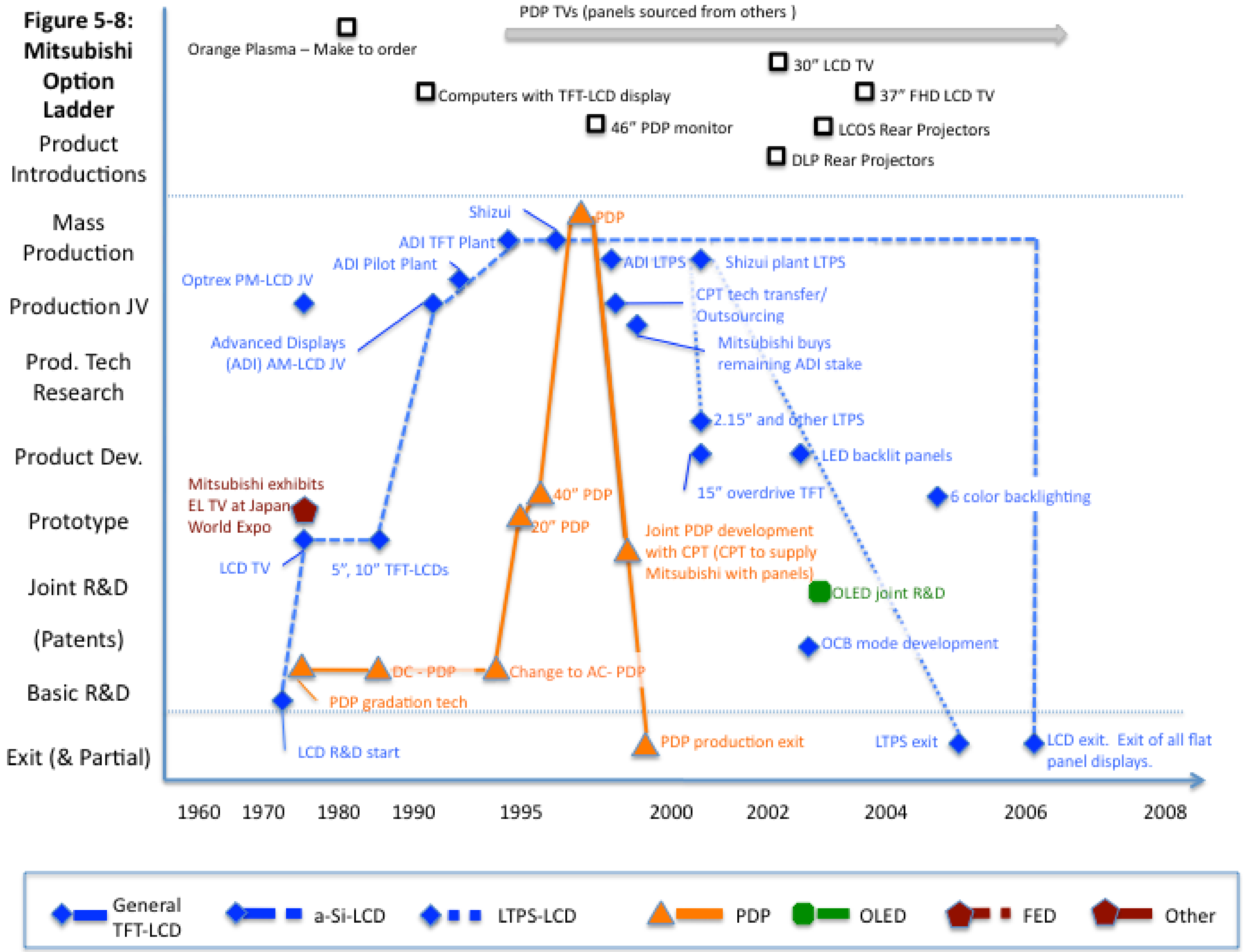
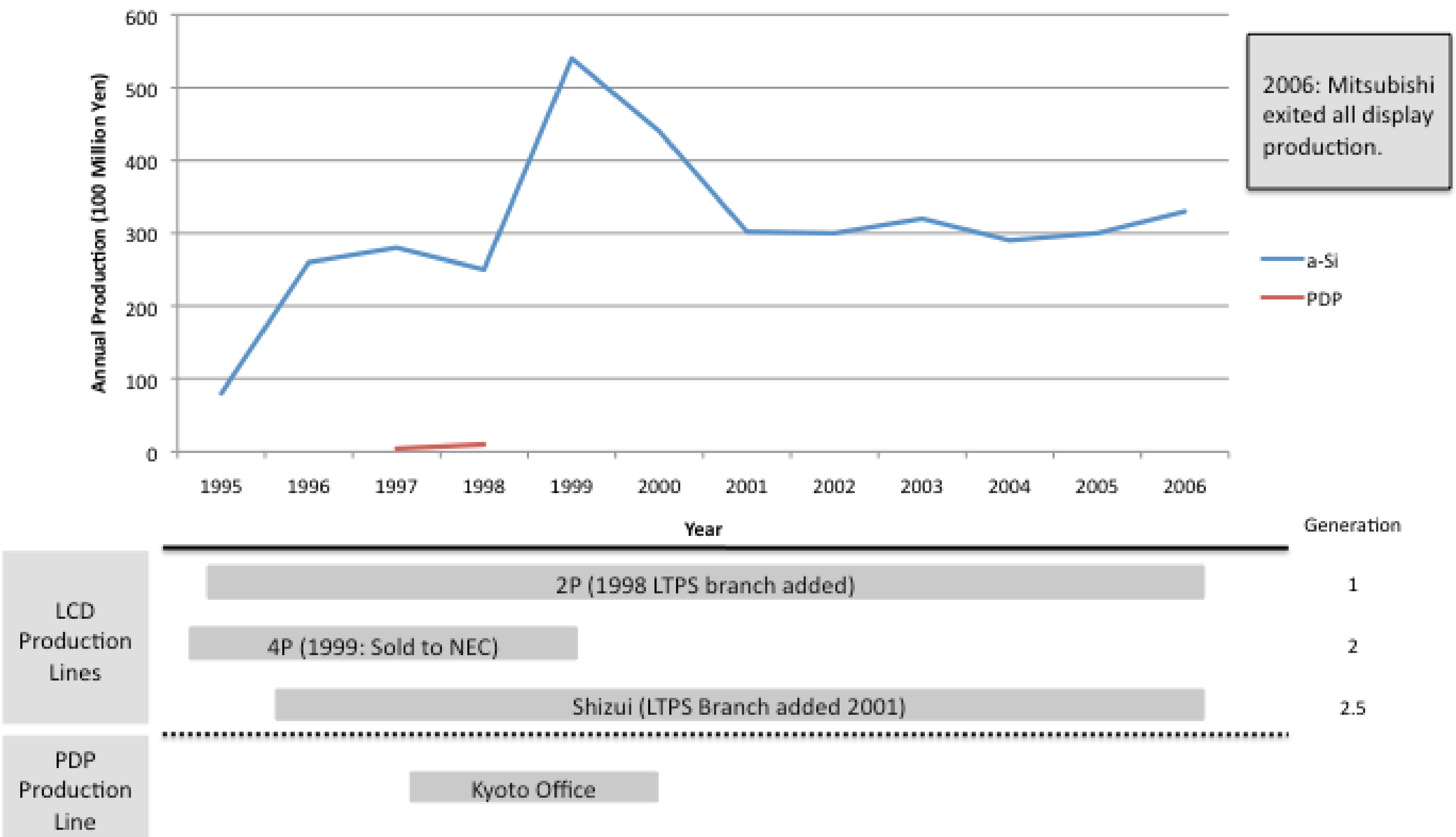
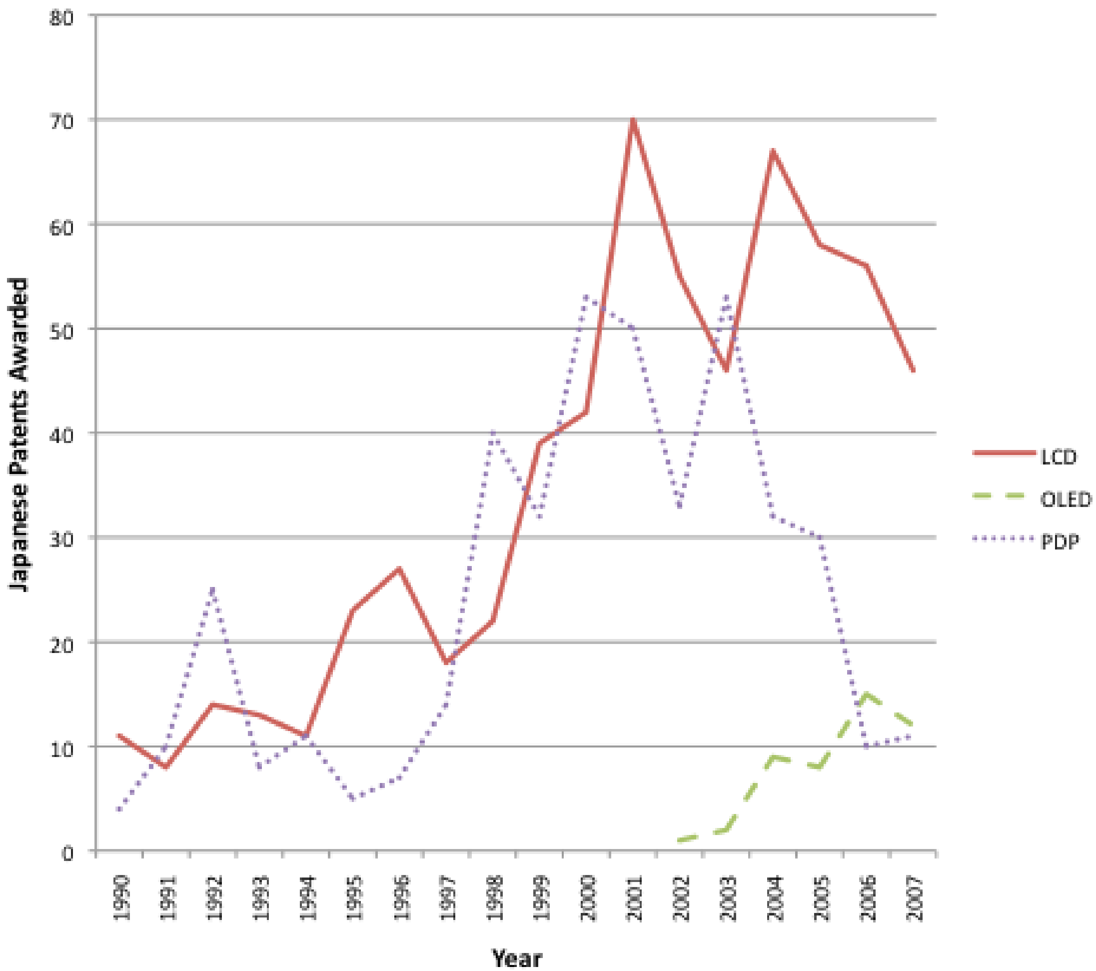


Figure 5-9: Mitsubishi Display Panel Production Volume and Production Lines



Note: LTPS, HTPS, and OLED production values were zero. Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-9: Mitsubishi Patents



Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Mitsubishi's Performance

Overall, Mitsubishi is not a large player in the TV industry. Mitsubishi had less than 1% of Japanese LCD TV market in the fourth quarter of 2002 (Nikkei BP, 2004 (Shijo bunseki hen)). One area of the TV business where Mitsubishi has been strong is RP TV. In 1998, Mitsubishi had about 10% of the worldwide market for RP TVs (Fuji Chimera, 1999). In the period flat panel TV was growing, Mitsubishi had worldwide RP

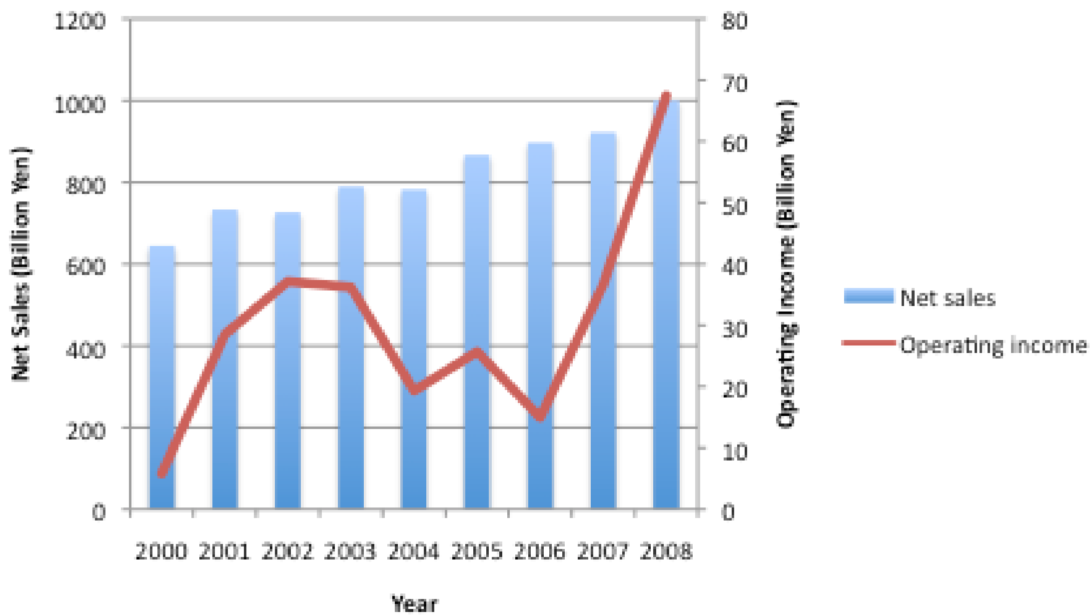
TV market shares ranging from 12% in 2002 to 6% in 2004 (Fuji Chimera, 2003-2005). RP TV has been shrinking as a TV segment. Mitsubishi still continues to produce although it has been hurt by the shrinking market for these TVs.[8] The RP TV technologies Mitsubishi has used recently, DLP and LCOS, were not developed or produced by Mitsubishi in house.

Although Mitsubishi developed flat panel technologies to a point where they could have been used in TVs, the company was not able to leverage this into a strong position in the FP TV market. Eventually, Mitsubishi withdrew from display production altogether, including PDP and LCD. Given these observations, Mitsubishi's performance cannot be considered strong as either a TV producer or a panel maker.

Like many of the other firms, Mitsubishi Electric is a large, diversified company. TVs are included in Mitsubishi's Home Appliances sector, where they do not represent a large portion of the business. This sector has had positive operating income since the year 2000. There is no discernable degradation of profitability or revenues that appears attributable to Televisions, as can be seen by Chart 5-10, below.

[8] Mitsubishi listed impairment losses for scrapping molds previously used to make RP TVs for the North American market in the 2008 annual report.

Chart 5-10: Revenue and Operating Income of Mitsubishi's Home Appliance Sector



Source: Mitsubishi Annual Reports

Toshiba

Toshiba is one of Japan's four large general electric companies, (The others are Hitachi, Fuji Electric, and Mitsubishi Electric). It is diversified within the electrical and electronics areas and its businesses include semiconductors, computers, electrical generation and transmission equipment, as well as household electronics and appliances.

Toshiba was an early mover in laptop computers, and greatly expanded its IT business at the time. Its involvement in displays gave it an edge in portable computing.

Toshiba has a long history in display development and production. The firm developed its first black and white CRT prototype in 1924 and its first color CRT prototype in 1959. It has also been a major TV producer in Japan for many years. Toshiba began work on TFT-LCD in 1980. Before producing TFTs, however, it began mass-producing STN-LCDs; these offered a lower cost, easier to produce but lower quality display for laptop applications. Toshiba soon began producing TFT-LCDs as well.

Toshiba has used cooperative arrangements in R&D and production of display technologies from an early stage. Toshiba and IBM began cooperating on LCD R&D in the late 1980s. The production joint venture they later formed, Display Technologies Inc. (DTI), was successful at TFT-LCD production and provided IBM a supply of displays for its Thinkpad line as well as supplying displays to meet Toshiba's notebook computer needs. DTI was dissolved in 2001 at the end of the joint venture contract.

Toshiba developed other LCD related technologies on its own outside of DTI. Toshiba developed LTPS, beginning R&D in the mid 1990s and building a pilot line and production line for LTPS shortly thereafter. In 2001-2002, Toshiba and Matsushita (Panasonic) began to cooperate on LCD including LTPS. The firms agreed to build an LTPS plant together in Singapore in 2001, and the following year established Toshiba Matsushita Display Technology (TMDT), a joint venture with Toshiba holding a controlling share. TMDT contained the LCD capabilities of both firms, and focused on smaller displays and LTPS. The two firms later became involved with Hitachi to form IPS Alpha, a joint venture focusing on larger TFT LCD panels for TV applications.

Over time, Toshiba shifted production of low margin, standardized a-Si displays to contract manufacturers in Taiwan and Korea. In the process, Toshiba transferred TFT technology to these firms. Toshiba's own LCD operations became more oriented to LTPS technology as it moved away from standard, commoditized display applications such as laptop displays.

The first evidence of OLED R&D at Toshiba was in 1999, when the firm established an OLED project team (Sangyo Times, 2001). Toshiba began producing single color OLEDs for car audio applications shortly thereafter. Development has continued for a number of years since then, with Toshiba participating in joint development (Nedo project, Idemitsu joint development) in the process. After TMDT was formed, OLED activities were merged into the joint venture. TMDT has kept its OLED options open, pursuing development of both small and large particle materials.

The majority of Toshiba's display related activities have been focused on a-Si, LTPS, and OLED. However, Toshiba also had exposure to several other technologies. It has produced PDP TVs although it never made the display panels in house. In 1999, Toshiba announced it would work with Canon to develop SED. Toshiba continued to cooperate with Canon on SED for a number of years, however it exited after a patent infringement lawsuit was brought against Canon. Toshiba also worked on AFLCD technology in 1998 (Sangyo Times, 1998), and produced EL displays in 2000 (Sangyo Times, 2001). There is no evidence these activities continued over the long term or that any of these technologies were actually used in products.

As a television producer, Toshiba entered LCD TV with its first "Face" model in 1998. The company released PDP TVs beginning in 2001, and has built a lineup of LCD TVs over time. In 2006, it launched a new brand of flat panel TVs called Regza (Menzawa et al., 2008).

Evidence of Option-like investments

Toshiba has developed and maintained options on a-Si, LTPS, OLED, and SED display technologies. It also briefly pursued and then abandoned options on AFLCD and EL display technologies (See Figure 5-10). Patent data suggest some PDP development (See Chart 5-11); however this is most likely due to overlap with other display technologies Toshiba was pursuing (e.g., SED) or development of PDP-TV, and does not represent a concerted plasma technology effort on the part of Toshiba. There is no other evidence suggesting such an effort. Toshiba did not have options on all major technologies, as it never became involved with PDP, however it held a portfolio of technology options that was wide and deep. Furthermore, Toshiba used cooperative arrangements to simultaneously increase flexibility while limiting the size of the investment in many cases.

The way in which Toshiba gradually changed its production focus from a-Si to LTPS LCD also exhibits option-like characteristics (See Figure 5-11). Toshiba needed to maintain access to substantial quantities of suitable quality displays for its own products, but did not want direct exposure to the turbulent a-Si LCD market.[9] By setting up supply agreements as part of a-Si technology transfers to Korean and Taiwanese firms, Toshiba was able to guarantee supply to meet its panel needs while reducing its exposure to uncertainty of price levels. Amorphous silicon technology was transferred to non-Japanese firms through more highly developed production equipment, formal technology transfer agreements, and flow of Japanese engineering talent to Korean and Taiwanese firms. The movement of technological knowledge was inevitable. Toshiba was able to

[9] The crystal cycle's primary impact is upon a-Si pricing and production capacity.

reduce its risk by reducing exposure to a-Si and placing a stronger emphasis on LTPS. LTPS production technology is more finicky and considered less transferrable than a-Si. At the same time LTPS panels are often made to fit customized specifications of the purchaser, unlike a-Si panels which tend to be standardized and treated as commodities in many cases. Focusing on LTPS allowed Toshiba a greater possibility of protecting profitability through customization and reducing its exposure to the commoditized LCD market.

Chart 5-11: Toshiba Patents

Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

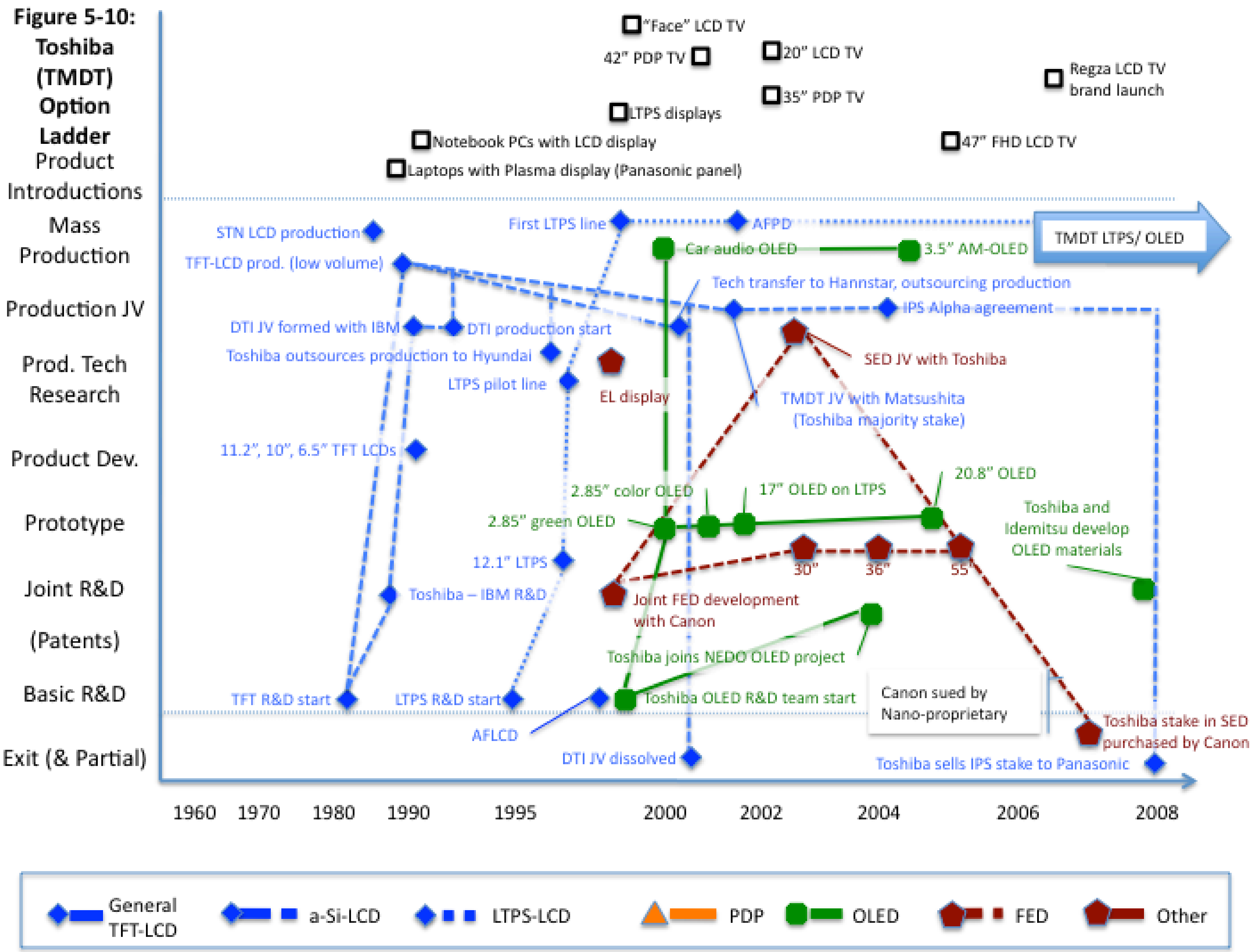
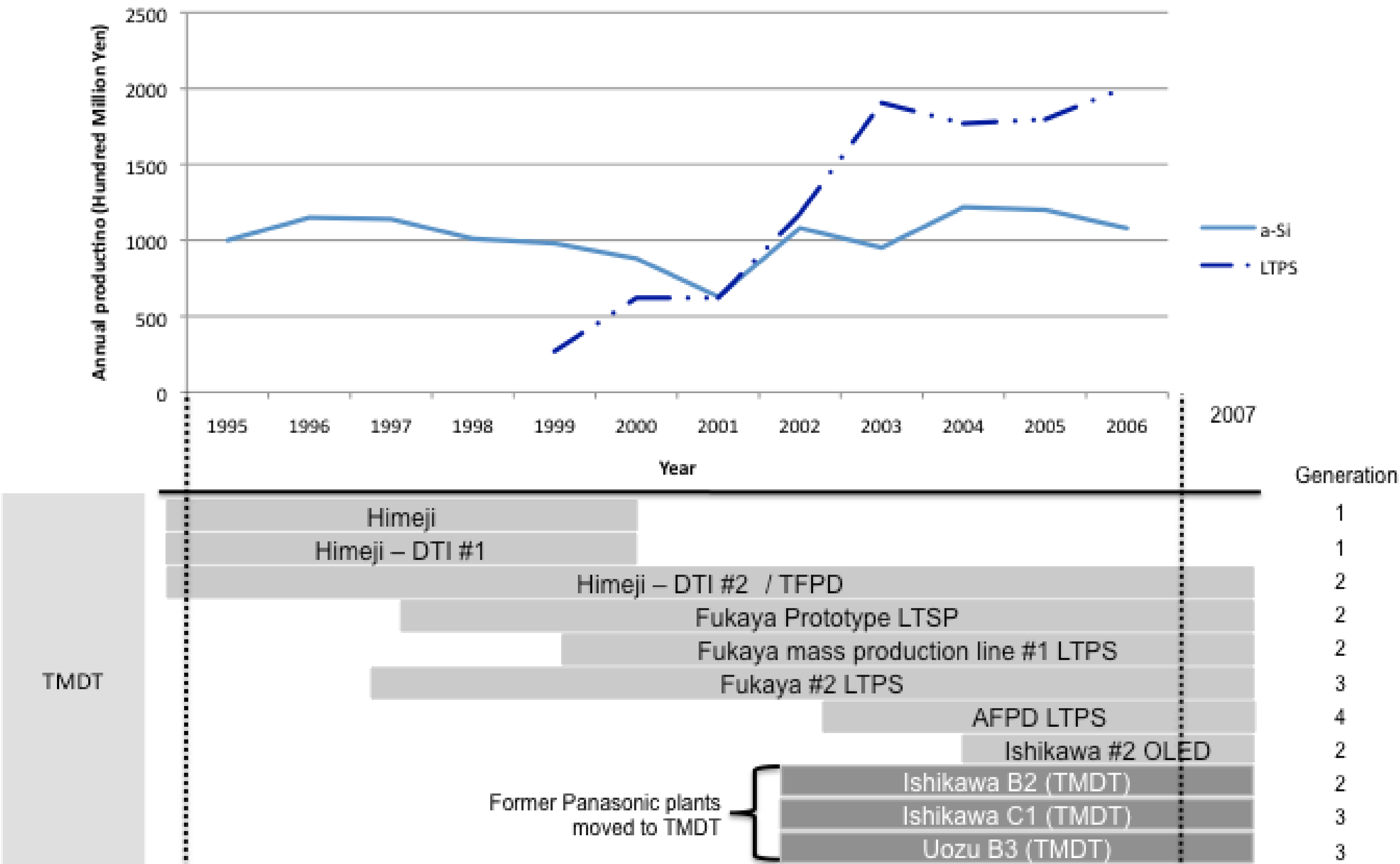


Figure 5-10: Toshiba (TMDT) Option Ladder

Figure 5-11: Toshiba (TMDT) Display Panel Production Volume and Production Lines



Notes: (1) includes Toshiba / DTI for 1995, 1996. Toshiba-Matsushita Display beginning 2002, (2) HTPS, OLED, and PDP values were zero. (3) production lines do not include IPS Alpha JV.

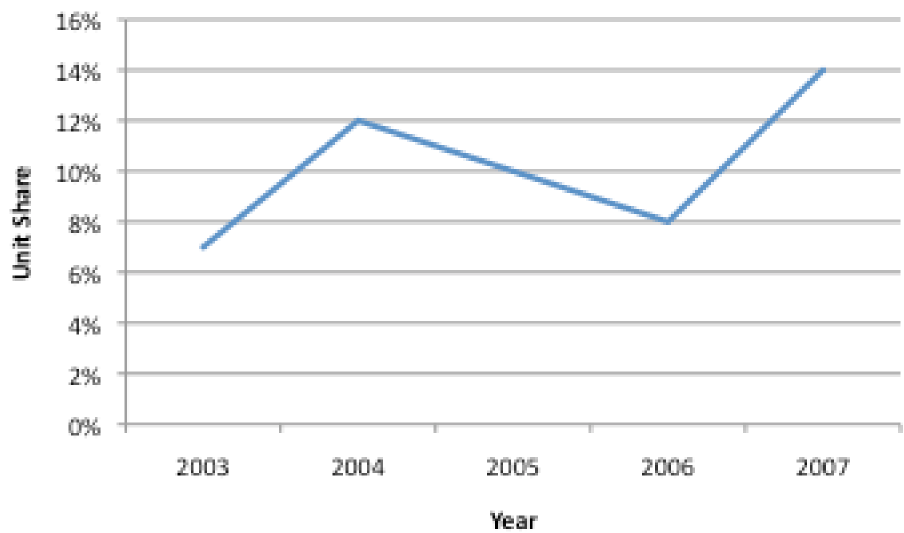
Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Toshiba's Performance

Toshiba does not appear to have benefited in terms of market share from the growth of flat panel TV. Toshiba's share of the overall Japanese domestic TV market share was as low as 2% during the fourth quarter of 2002 (Nikkei BP, 2004 (Bunseki hen)). For the same period, Toshiba had 5% of the Japanese PDP TV market (Nikkei BP, 2004 (Bunseki hen)). Toshiba's position in the LCD TV market has recovered significantly. Chart 5-12, below, shows the market share for the period 2003-2007. For most of these years Toshiba was in fourth place behind Sharp, Sony, and Panasonic. Toshiba is relatively weak outside of Japan. Fuji Chimera (2001) reported Toshiba's global TV market share for all technologies to be 3.1%. Techno Associates Research (2006) reported Toshiba's global LCD TV market share for the second quarter of 2005 to be 3.8%. These data points suggest that Toshiba's overall position in the TV market has not changed dramatically before and after flat panel TV became prominent. Toshiba also produced RP TVs. In 1998, Toshiba was number two in world market share with 10%; this decreased to 8% in 2004 (Fuji Chimera, 1999, 2005).

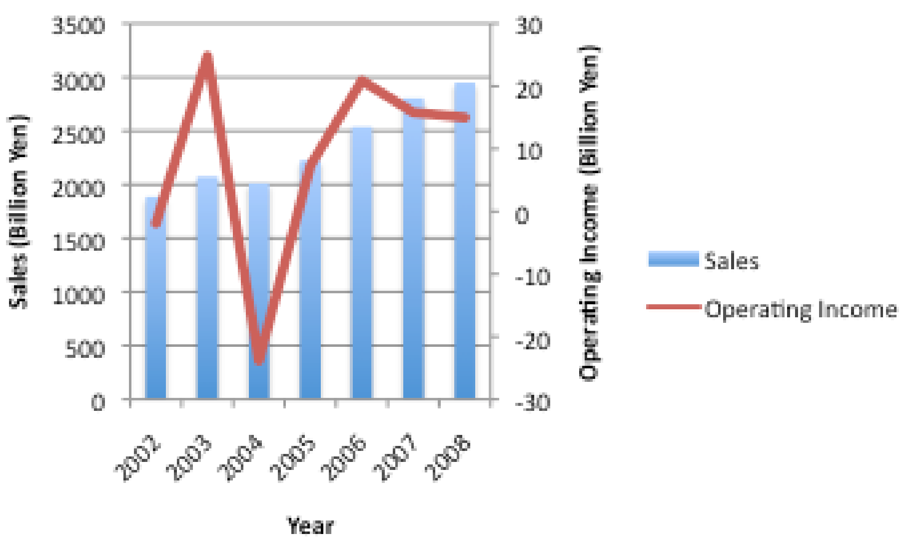
Financial performance in the Digital Products Segment, which includes Toshiba's television set business, is shown in Chart 5-13, below. The segment is relatively large and includes mobile communications, digital media network (TV and related Audio-Visual products), and personal computers. Toshiba reports that LCD TV sales have increased revenues for its digital products segment, although price pressures have negatively impacted the profitability of this sector. Operating income in the segment has been decreasing since 2006, but remains positive.

Chart 5-12: Toshiba Domestic Japanese LCD TV Market Share



Source: Rikku, 2008.

Chart 5-13: Toshiba Digital Products Segment, Sales and Operating Income



Source: Toshiba annual reports.

By selling its stakes in IPS Alpha and SED, Toshiba has essentially exited the large display panel business. Although Toshiba never became a leader in TV displays, it still has a meaningful place in the broader display business. Toshiba remains a major player in LTPS and continues to invest in OLED. Toshiba is considered to be relatively strong in digital image processing chips. It has an agreement with Sharp under which Sharp is to supply Toshiba with LCD TV panels and Toshiba to supply Sharp with image processing chips, leveraging the strength of each. Altogether, Toshiba's performance data suggests that although it has not made major gains from the switch to flat panel television, at the same time it has not found itself at a particular disadvantage either.

Firm Level Analysis – Tier Three Focal Firms

Pioneer

Pioneer is smaller and less diversified than many of the other firms in this study, however it has made an impact on flat panel technologies and the FP TV business. Pioneer did not have a CRT production capability, and was a minor TV producer prior to FP TV's rise. Pioneer's TV business also included both CRT and projection based TVs.

Pioneer started research on OLED and PDP in the late 1980s and early 1990s, as depicted in Figure 5-12. Evidence suggests Pioneer performed some limited work on FED, however this must have been a small effort as no prototypes were identified. Patent data shows a strong emphasis on PDP (See Chart 5-14), as do the production line and production volume data (see Figure 5-13). The small number of LCD patents shown is likely spillover from OLED development and noise in the data source. Through the 1990s and into the early 2000s, Pioneer consistently invested in PDP and OLED technology. The firm's Tohoku Pioneer subsidiary produced the world's first commercial OLEDs. Later, Pioneer became recognized for its PDP technology and its critically acclaimed Kuro line of PDP TVs.

Evidence of Option-like investments

Pioneer invested chiefly in two display technologies: PDP and OLED. The two technologies pursued by Pioneer were developed in parallel, however they should not be considered competing technologies in this case, as the aims of development were quite different. The PDP effort was largely focused upon television, whereas the OLED effort was focused on small displays. Furthermore, when Pioneer encountered difficulty in finding customers for AM-OLEDs it was starting to produce, it exited AM-OLED to remain in the PM-OLED area it had already developed. Given that OLEDs need to have active matrices in order to be use in reasonably sized TV sets, exiting AM-OLED was also giving up on the idea of producing an OLED TV. Meanwhile, Pioneer's investments in its PDP capability grew increasingly commitment-like over time. PDP production became integrated with TV set manufacturing. One could say that Pioneer made commitments to PM-OLED and PDP and held an option on AM-OLED which it later exited. It did not hold options on other technologies.

One instance of option-like investment exists in Pioneer's ELDIS JV. Rather than build LTPS equipment on its own for AM-OLED, ELDIS allowed Pioneer enter AM-OLED for a low cost and using partner LTPS capabilities. Pioneer opted to go it alone in many other circumstances, however. As shown in Figure 5-13, Pioneer invested in its own OLED and PDP lines, even buying the PDP capability of its competitor, NEC.

Figure 5-12: Pioneer Option Ladder

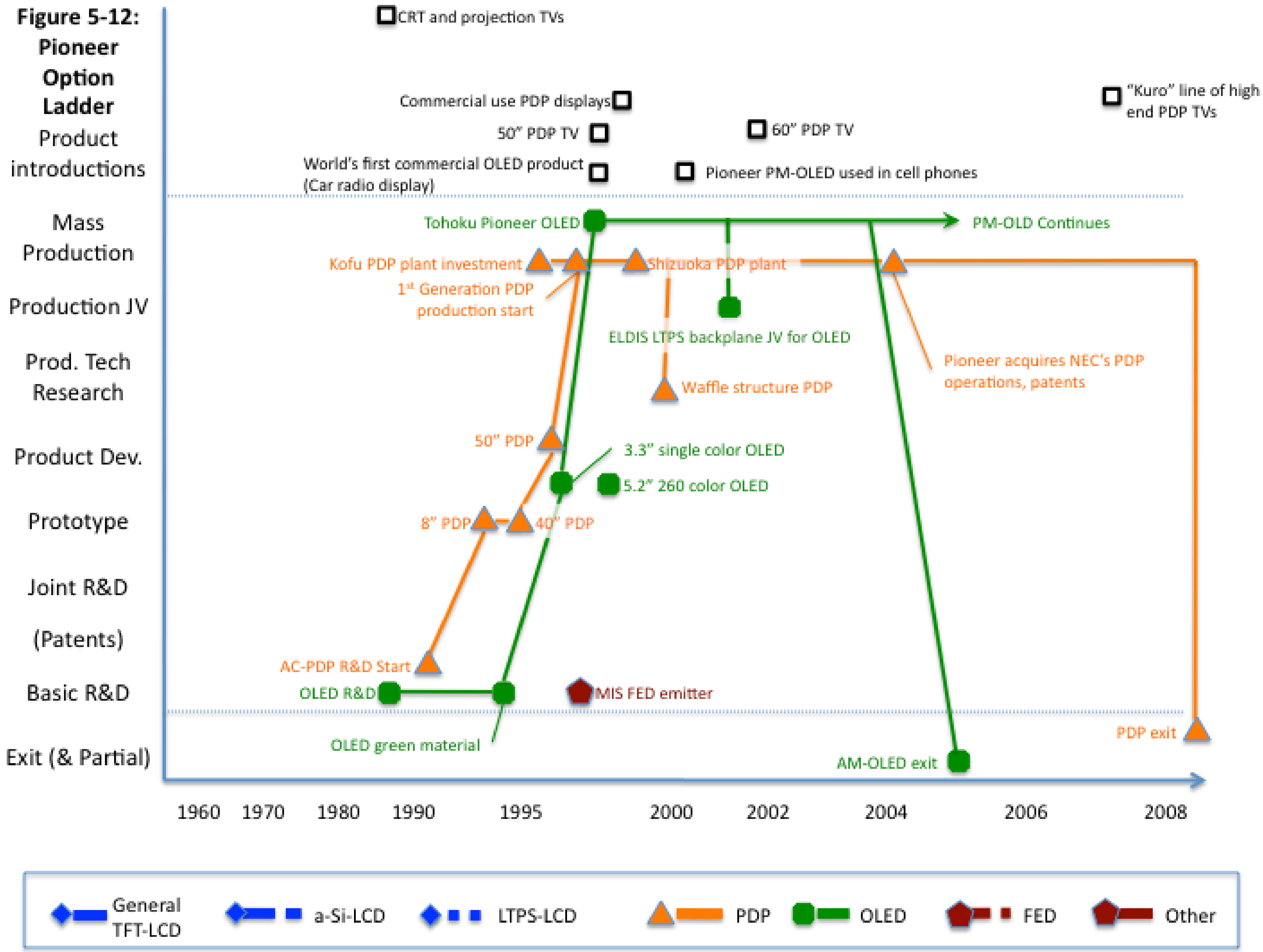
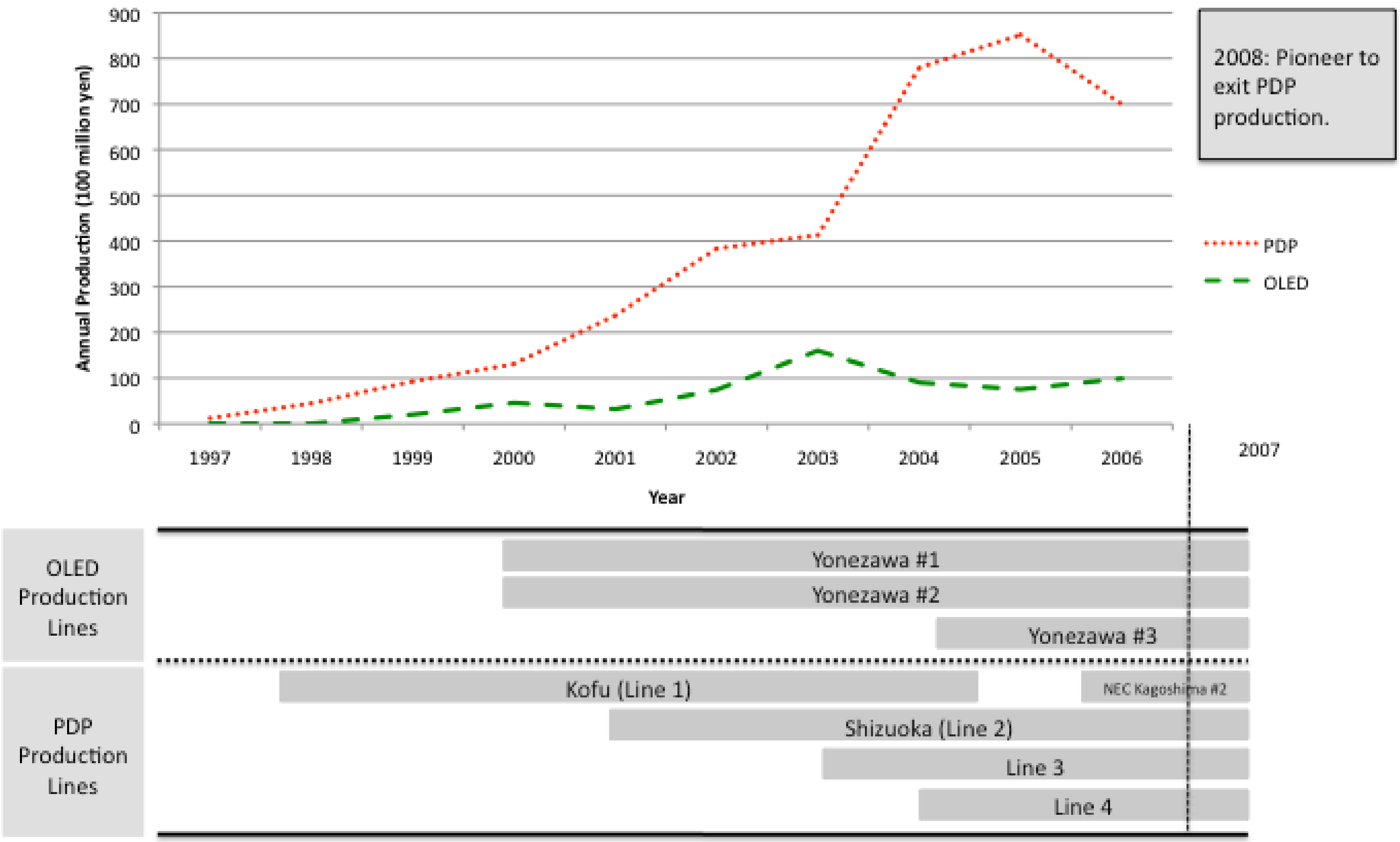


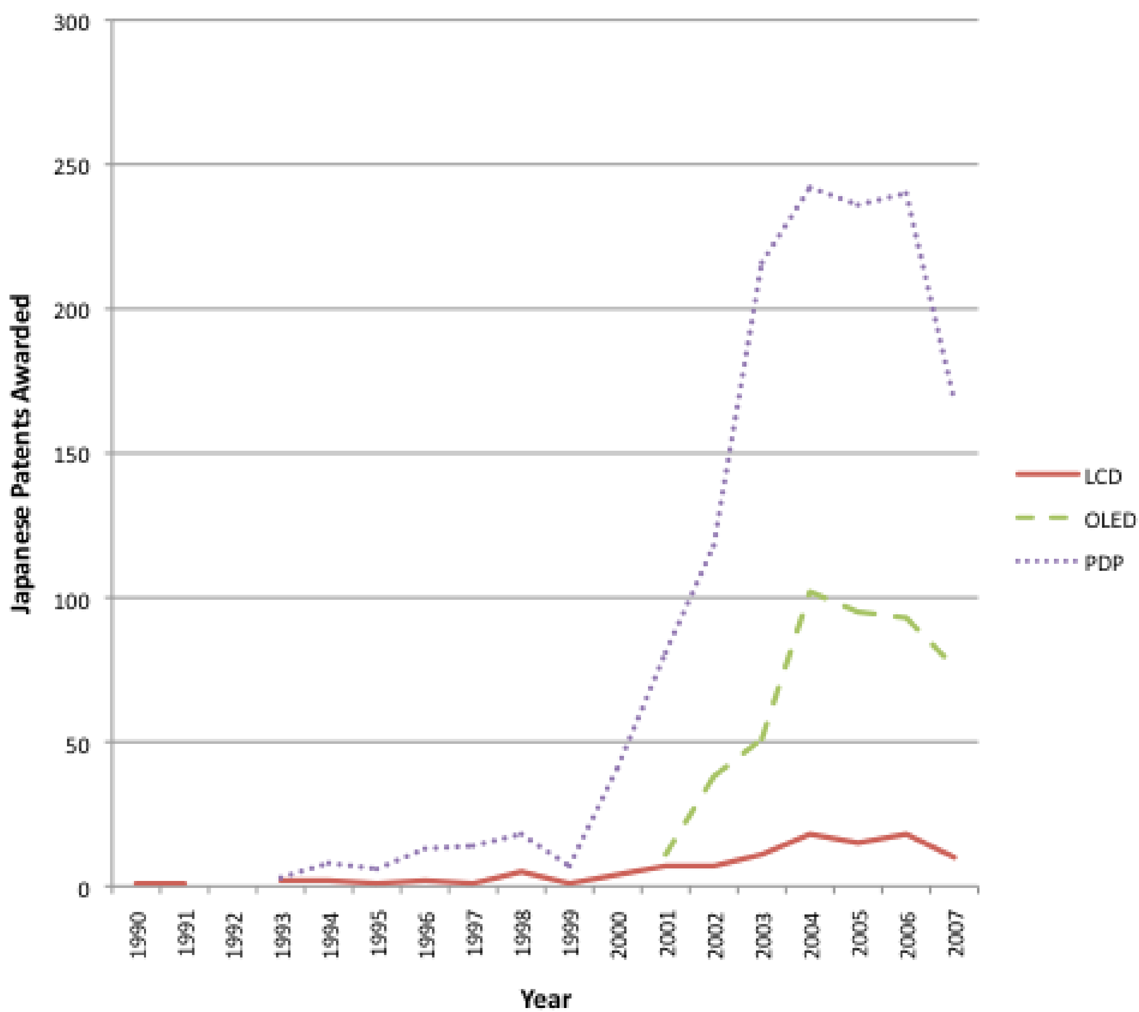
Figure 5-13: Pioneer Panel Production and Production Lines



Note: a-Si, HTPS, and LTPS values were zero.

Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-14: Pioneer Patents



Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Pioneer's Performance

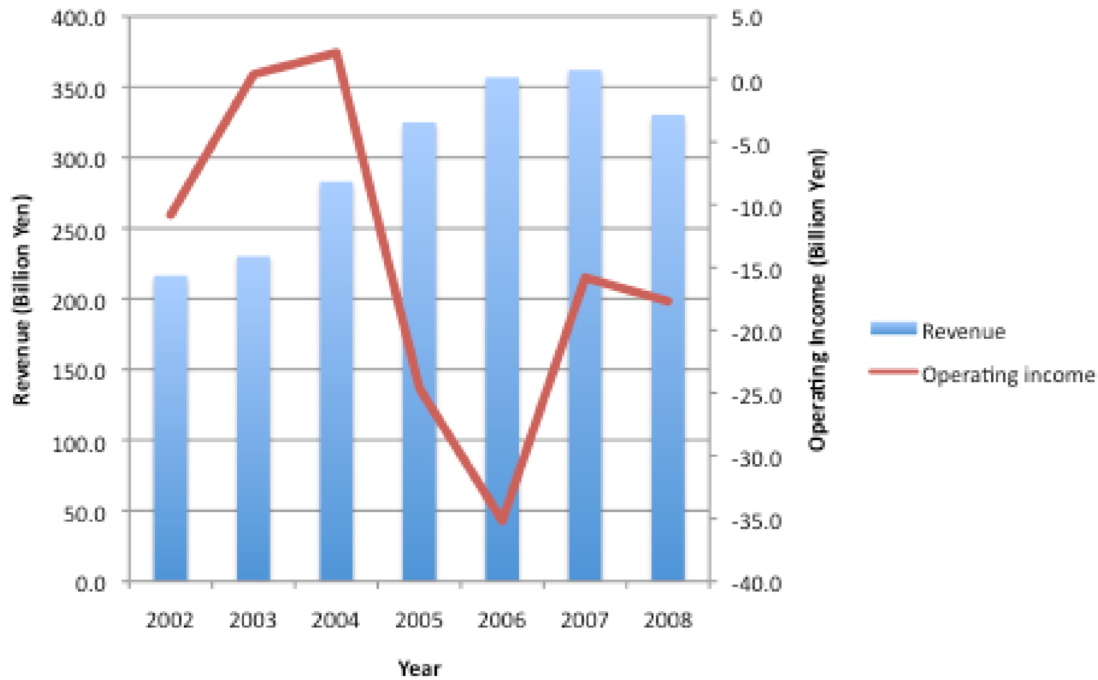
Pioneer increased its share in the TV market with the introduction of flat panel TV, but could not maintain this position for long. As the market grew and TV set prices declined, Pioneer implemented a differentiation strategy for its PDP TV offering on the basis of image quality. This was successful in that experts identified Pioneer plasma TVs as having superior image quality than their competitors. However, Pioneer was not so successful in the marketplace. Pioneer sets were expensive, and competing LCD TVs improved in affordability and image quality rapidly.

Pioneer's market share declined as the FP TV market grew. Techno System Research (Sangyo Times, 2002) estimated Pioneer had a 19.3% share of the combined market for PDP TVs and monitors in the fourth quarter of 2000, and 11.9% that time in 2001, ranking first and second respectively. Techno Associates Research (2006) reported Pioneer's worldwide 2005 PDP TV market share to be 7.4% and PDP panel share to be 10.4%, placing Pioneer in 5th and 4th place respectively. Nikkei Report (2008) listed Pioneer's Japanese domestic PDP TV market share as 2.5%, or last place. When one considers that total PDP TV growth was much slower than growth of LCD TV over this period, it becomes clear that Pioneer's overall TV market share has declined even more dramatically.

Financial performance has also not been good for Pioneer. Chart 5-15 shows revenue and operating income for Pioneer's Home Electronics Sector, which includes its PDP-TV business. Overall, the firm is reporting a loss for the period 2002-2008.

Finally, Pioneer's performance was low in terms of survival. Pioneer exited PDP production in 2008, transferring many of its PDP resources, engineers, and know how to Panasonic. Pioneer planned to shut down its TV operations and exit TV altogether in 2009.

Chart 5-15: Pioneer Home Electronics Sector Revenue and Operating Income



Source: Pioneer Annual Reports

Sanyo

Sanyo has a long history in the consumer electronics business.[10] It began TV assembly in the 1950s (Hiramoto, 1994), however it never established its own CRT production capability. Without this capability, the company found itself unable to make high value, differentiated television sets.[11]

Sanyo has been involved with several display technologies, but its main focus was LCD. Sanyo began developing LCDs in 1970, and has worked on a number of LCD technology types including early segment displays, TN mode LCD, a-Si TFT LCD and

[10] Sanyo was started by a relative of Konosuke Matsushita, the founder of Panasonic.
[11] In person anonymous interview: November 5, 2008.

LTPS. LCD development has been relatively centralized at times, and at other times divided between subsidiaries and group companies. Group company Tottori Sanyo has played a major role in LCD and OLED development and production. Sanyo was the first to develop a low temperature process for producing poly-silicon TFT-LCDs (LTPS) in volume (Sangyo Times, 2001). For a period, Sanyo was also a prominent OLED developer and producer. Its joint venture with Kodak, SK Display developed and produced PM-OLED and AM-OLED panels. Additionally, Sanyo performed some joint development work on EL display technology, but this did not result in further investments.

Sanyo developed some small LCD TV sets early on. For example, Sanyo developed the world's first black and white TV using an active matrix LCD in 1982. However Sanyo's LCD operations were not focused on TV. Instead Sanyo developed small, high-resolution displays for applications such as digital cameras. Sanyo entered into market for large LCD TVs later, however it did not produce these larger panels itself. Given Sanyo's limited market share and financial resources, investment required to make the large LCD TV panels was unattractive. Furthermore, smaller size displays fit with Sanyo's strengths in cell phones and digital cameras, where it produced both under its own brand and as a contract manufacturer. Sanyo LCD TVs made in house used panels purchased from other producers; some LCD TV production was outsourced to Taiwanese firms (In person anonymous interview, November 4, 2008). TV was considered an attractive potential application when Sanyo began working on OLED, however this was not a central goal or focus of the OLED activities.[12]

[12] In person anonymous interview: November 5, 2008.

Sanyo merged its LCD capabilities with Epson's in 2004. In 2006, Sanyo exited LCD. In the same year, Sanyo exited OLED after the SK-Display joint venture was dissolved.

Evidence of Option-like investments

As Sanyo's option ladder shows (See Figure 5-14), the company's display efforts have focused on LCD and OLED. Sanyo had brief involvement with EL, but did not maintain an option on this technology. Patenting data shows activity for LCD and OLED (See Chart 5-16). The rapid fall in LCD patents appears to coincide with the movement of Sanyo's LCD capability into a joint venture with Epson. Sanyo's LTPS technology was a strongpoint for the company, however its production capability was relatively modest (see Figure 5-15). In addition to the TFT-LCD production shown, Sanyo also had several passive matrix LCD production lines.

Sanyo's LCD and OLED developments were sequential; Sanyo only became involved in OLED after it had built a production capability for LTPS. From a real options perspective, OLED made LTPS options more valuable as Sanyo could use them to pursue either of the two technologies. Sanyo maintained both OLED and LCD for some time at mass production levels. These could be considered to be options on competing display technologies.

Figure 5-14: Sanyo Option Ladder

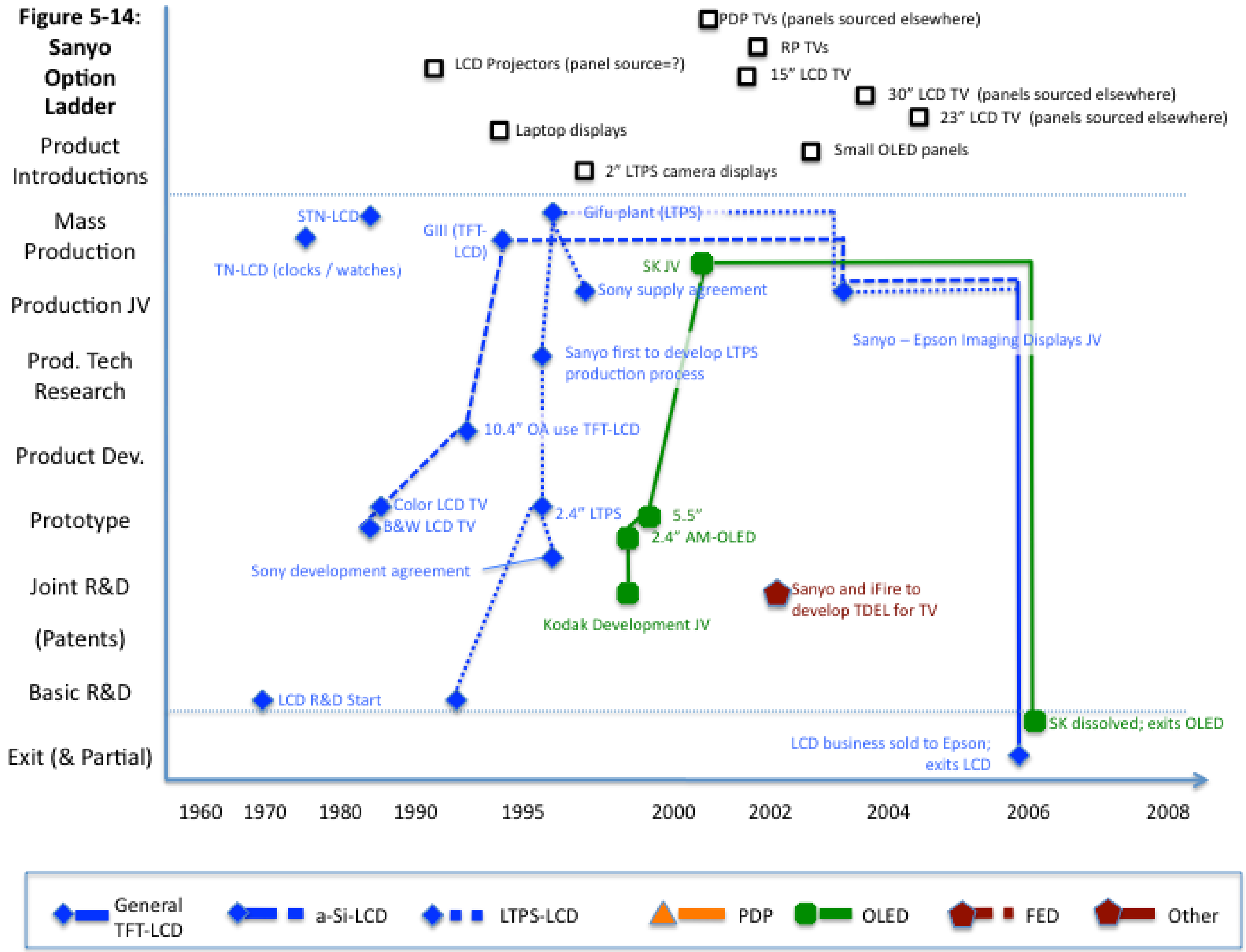
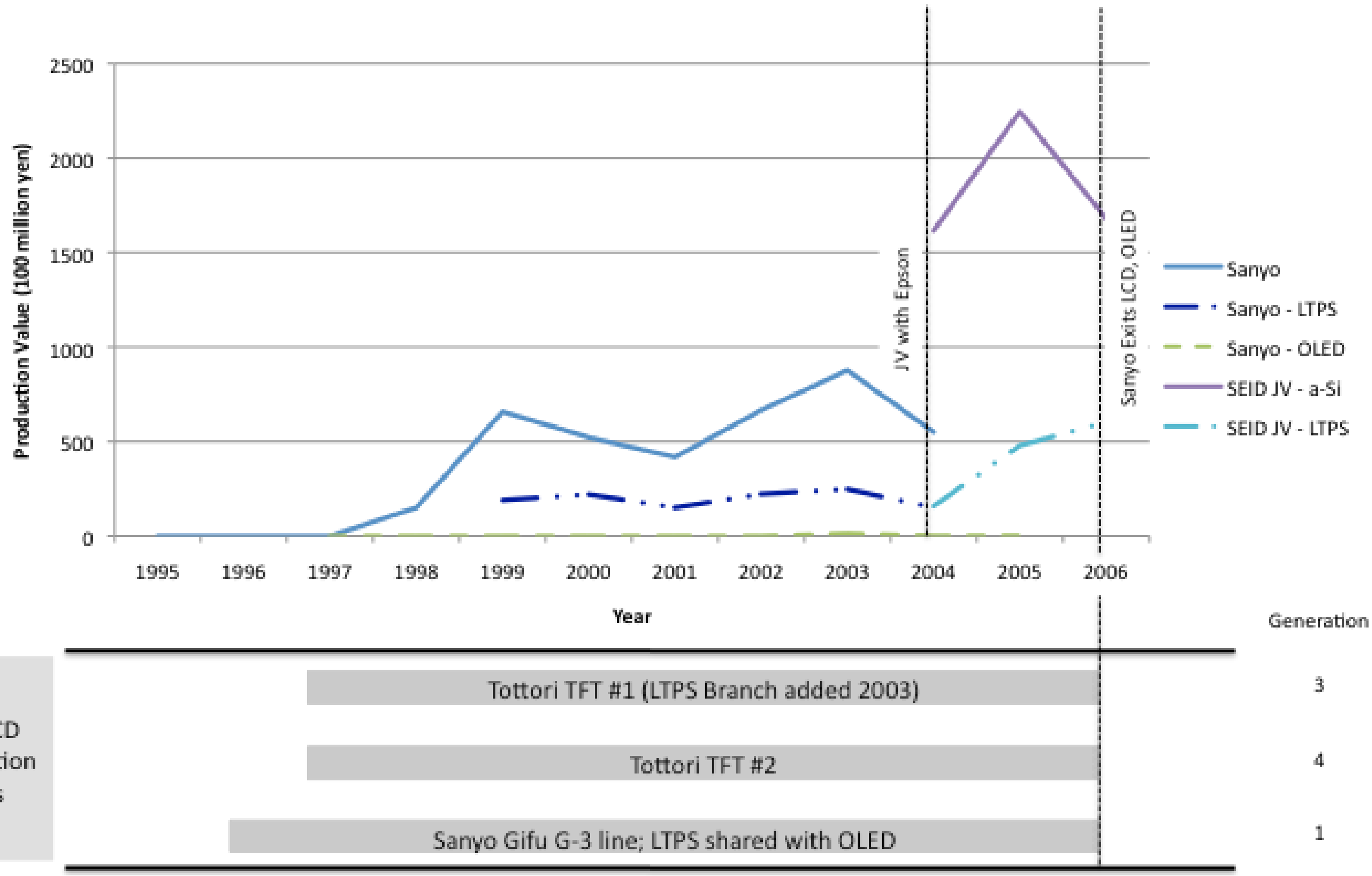


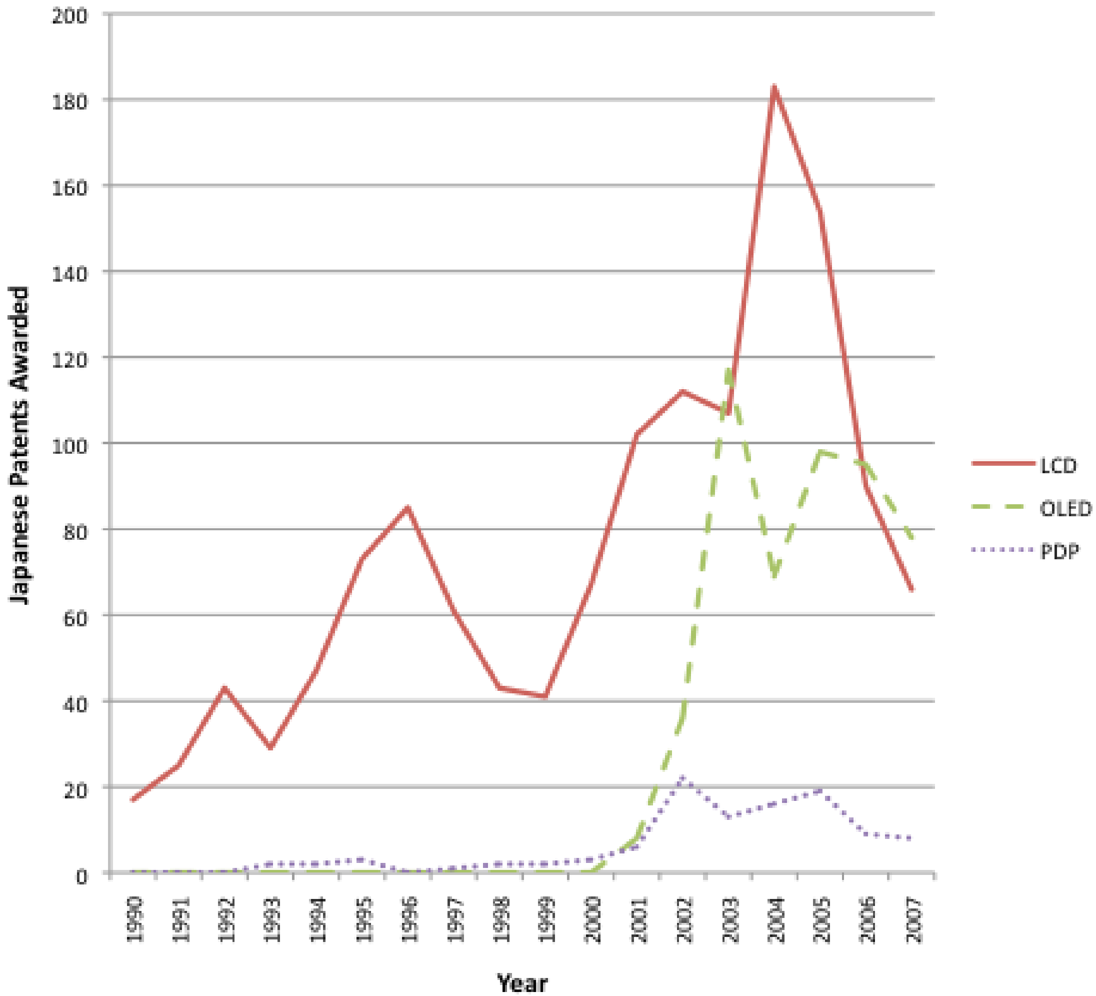
Figure 5-15: Sanyo Display Panel Production Volume and Production Lines



Note: HTPS, PDP, OLED values were zero.

Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-16: Sanyo Patents



Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Sanyo used cooperative arrangements in LTPS and OLED. In the case of LTPS, Sony cooperated on development and Sanyo agreed to supply Sony with LTPS displays. This arguably decreased uncertainty for Sanyo in that Sanyo was guaranteed sales to a degree. Sanyo's OLED development and production was done in cooperation with Kodak, the holder of important patents on small particle OLED. The arrangements included a production joint venture, SK Display. Kodak's involvement in the joint venture provided basic technology and a ready customer when the display technology matured. It also reduced Sanyo's investment requirements. The JV may also have given Sanyo more flexibility because it allowed Sanyo to buy Kodak's share in the venture.

Sanyo's Performance

The impact of Sanyo's display operations on its TV business is not straightforward. Sanyo did not invest in display technologies to improve its TV business; the focus of display development and production was small screen displays. Sanyo never invested in the kinds of manufacturing plants required to produce displays in sizes large enough for use in TVs. Although Sanyo entered the LCD TV market it did so with supply from other panel makers and in some cases by purchasing TVs from ODM makers.

Sanyo's TV business has been concentrated at the lower end of the market. It has a long-standing relationship with Wal-Mart, which represents a large portion of Sanyo's TV set sales. Wal-Mart's sales have substantially contributed to revenues, but TV set business has not been a major source of profits for Sanyo.[13]

Although data limitations make it difficult to precisely evaluate Sanyo's performance in the TV market, it is clear that Sanyo has not dramatically improved its situation as sales of flat panel televisions grew in the market. Sanyo continues to be an also-ran in the industry. Generally, its share was so low it was included in the "Others" category of available market share data. Fuji Chimera (1999, 2001) reports Sanyo had 4% of the worldwide unit share in 1998 and 2000. Sanyo has been weak in Japanese

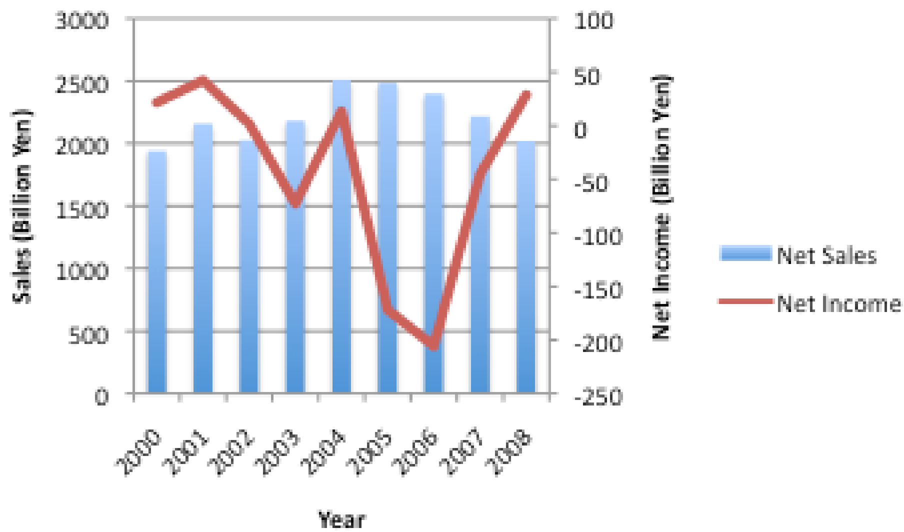
[13] In person anonymous interview, November 4, 2008.

domestic TV market. In 2004, Sanyo had 2.3% of the Japanese domestic PDP TV market, putting it in last place (Fuji Chimera, 2005 (Digital AV)).

Sanyo's overall financial performance has been low. In the period 2000-2008, net sales were flat, and the company had a cumulative loss of 388 billion yen (See Chart 5-17, below). An earthquake hit one of Sanyo's production facilities in 2004, causing 73 billion yen in losses including damage to plant and equipment and opportunities lost (Sanyo 2005 Annual Report). Performance of Sanyo's Consumer Business sector, which includes TV sets shows declining sales and profitability over the years 2004 to 2008 (See Chart 5-18, below).

In terms of survival, Sanyo's performance has also been poor. Sanyo and Epson integrated their LCD operations in a joint venture in 2004 (Sanyo, 2006). Sanyo exited displays altogether in 2006, transferring its LCD operations to Epson (Sanyo, 2007). In December of 2008, Panasonic and Sanyo agreed (Sanyo, 2008) Panasonic would conduct a tender offer for all outstanding shares of Sanyo. Although the deal is still in process at the time of writing, it appears that Sanyo will become a part purchased and integrated with Panasonic in the near future.

Chart 5-17: Sanyo Net Sales and Net Income



Source: Sanyo Annual Reports

Chart 5-18: Sanyo Consumer Business sector: Net Sales and Operating Income

Source: Sanyo Annual Reports

Sharp

Sharp has become closely associated with LCD technology. It has focused a great deal of energy and money on the technology since the late 1960s (Numagami, 1999). Sharp's growth as an LCD producer has occurred largely in parallel to its development from being an also ran electronics manufacturer to a respected firm known for "Only one" products (Miyamoto, 2007).

While Sharp has developed and in some cases produced other display technologies, LCD has taken a unique place in the firm. It may not be an overstatement to say Sharp's overall competitiveness rests on its LCD capability[14]. Sharp manufactures a large variety of consumer and business electronics, most of which incorporate an LCD display in some form. Sharp has also actively pursued sales of LCD panels to other firms for many years. Sharp invests early in new generation LCD plants, and for the last several generations has been going to extreme lengths to keep the internal workings of these plants secret. In addition to LCD products and manufacturing plants, Sharp has also developed a strong reputation in the industry for its overall LCD knowledge base and related training capability. It has an internal LCD technology school that is reputed to have the deepest, most thorough training of its kind in the world.

Sharp's LCD focus has been emphasized by top management on several occasions. President Tsuji, who had risen through the sales ranks and did not have a technical background, was a strong promoter of LCD, pressing it to be developed for TV applications in the 1980s.[15] In 1997, President Machida stated that all TV sets Sharp produced would use LCDs by the year 2005 (Miyamoto, 2007). This statement is famous

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[14] In person anonymous interview: March 19, 2009
[15] Ibid.

in the display and TV set industries and has become known as the "Machida Declaration." Sharp's rank and file employees were also big believers in LCD technology; one reason Sharp had not been involved with joint ventures in LCD (until recently) lied in their assumption that potential partners would not share their passion for the technology.

Evidence of Option-like investments

Sharp's option ladder exhibits a breath of different display technologies at a low level and a strong emphasis on LCD technologies at higher options levels (See Figure 5-16). Sharp has developed large varieties of LCD technologies, but its involvement with other displays has been limited (See Appendix for additional evidence of Sharp's involvement with LCD varieties). There is evidence that Sharp developed options on FED, OLED and PALC without making investments into production capabilities. Sharp also produced EL for a number of years. However, EL volumes appear to have been low. With the exception of EL, Sharp's short and limited involvement with non-LCD display technologies suggest it did not hold significant options on alternative display technologies. The degree of emphasis in LCD is evident from Sharp's production volume and production line data (Figure 5-17) and patent data (Chart 5-19). Although Sharp does have some patents coded as belonging to OLED or PDP, LCD patent volume is overwhelming.

To put this in a fuller perspective, Sharp had been interested in displays prior to learning of RCA's success with LCD. Evidence suggests it was working on EL display technology at the time (Numagami, 1999). PALC and OLED efforts began after Sharp was already mass-producing a-Si LCDs, and therefore may have been defensive moves in case LCD proved to be less suitable for large display applications. Development of PALC, in particular, was stopped after Sharp management came to the conclusion it would never work as well as LCD (In person anonymous interview, March 19, 2009).

Several characteristics of Sharp's involvement in LCD are worthy of note here. First, Sharp developed a large number of LCD related technologies whereas most competitors did not. Arguably, Sharp's involvement with LCD overall was both broader (number of related technologies) and deeper than its competitors. To rephrase this point, Sharp has a strong strategic commitment to LCD in general, and has developed and help options on a large variety of LCD related sub-technologies.

Sharp's aggressive stance in investing in new generation production capabilities is another key point, as mentioned above and further discussed in the following chapter. Sharp has been willing to make large investments, commitments in the true sense of the word, to be the first firm to have new generation technology. Amongst the firms studied, only Samsung, LG, and Panasonic have been willing to make investments in display panel production facilities on similar scales to those of Sharp.

Analysis of the panel specifications data discussed in Chapter Three provides a mixed picture of technology in Sharp's LCD panels. In terms of viewing angle, Sharp has arguably the strongest record of any firm. Although Sharp did not always have panels with the widest viewing angle specification, it had panels with one of the three widest viewing angle specifications of the year in seven out of the eleven years covered. Using this metric, Fujitsu and Panasonic were immediately behind Sharp but only had panels with one of the three widest specifications in 4 out of the 11 years. On the other hand, similar investigation of response speed puts Sharp behind a number of competitors. Panasonic, Samsung, and NEC, had LCDs with one of the three fastest specifications in six or more years out of 15, whereas Sharp and Toshiba had panels with one of the three fastest specifications of the year in 5 years. Other firms trailed. In terms of response speed, Sharp did not show the kind of clear leadership it had in viewing angle.

Panel size data also did not show consistent leadership by Sharp, however this needs to be interpreted with care. In the early 1990s, Sharp deliberately focused on making smaller panels efficiently. Although the idea of having large panels on laptops sounded good, the high cost of such panels limited the market for such products for many years. Rather than expend resources on large but difficult to sell panels, Sharp put its emphasis on the smaller panels (In person anonymous interview, March 19, 2009). Sharp has changed its emphasis with regard to size in relation to market opportunities, developing and producing relatively large displays as opportunities presented themselves. In this sense, Sharp's approach to LCD exhibits considerable discipline.

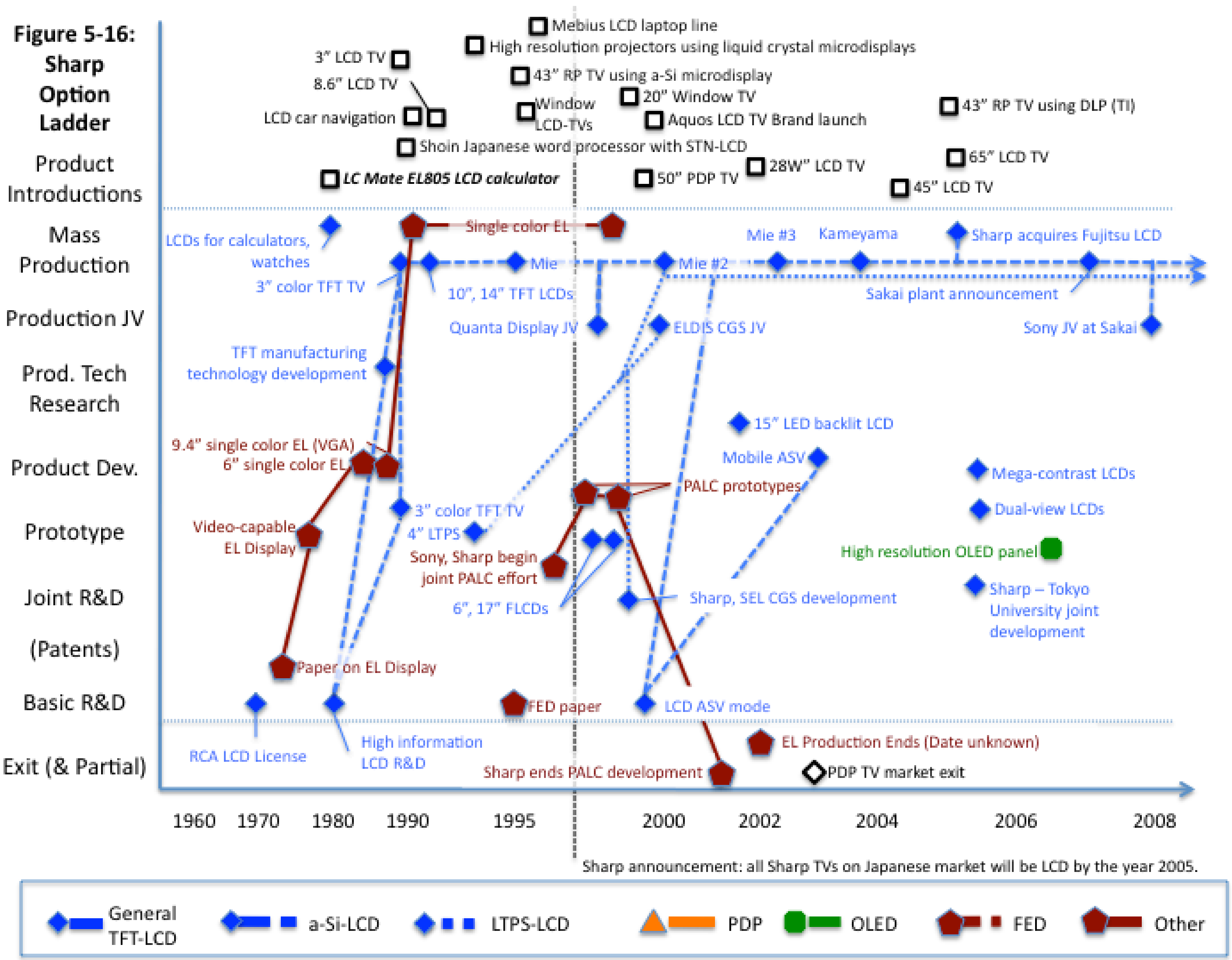
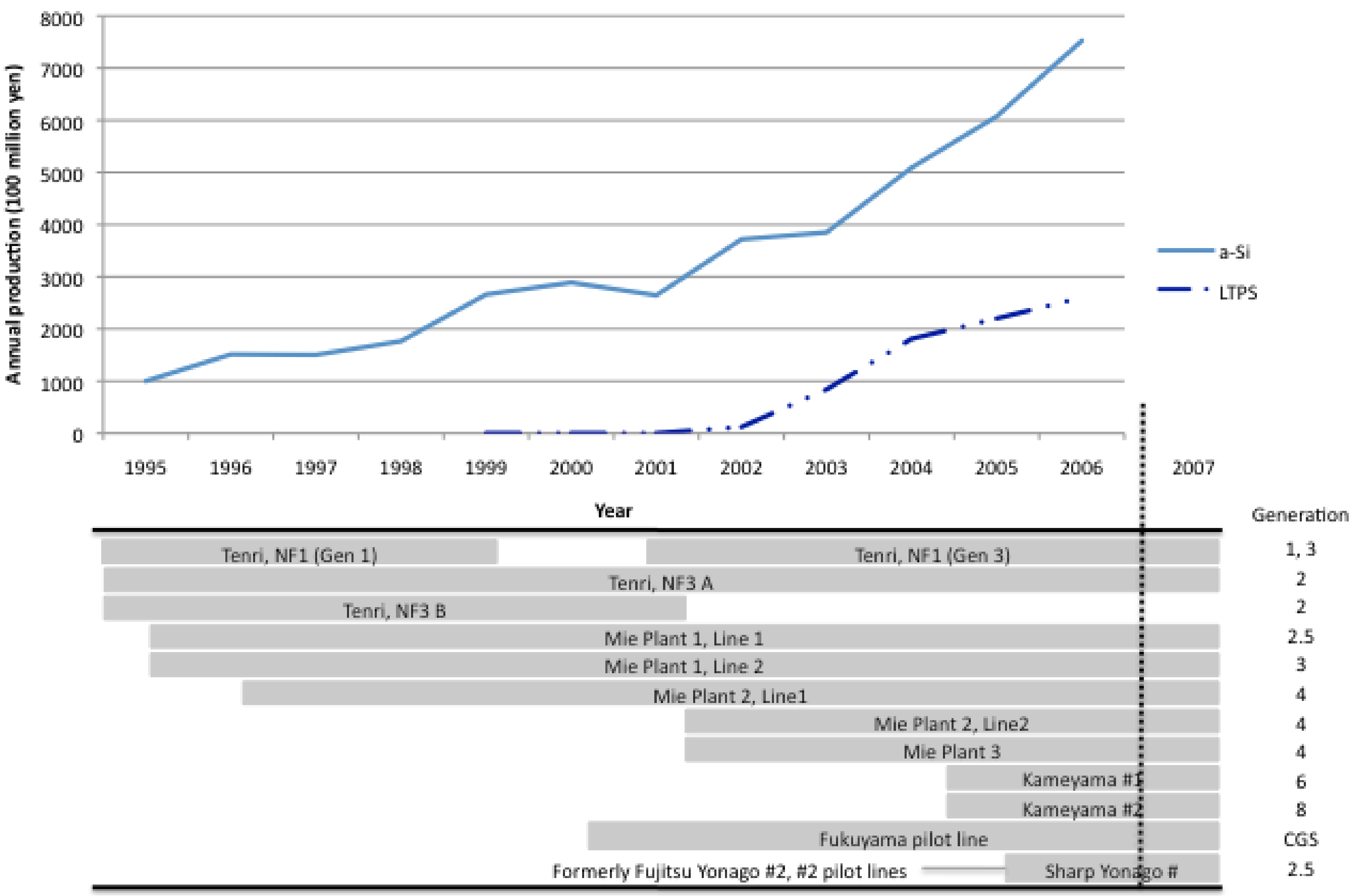


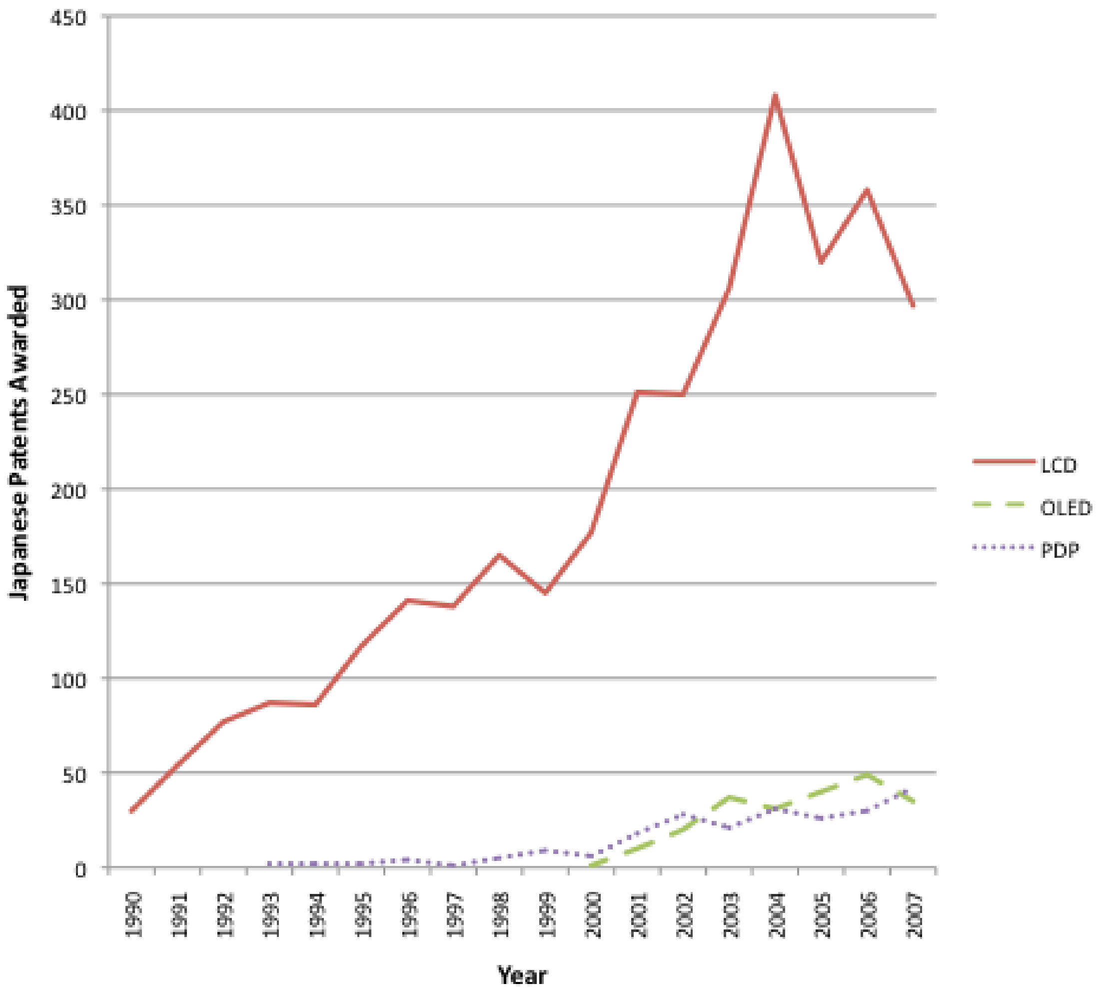
Figure 5-16: Sharp Option Ladder

Figure 5-17: Sharp Display Panel Production Volume and Production Lines



Note: HTPS, PDP, and OLED values were zero. Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-19: Sharp Patents



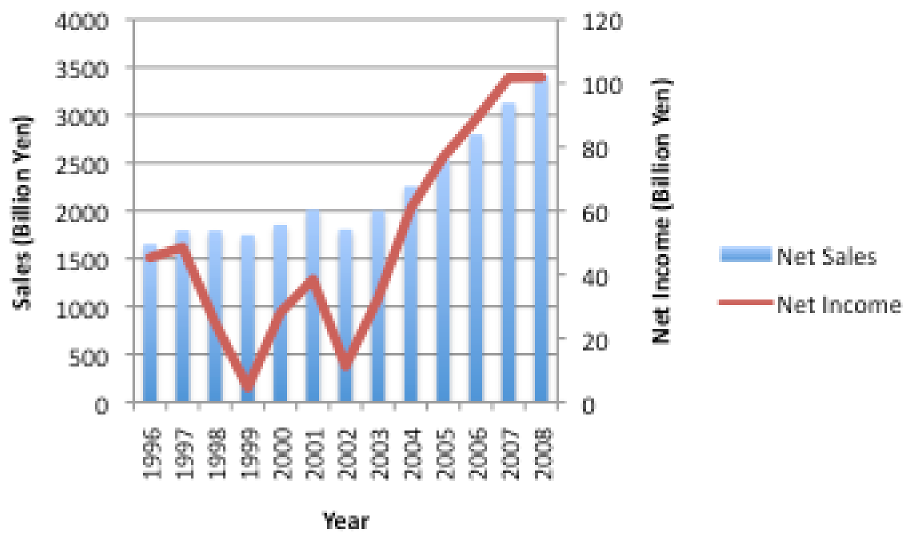
Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Sharp's Performance

Sharp's performance has been strong in terms of market share, sales and profitability. While a minor CRT TV player, Sharp did not have a CRT production capability and relied on CRT supplies from competing consumer electronics firms. It was not a top Japanese TV manufacturer until LCD became prominent. With the growth of LCD TV, Sharp became a top TV manufacturer and for a period outsold even its largest traditional competitors, Panasonic and Sony. Over time, Sharp has been willing to make major LCD plant investments and had used these to strengthen its position in the TV set business. Although the advantage Sharp had in flat panel televisions is decreasing, it continues to be a major player. Sharp stands as the only firm that was able to effectively leverage its technological superiority to dramatically improve its position in the TV set industry over the long term. Other firms tried, but none was able to realize a lasting benefit of the technology (See the following chapter for a more thorough comparison). Sharp's long-term share gains appear to have been largely at the expense of firms originally in the second and third tiers of the industry.

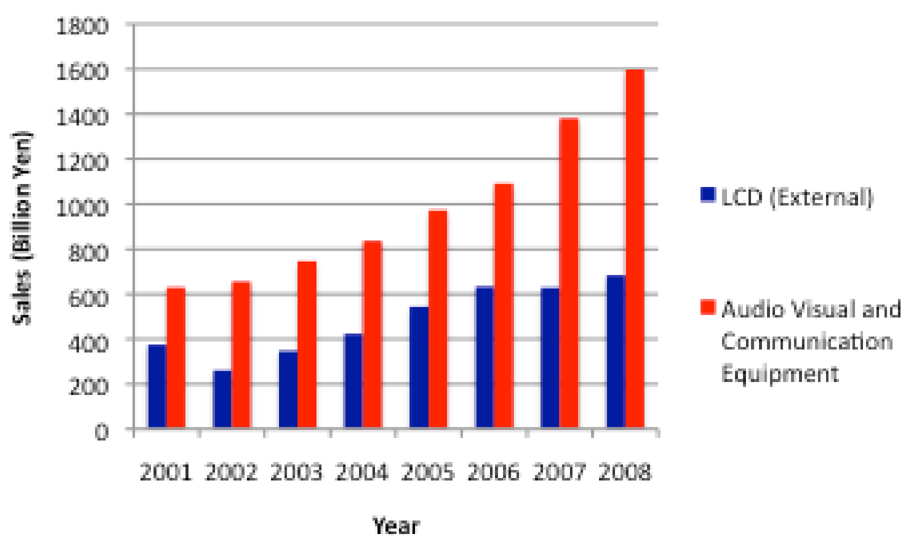
Sharp's financial results reflect its strong position in LCD. Chart 5-20 shows substantial increases in consolidated sales and net income since 2002. Chart 5-21 shows increasing sales revenues in Sharp's audio-visual and communications segment as well as growth of LCD panel sales to external customers. Compared to other Japanese firms, Sharp has generally been more effective at protecting its margins in the face of falling LCD and LCD TV prices. Sharp's consistent investment in leading generation production capabilities has allowed it to produce larger and larger sets and capture more value amongst the high-end product segments. Meanwhile, Sharp's proprietary low cost production methods also helped it maintain profitability.

Chart 5-20: Sharp sales and net income



Source: Sharp Annual Reports

Chart 5-21: Sharp Corporation external revenues of LCD, Audio Visual and Communication Equipment Sectors



Source: Sharp Annual Reports

Firm Level Analysis – Other Japanese TV Set Manufacturers

Funai

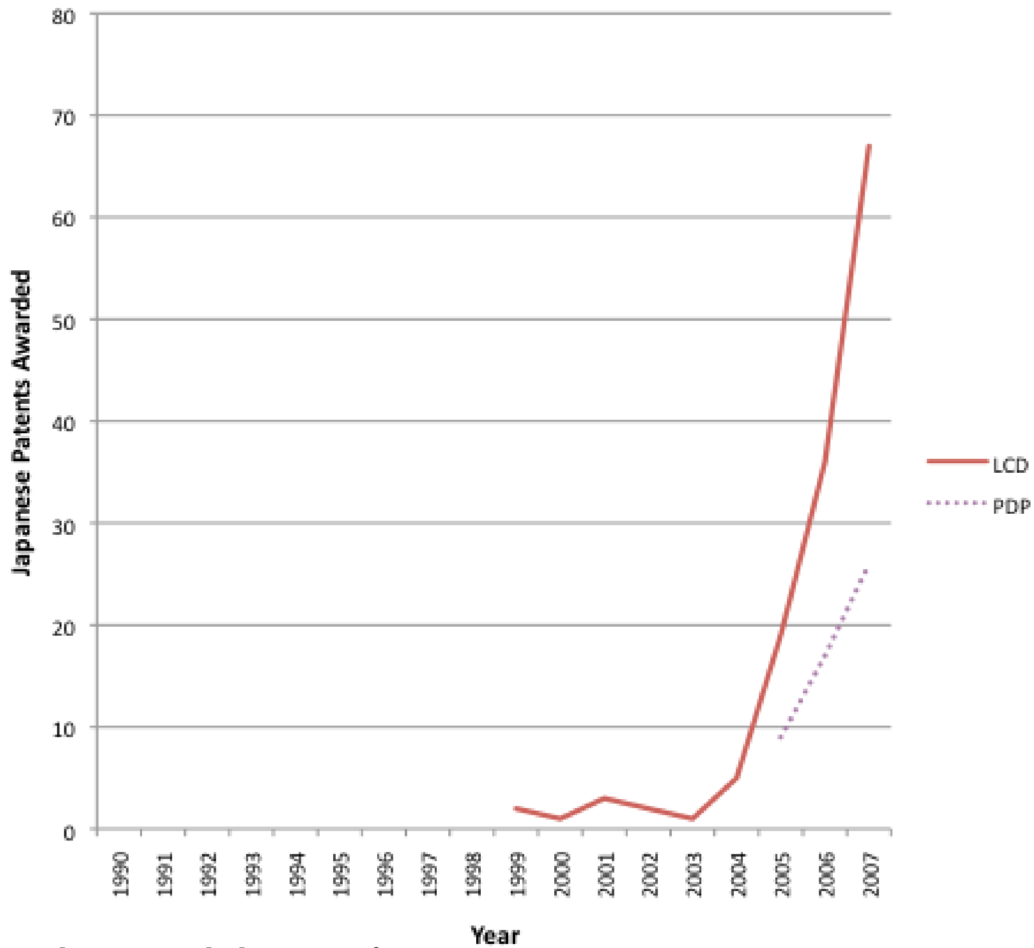
Funai Electric is an efficient, low cost competitor that produces low-end consumer electronics products. In addition to selling its own brand of electronics, it is also a contract producer for other well-known Japanese consumer electronics firms.

Funai has not built a flat panel production capability and there is little evidence of Funai developing display technology in house (accordingly, there is no option ladder for Funai). Instead of building its own production capability, Funai has searched for low cost partners to buy display panels from. Since 2001, Funai has developed and invested in a relationship with Taiwanese LCD panel producer CMO. In return for receiving assurances of access to panel supply, Funai has made several small investments in CMO (e.g., Sangyo Times, 2003, 2008; Techno Associates, 2008).

Recent patent data indicates Funai is working on LCD and OLED (See Chart 5-22 below). The increased patenting coincides with Funai's growth in LCD TV. Funai first decided to produce LCD TVs in 2002, and created a LCD TV business organization in 2007 (Funai, 2007).

Funai's approach to technological uncertainty has been to wait until it is resolved and not hold options. Funai's relationship with CMO is practical. It guarantees future supply of LCD panels in a way similar to a futures contract. Prices are sometimes lower on the spot market than what Funai pays CMO. Although the arrangement reduces uncertainty about pricing and volume of panels Funai will purchase, it does not provide an option for Funai to enter LCD production.

Chart 5-22: Funai Patents



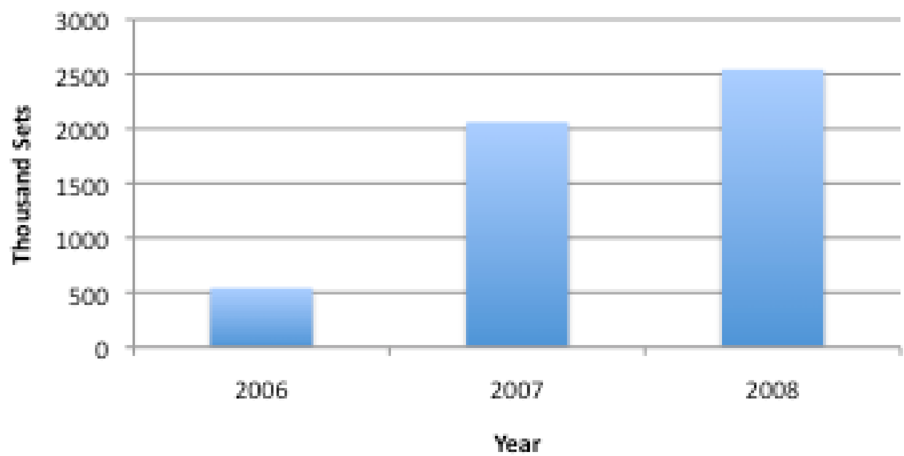
Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Funai's Performance

Funai entered the LCD TV business, and has been increasing its unit sales (See Chart 5-23, below). However, Fuji Chimera data suggests Funai's worldwide LCD TV market share is low. In 2005 and 2006, Funai had 0.3% and 1.5% unit share, respectively (Fuji Chimera 2006, 2007). By comparison, Funai's worldwide unit share of CRT TVs ranged from 8% to 4.3% over the period 2000 to 2005 (Fuji Chimera, 2001-2006).

Overall, this suggests Funai's position in the overall TV Set market has deteriorated as flat panel TV has grown.

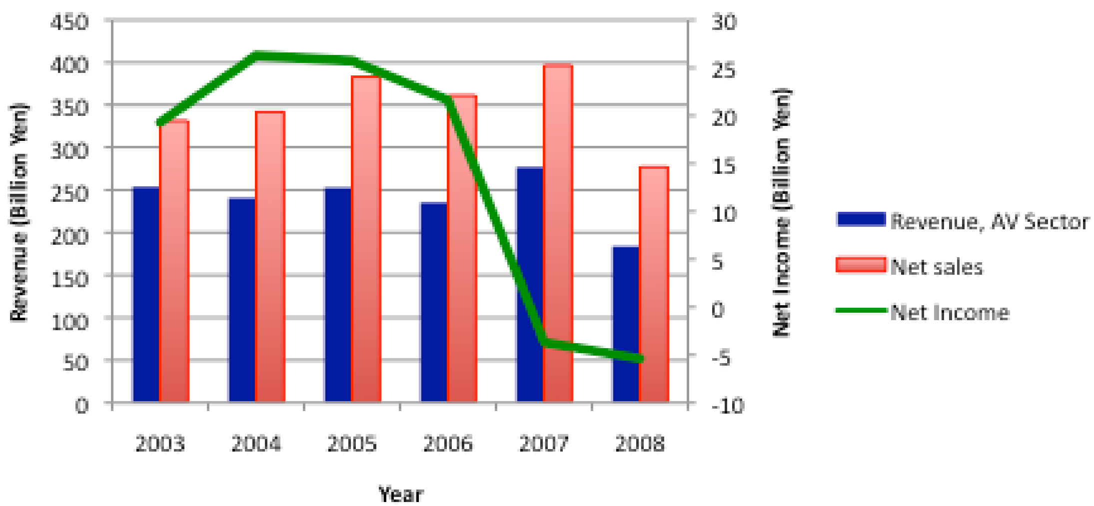
Chart 5-23: Funai LCD TV Unit Sales



Source: Funai Annual Report, 2008.

The financial data appears to agree with this analysis. According to its 2009 annual report, Fuani's financial performance has suffered as the CRT TV market shrank. Revenues for Funai's AV sector, which includes televisions, has not grown over the period 2003-2008, as shown in Chart 5-24, below. Decreasing sales of CRT TVs were not sufficiently made up for by LCD TV sales. Funai's limited ability to ship LCD TVs was cited as a reason. Furthermore, Tomonori Hayashi, Funai's President and CEO, cited insufficient procurement of LCD panels in FY2008 as a source of operating loss in the LCD TV business (Funai Annual Report). Funai posted net losses for 2007 and 2008. Although other factors may also be at play, company reports suggest the TV business performance has had a major negative impact on profitability for Funai.

Chart 5-24: Funai Revenues and Net Income



Source: Funai Annual Reports

JVC

Compared with other firms in the television business, JVC is relatively small. Formerly part of the Panasonic group, it is currently part of JVC Kenwood Holdings. JVC produced CRT TVs, but was not a major player. It has not become a major flat panel TV manufacturer. JVC has had a small involvement with display technologies, as can be seen from the option ladder in Figure 5-18, below. Its focus has been D-ILA, a proprietary version of LCOS, and a liquid crystal technology. It has used this technology in RP TVs. JVC also briefly worked with Canon developing FED technology, prior to Canon's cooperative arrangement with Toshiba. In addition to RP TV, JVC also entered the flat panel TV market with panels sourced from other firms. It has since exited RP TV, however it continues to use D-ILA in front projectors. It has exited the Japanese TV market altogether.

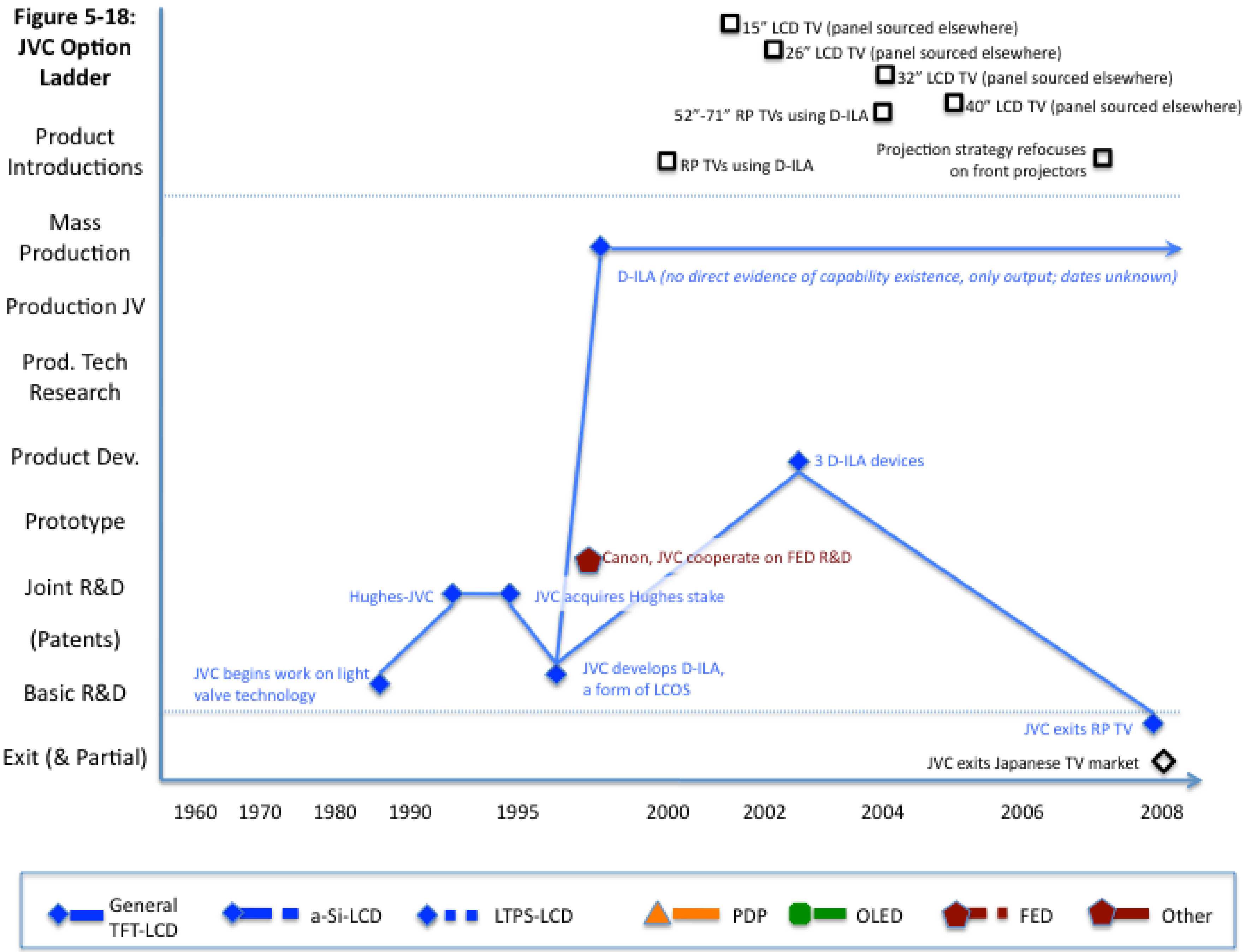
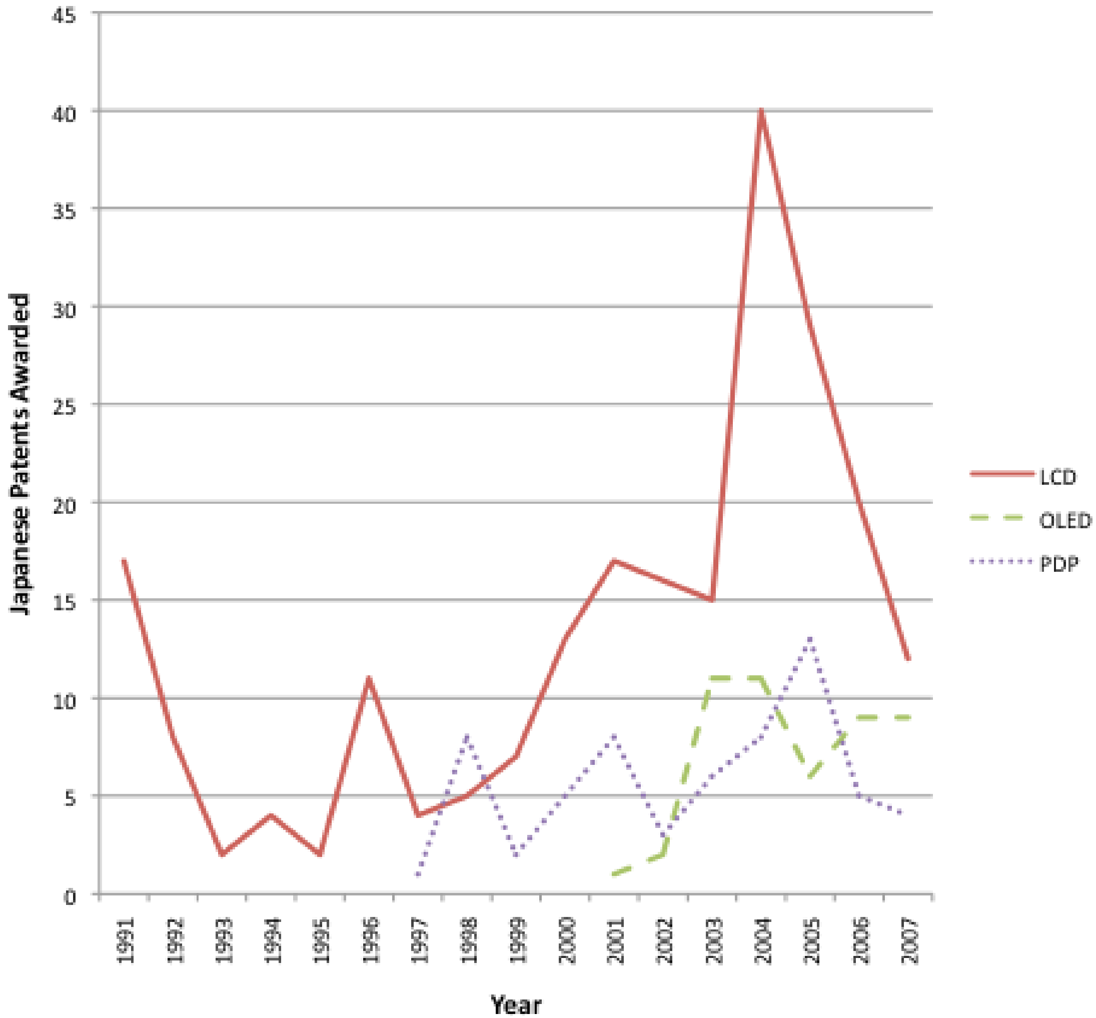


Figure 5-18:
JVC Option Ladder
Product Introductions
Mass Production
Production JV
Prod. Tech Research
Product Dev.
Prototype
Joint R&D
(Patents)
Basic R&D
Exit (& Partial)
15" LCD TV (panel sourced elsewhere)
26" LCD TV (panel sourced elsewhere)
32" LCD TV (panel sourced elsewhere)
52"-71" RP TVs using D-ILA
40" LCD TV (panel sourced elsewhere)
RP TVs using D-ILA
Projection strategy refocuses on front projectors
D-ILA (no direct evidence of capability existence, only output; dates unknown)
3 D-ILA devices
Canon, JVC cooperate on FED R&D
Hughes-JVC
JVC acquires Hughes stake
JVC begins work on light valve technology
JVC develops D-ILA, a form of LCOS
JVC exits RP TV
JVC exits Japanese TV market
1960
1970
1980
1990
1995
2000
2002
2004
2006
2008
General TFT-LCD
a-Si-LCD
LTPS-LCD
PDP
OLED
FED
Other

Chart 5-25: JVC Patents



Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Evidence of Option-like investments

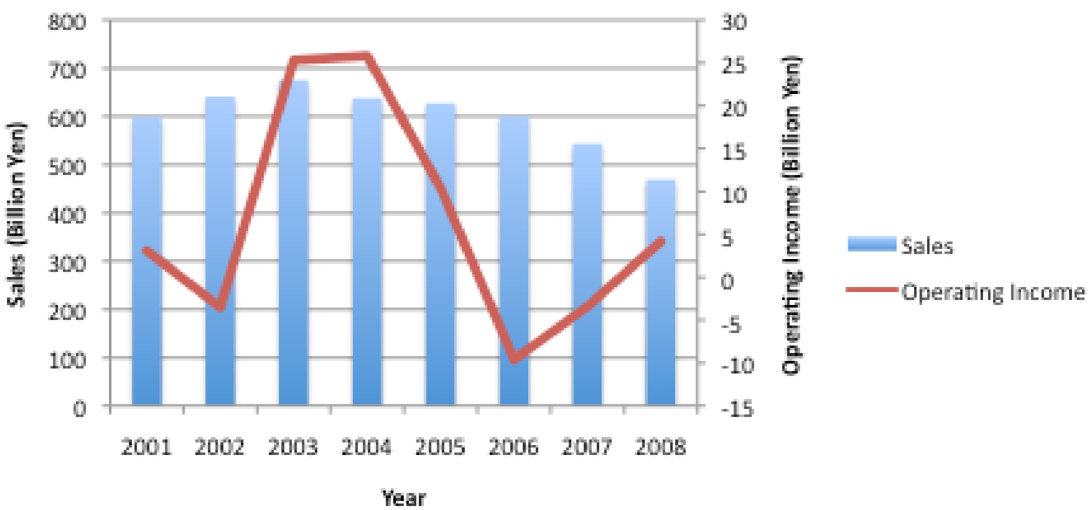
JVC focused efforts and resources on D-ILA rather than developing a portfolio of options on competing display technologies. The LCD patents shown in Chart 5-25 (above) are presumably related to D-ILA. The other display patents JVC holds may have been spill over from D-ILA activities and JVC's work with Canon on FED or patents related to implementation of display panel technology in products but not the basic display technologies themselves. The firm's involvement with Canon provided a low cost option on FED. However, JVC did not maintain the option for long. Considering JVC's size, most display technologies may have required production investments that were too large for the company. Given the small size of D-ILA devices, large plants were not required, keeping investment requirements more reasonable for a company with JVC's resources.

JVC's Performance

JVC's market share in TVs was not large prior to the introduction of flat panel TVs, and it did not grow large through FP TV. Accordingly, JVC is generally included in the "Other" section of available market share data. JVC was active in LCD TV, PDP TV, and RP TV. Fuji Chimera lists JVC's RP TV market share in only one year, 2004, for which JVC had 1% of the worldwide RP TV market (Fuji Chimera, 2005). In the 4th quarter of 2002, JVC had 4% of Japanese PDP TV market by units (Nikkei BP, 2004 (Bunseki hen)), however it was not listed in subsequent periods. Data is not available for other TV types. In 2008, JVC exited RP TV worldwide and the Japanese TV market across all TV display technologies, shutting down related production facilities. From the standpoints of market share and survival, JVC's TV business performance is low.

JVC's overall financial performance has been generally deteriorating in terms of sales and profitability since 2003. Chart 5-26 depicts sales and operating income of JVC's Consumer Electronics business, of which the TV business is a part. As with the company wide data, sales have decreased since 2003. Operating income for this sector is off of its highs, but there is little overall trend. D-ILA's impact on financial performance appears to have been negative, at least in the recent past; company reports describe the display business as the source of more than ten billion yen in losses during the 2008 fiscal year. The financial performance data agrees with the low performance in terms of market share and market exit.

Chart 5-26: JVC Consumer Electronics Business Sector Sales and Operating Income



Source: JVC Annual Reports

Firm Level Analysis – Korean Firms

LG

LG is a diversified Korean Chaebol group. LG Electric is a major flat panel TV set manufacturer and PDP producer. LCD displays are produced by LG Display, which was formally LG Philips LCD, prior to Philips selling most of its stake in the operation. LG Electronics is the largest shareholder of LG Display, holding 37.9% as of March 2008

(LG Display, 2006 (SEC Form 20-F)). Display related development and production have not always been centralized, and sometimes occurred in different group companies simultaneously. This has been the case mostly with earlier stage development and technologies comprising of divisible parts with different capabilities required for the different pieces (e.g., PDP). However, competition does not occur between these different groups, and capabilities are often integrated later. This has been the case for PDP, LCD, and OLED, which are now each integrated into a single member of the LG Group (Sangyo Times, 2008, 2009).

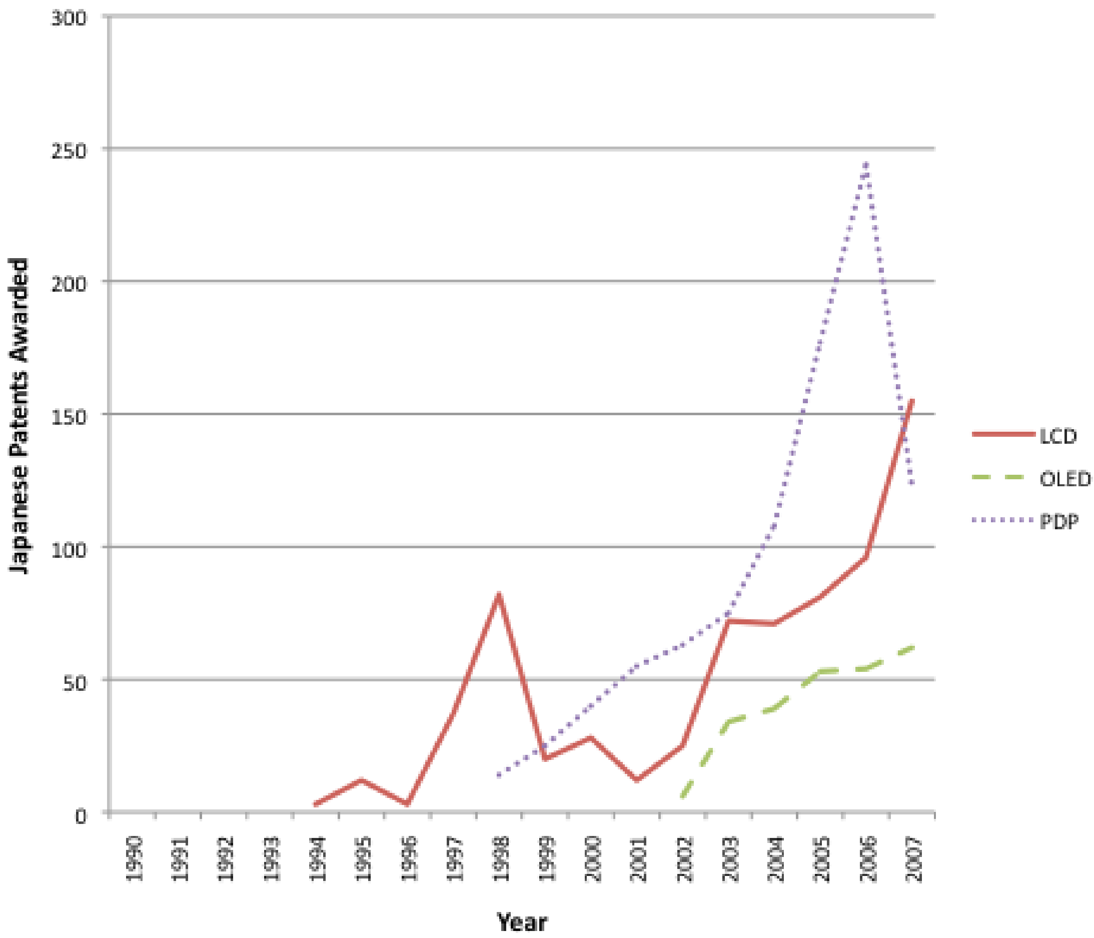
LG has not been a developer of new-to-the-world technology, but does have a track record of incremental improvements to existing technologies. It has a large appetite for risk and large-scale investments into production capabilities. LG's aggressive investment stance has helped to make it a leading volume producer of both PDP and LCD panels.

Evidence of Option-like investments

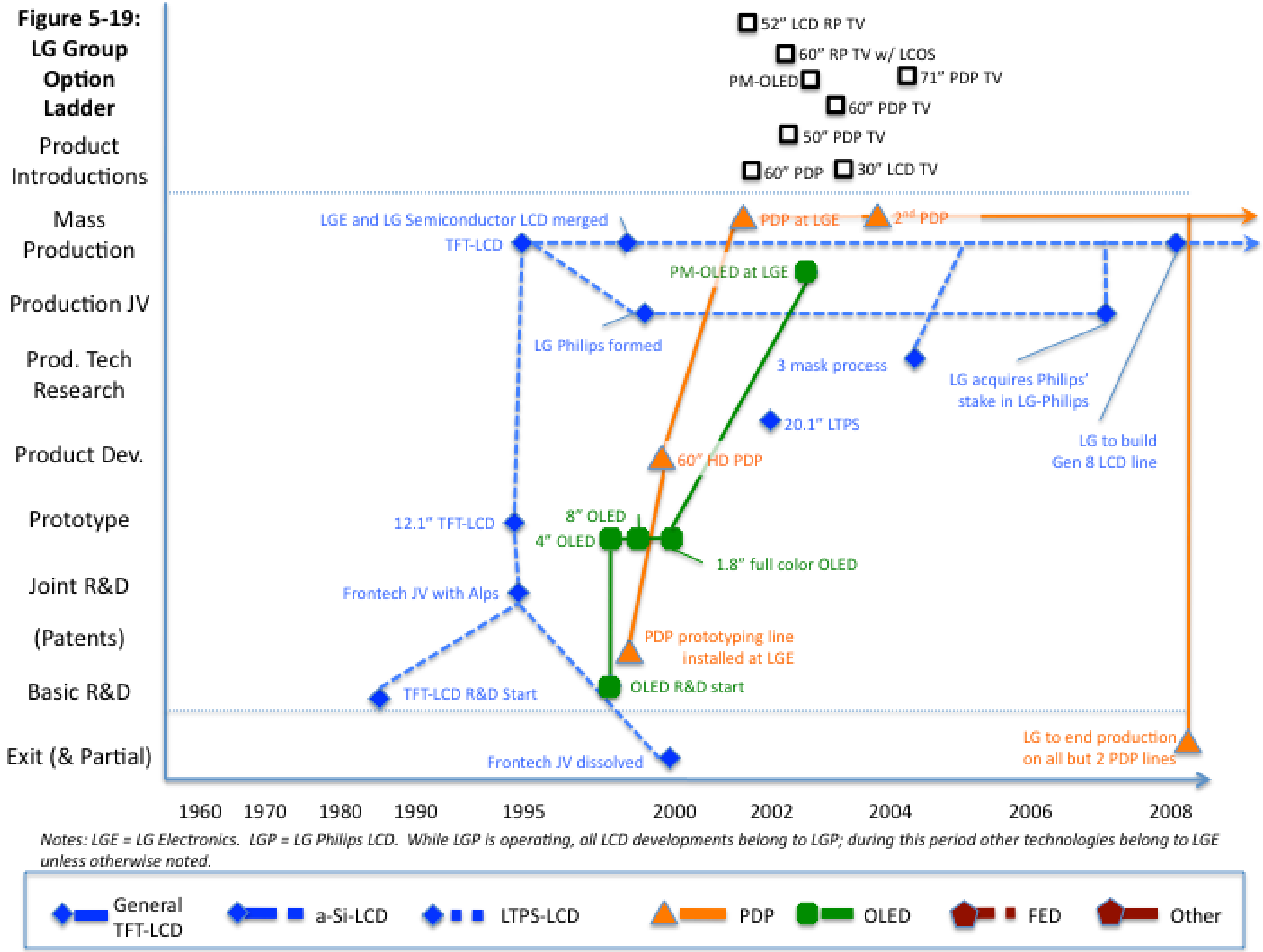
LG group has a broad and deep portfolio of display technology options, covering a-Si LCD, LTPS, PDP, and OLED (see Figure 5-19). LCD started before OLED and PDP development, however they have been concurrent most of the time. Patent data shows active R&D in LCD, PDP, and OLED (see Chart 5-27). LG has typically taken some time to go from developing initial options to increasing investment to mass production levels. However, when LG exercises an option and increases the level of commitment, it does so boldly (see production data, Figure 5-20). With the exception of LG Philips, it has not looked to joint ventures to build production capabilities. On the other hand, it has used cooperative arrangements for development, including those with Alps in TFT LCD and Thomson in PDP.

LG continues to pursue options in all of the display technologies it entered. It has slimmed down its PDP production capacity in line with market requirements, but has not exited.

Chart 5-27: LG Patents

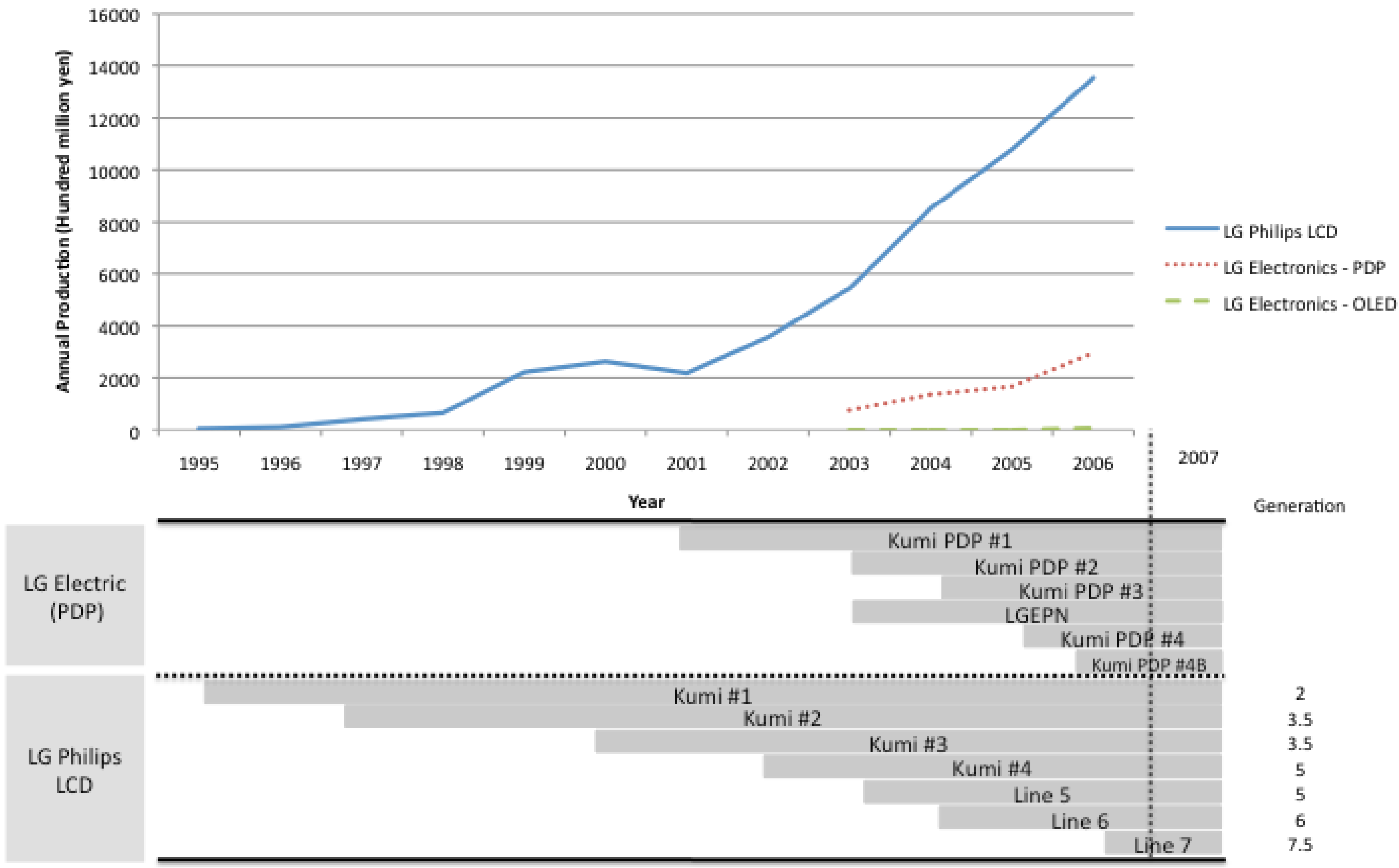


Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.



Notes: LGE = LG Electronics. LGP = LG Philips LCD. While LGP is operating, all LCD developments belong to LGP; during this period other technologies belong to LGE unless otherwise noted.

Figure 5-20: LG Panel Display Production Volume and Production Lines



Note: HTPS, LTPS, and PDP values were zero.

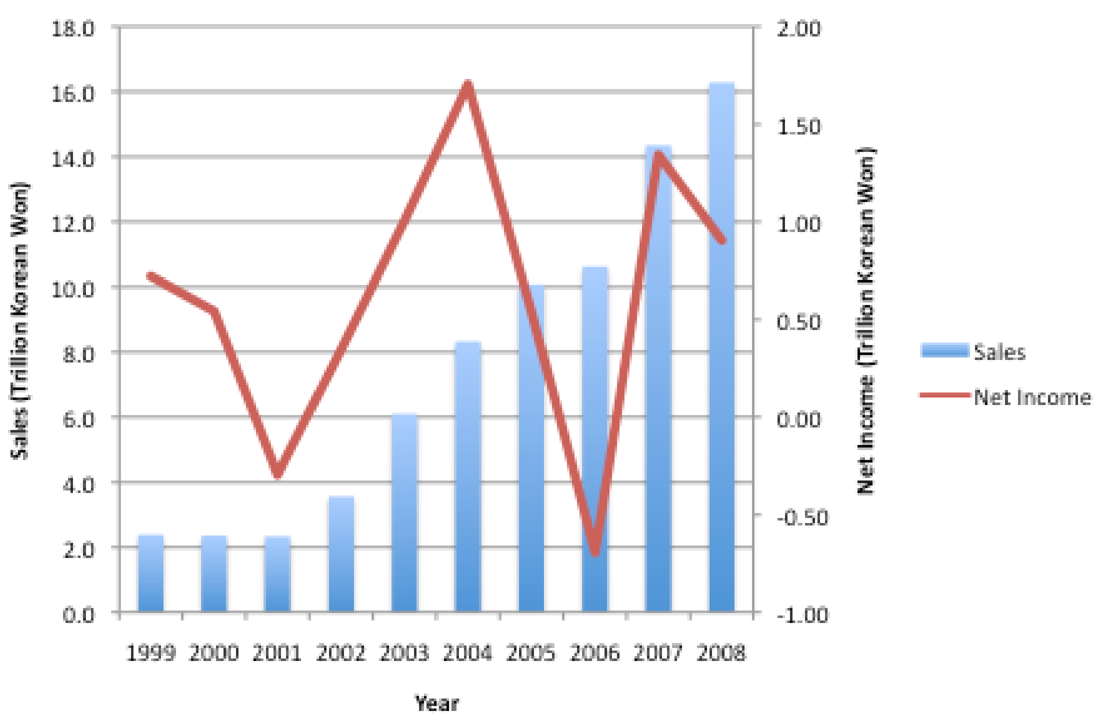
Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Performance

LG's flat panel TV and related display businesses have been growing, and this growth has been profitable for the most part. Chart 5-28 shows an upward trend in sales of LG Displays, with mixed net income results. The highly volatile nature of markets for LCD displays impacts sales price but has smaller impact upon production cost, amplifying variability in profitability. Chart 5-29 depicts LG Displays' sales by segment. LCD TV panels represent a growing portion of LG Displays' overall sales.

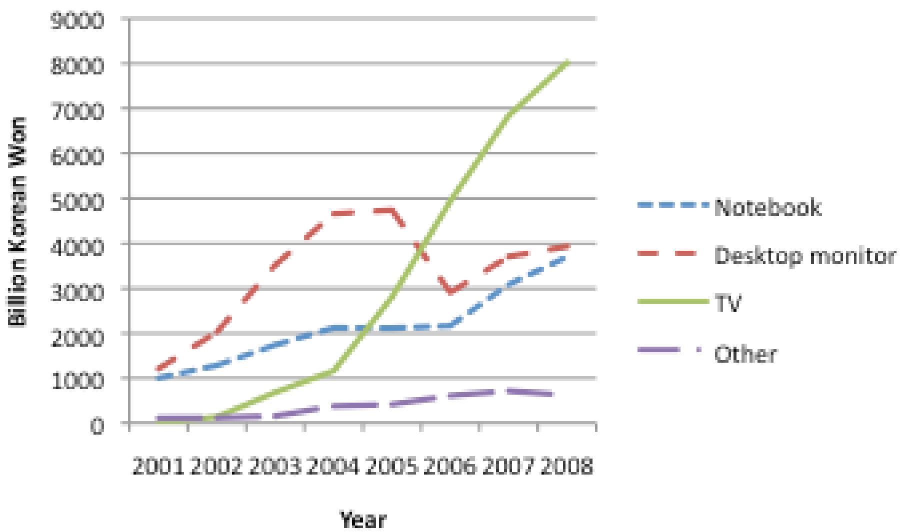
LG Electronics (see Chart 5-30) shows rapidly growing sales, but a large variability in net income. As LG Electronics display business is focused on PDP, results for this sector shown in Chart 5-31 are impacted by PDP prices.

Chart 5-28: LG Displays Sales and Net Income



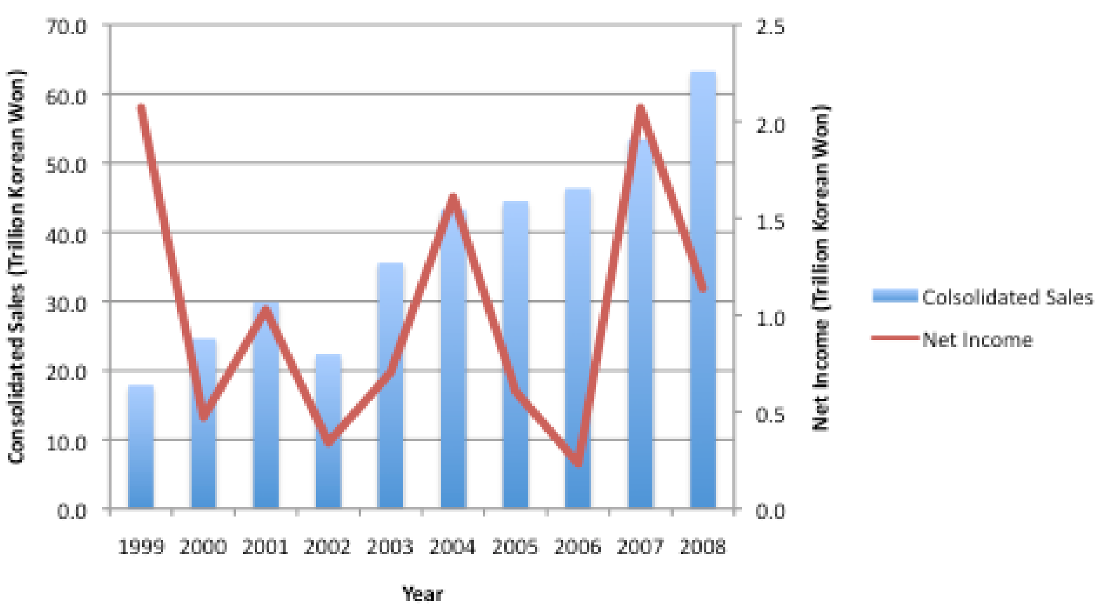
Source: LG Displays SEC filings

Chart 5-29: LG Displays Sales Revenue by Display Segment



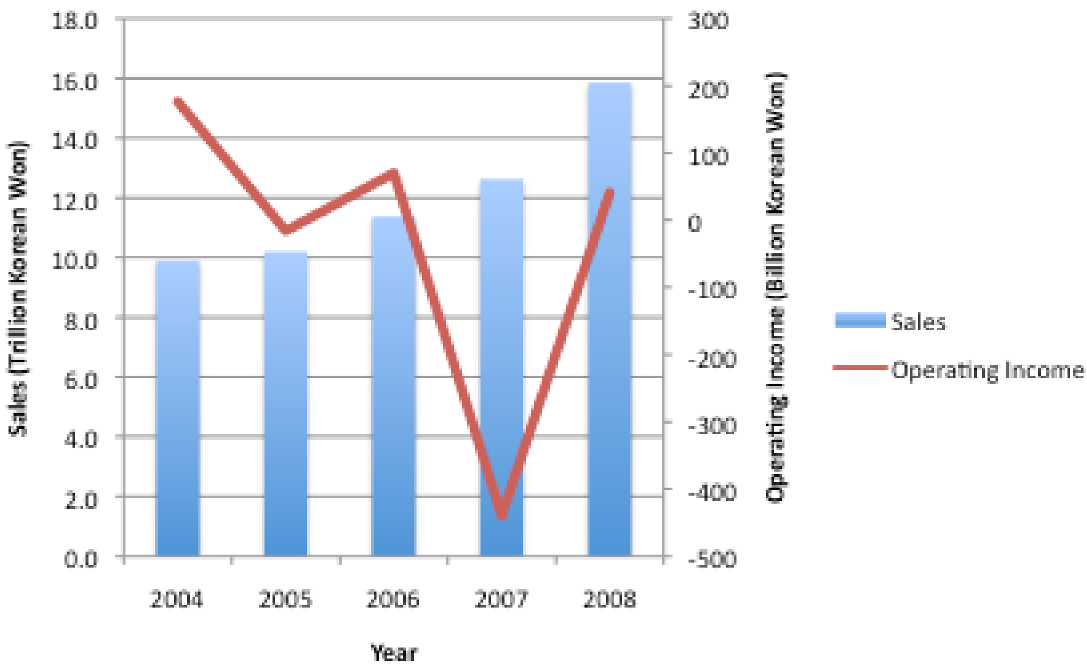
Source: LG Displays SEC filings

Chart 5-30: LG Electronics Consolidated Sales and Net Income



Source: LG Electronics Consolidated Financial Statements

Chart 5-31: Sales and Operating Income, LG Electronics Digital Displays Sector



Source: LG Electronics Consolidated Financial Statements

Samsung

Samsung is a diversified Korean Chaebol. Samsung Electronics is one of the central companies in the Samsung group and also one of the largest. Samsung Electronics is a flat panel TV set manufacturer and parent of Samsung LCD, a panel producer. Samsung SDI is a publicly traded Samsung group company that produces displays. It focus is on CRTs, PDPs, and mobile displays including LCD and OLED. Since 2000, Samsung Electronics has reported holding stakes in Samsung SDI in the range of 19% and 20% (Samsung Annual Reports, 2000, 2005, 2006, 2007).

Samsung flat panel development has not always been centralized. At times, Samsung LCD and Samsung Electronics have developed technologies concurrently; the same is true with Samsung Electronics and Samsung SDI. However, intra-group competition has not lasted for long; group companies have settled on a central location for each technology before large production infrastructure investments became necessary.

Evidence of Option-like Investments

As a group, Samsung held options on a-Si and LTPS LCD, LCD, FED, and OLED technologies (See Figure 5-21, below). Samsung Electric focused its investment into a-Si TFT, rapidly entering and building up production capacity after entering the TFT-LCD business. Samsung SDI, which was a major CRT producer, focused on PDP and to a lesser extent OLED. In the case of PDP, Samsung held low cost options for a longer time than LCD, waiting to make investments in production. OLED development has taken place in several parts of the organization, and is currently in a JV between Samsung Electronics and Samsung SDI.

Samsung's significant investments in LCD production reflect a major commitment by the firm. The company has publicized its very aggressive stance towards investment in a-Si production. Samsung's production capability has grown accordingly (see Figures 6-22, 6-23). At the same time, Samsung has maintained PDP production capacity. Samsung does not appear to have had long and continued development in LTPS or FED. Although it continues to build its portfolio of display options, recently investing more heavily in OLED options (see patenting data, Chart 5-32), it is focusing its investment into three technologies – a-Si LCD, PDP, and OLED.

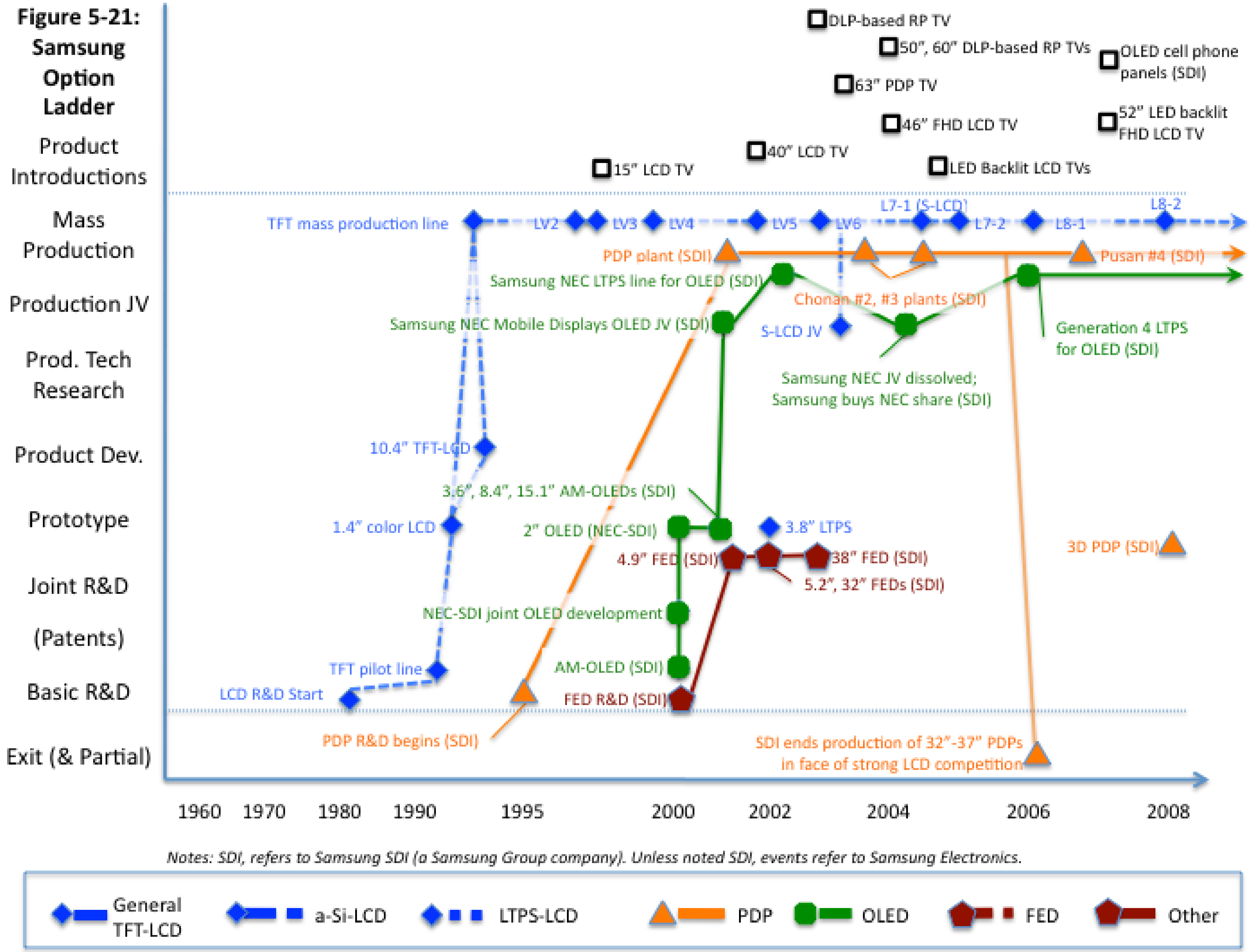
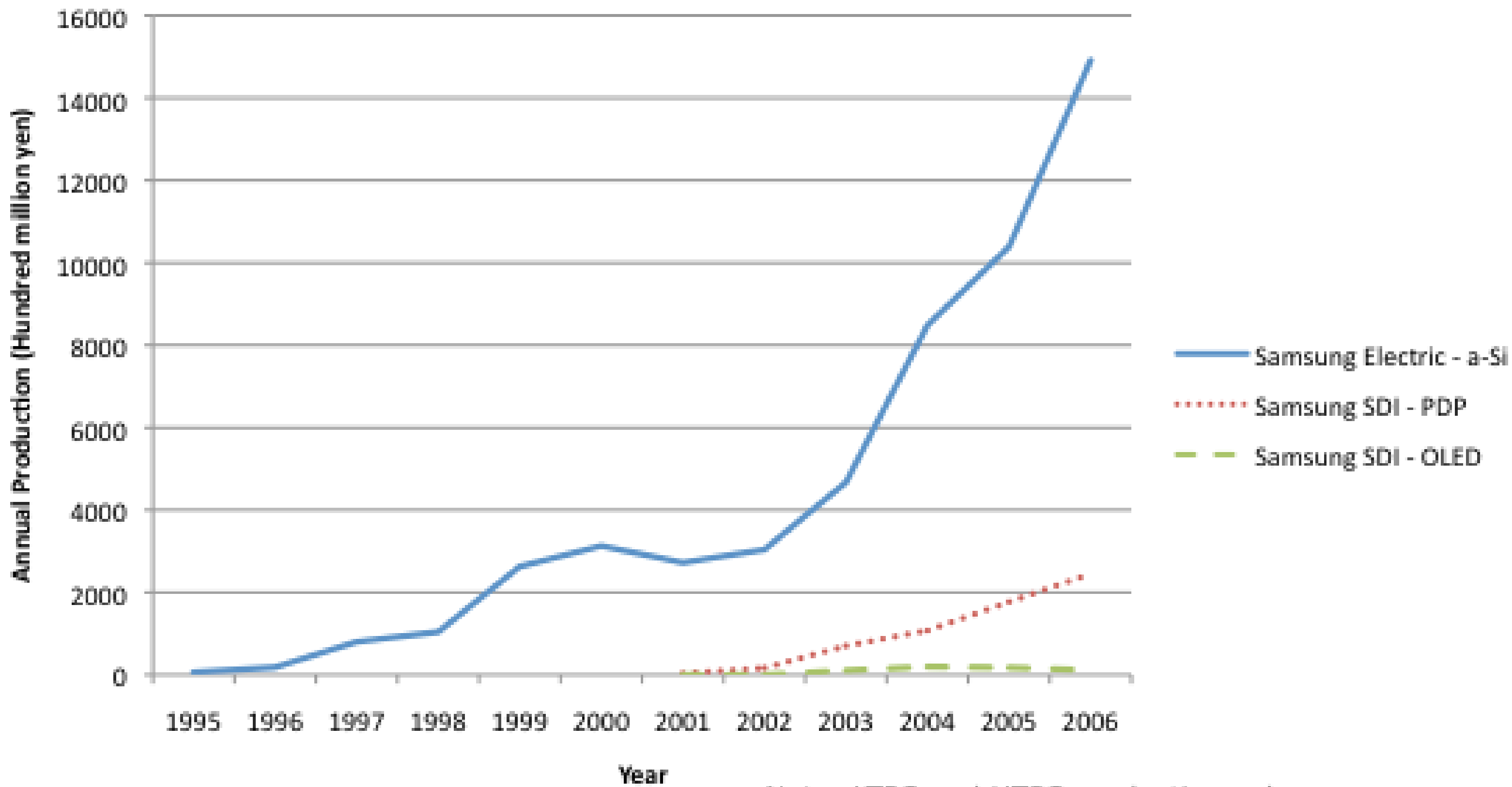


Figure 5-21: Samsung Option Ladder

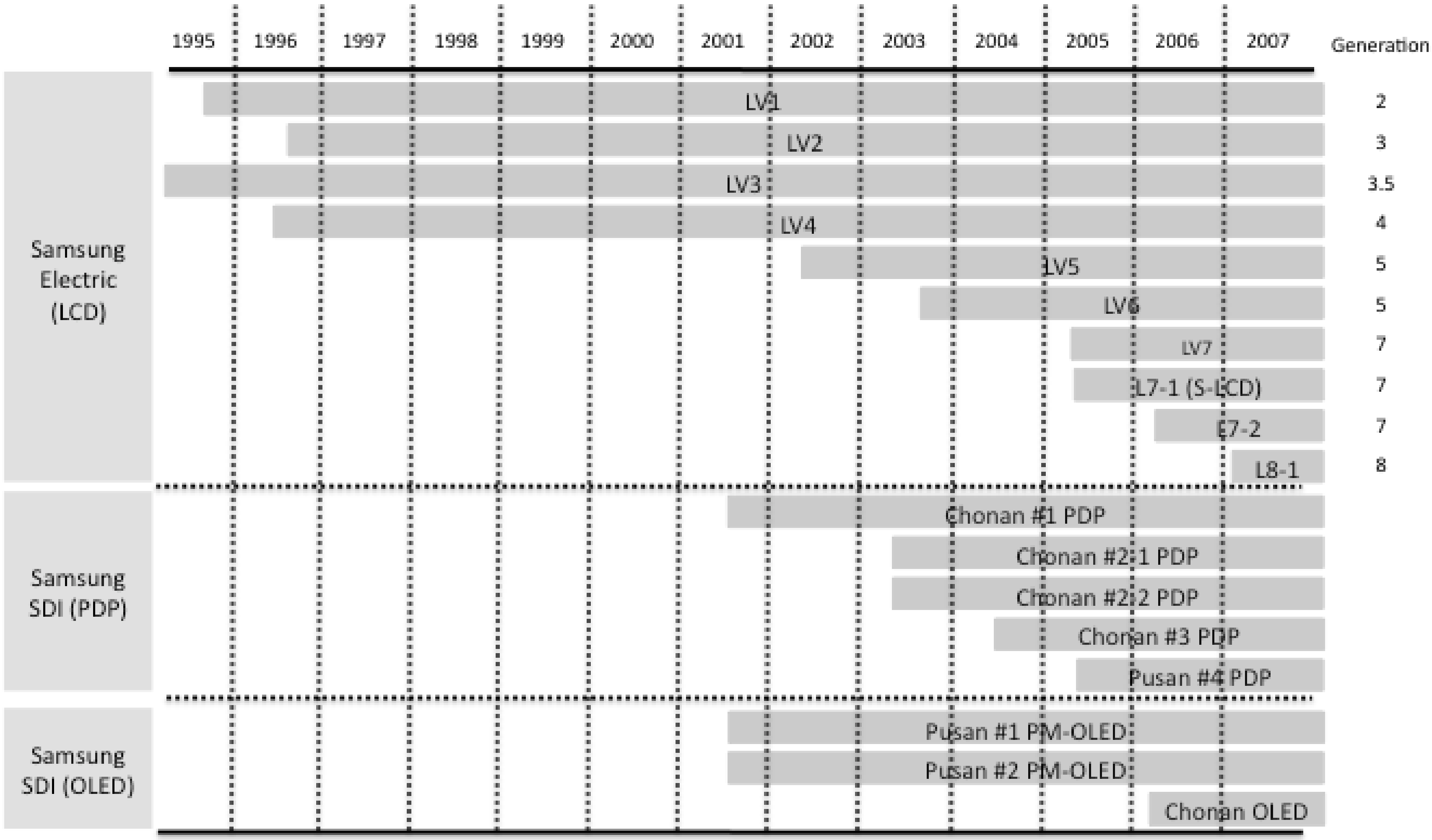
Figure 5-22: Samsung Display Panel Production Volume



Note: LTPS and HTPS production values were zero.

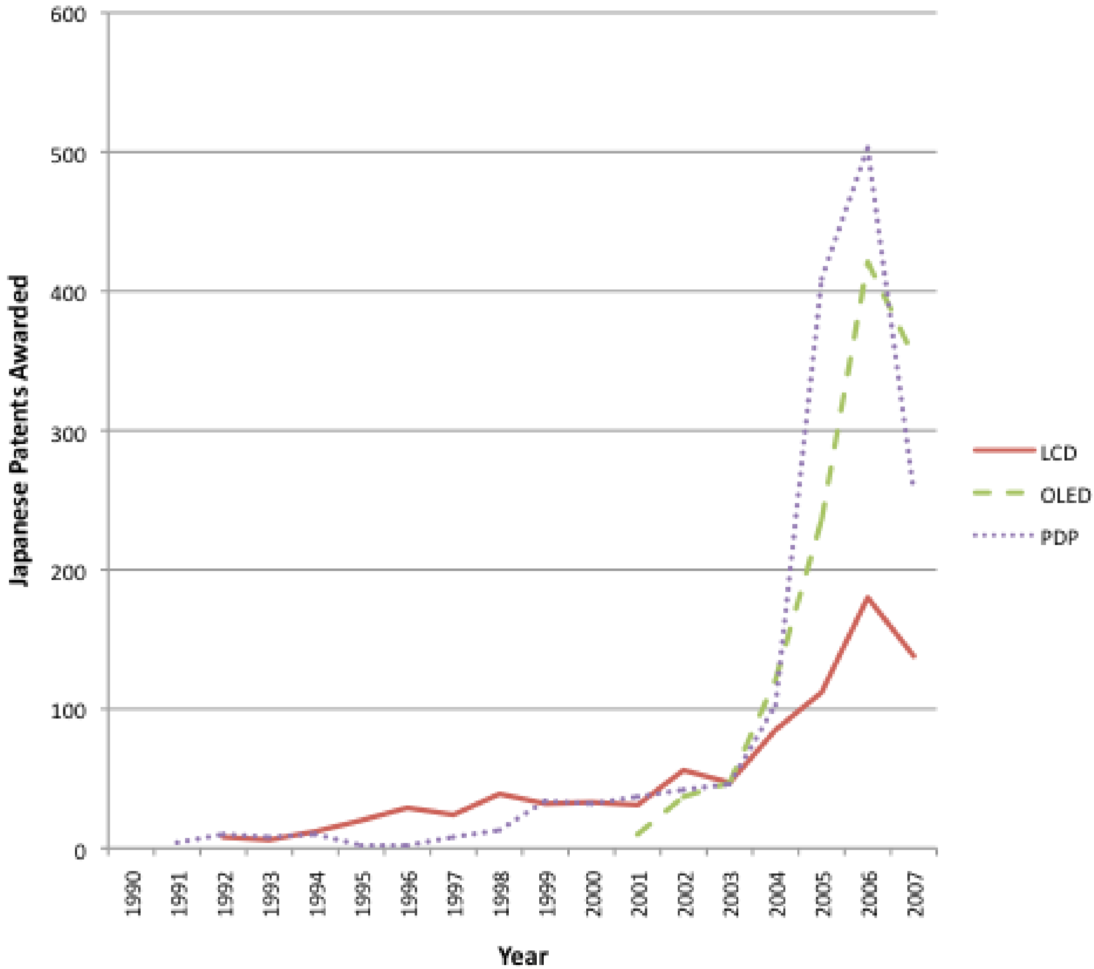
Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Figure 5-23: Samsung Production Lines



Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-32: Samsung Patents



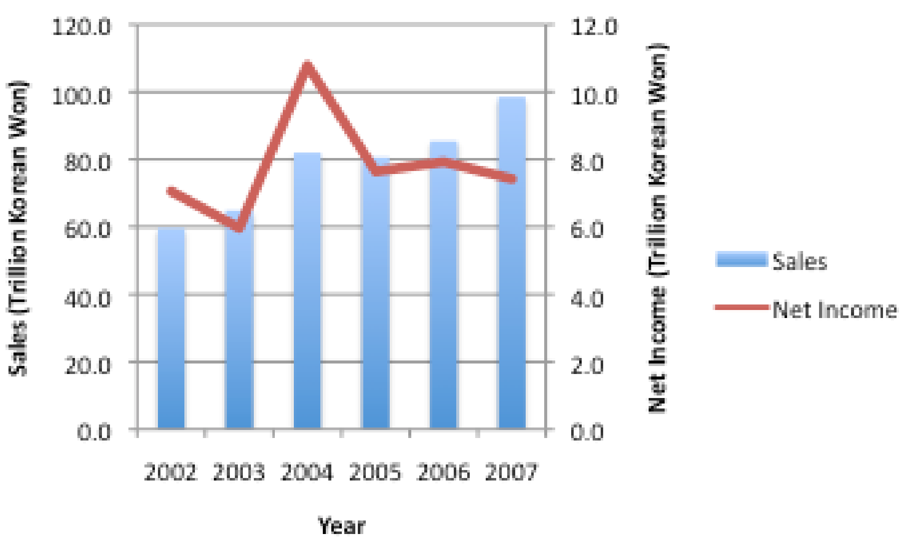
Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Samsung's Performance

Samsung has performed well in terms of flat panel TV market share. In 2007, Samsung's worldwide TV set market share was 17.8% by sales (Samsung Annual Report 2007). In 2008, Samsung ranked number one in LCD TV share worldwide, and number two for PDP TV (Samsung Annual Report, 2008). As an LCD producer, Samsung Electronics has held the top share worldwide for large panels for most of the 2000s.

Samsung's financial performance has also been strong. Due to reorganization and changes in segment reporting, performance of Samsung Electronics' TV business is difficult to analyze over time. However, Samsung Electronics is profitable and has been growing at the firm level as can be seen from Chart 5-33. Recent data on the LCD business suggest it has also been growing profitably although profits have not been steady. Samsung's Digital Media sector, which includes Samsung Electronics' TV business, is growing but lost money in 2007 and 2008.

Chart 5-33: Samsung Electronics Performance

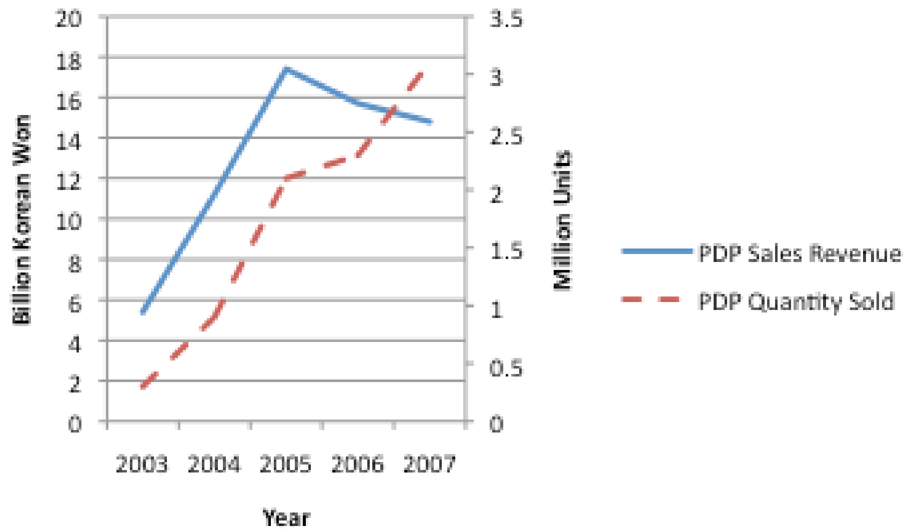


Source: Samsung Electronics Annual Reports

Samsung SDI has not fared as well as Samsung Electronics. Its PDP business stopped growing in revenue terms in 2005 due to deterioration in the price of PDPs (see Chart 5-34). Overall, Samsung SDI's total revenues have been shrinking since 2004 (see Chart 5-35, below). As CRT sales declined at SDI, PDP sales increased, however so did

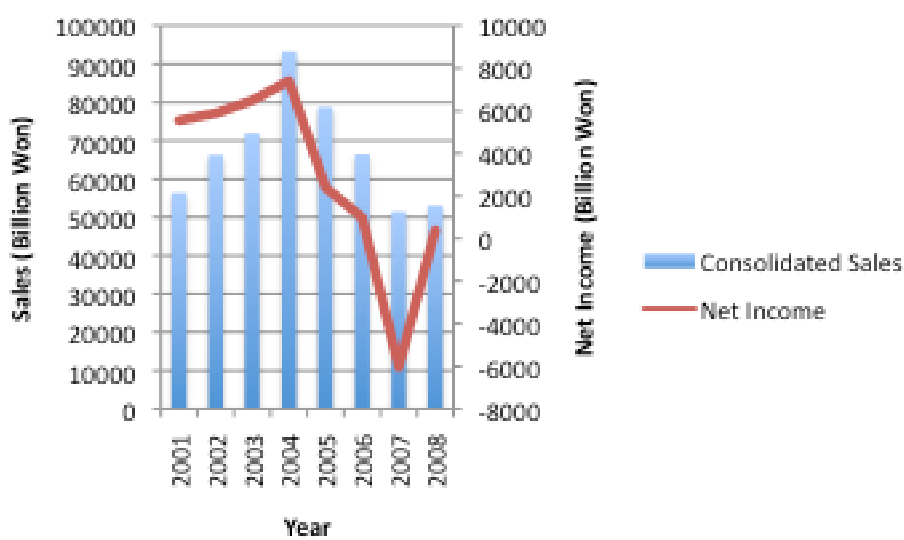
LCD sales, which were at Samsung Electric and not SDI. SDI has several other businesses, however the impact of CRT decline on the firm was substantial.

Chart 5-34: Samsung SDI PDP Sales



Source: Samsung SDI web site[1]

Chart 5-35: Samsung SDI Consolidated Sales and Net Income



Source: Samsung SDI web site

1 http://www.samsungsdi.com/eng/ivt/ir_2_1_2t_2008.jsp

Firm Level Analysis – European Firms

Philips

Philips has been involved with a number of display technologies, including PDP, PALC, a-Si LCD, LTPS, liquid crystal based micro displays, and OLED (see Figures 5-24 and 5-25, below). Philips has reported joint R&D participation in PDP, PALC, and OLED, however it has announced relatively few prototypes or other developments publicly. Philips has been active in LCD through joint ventures with Hoshiden and LG. Generally, LCD research results have been reported by the JVs and not by Philips. Still, some patent activity attributed to Philips can be observed in each of the display technologies (see Chart 5-36). Philips' OLED development has a different pattern from that of other technologies; development has been done at Philips' headquarters and more prototypes have been announced (Fuji Chimera, 2002; Sangyo Times, 2002).

Philips has invested in production for LCD and OLED. Philips entered into a JV with Hoshiden on small to mid sized TFT-LCDs in 1996 (Sangyo Times, 1997; Jiji Press, 1996), and later bought out Hoshiden's share, making it a wholly owned subsidiary in 2000 (Sangyo Times, 2001). Philips and LG established a joint venture in 1999, "LG Philips LCD" for mass production of LCDs including large displays (Nikkei BP, 2006 (Gyokai bunseki hen)). Philips stayed with this JV for a number of years. However, after several quarters of significant losses, it exited the JV, selling its stake to LG.

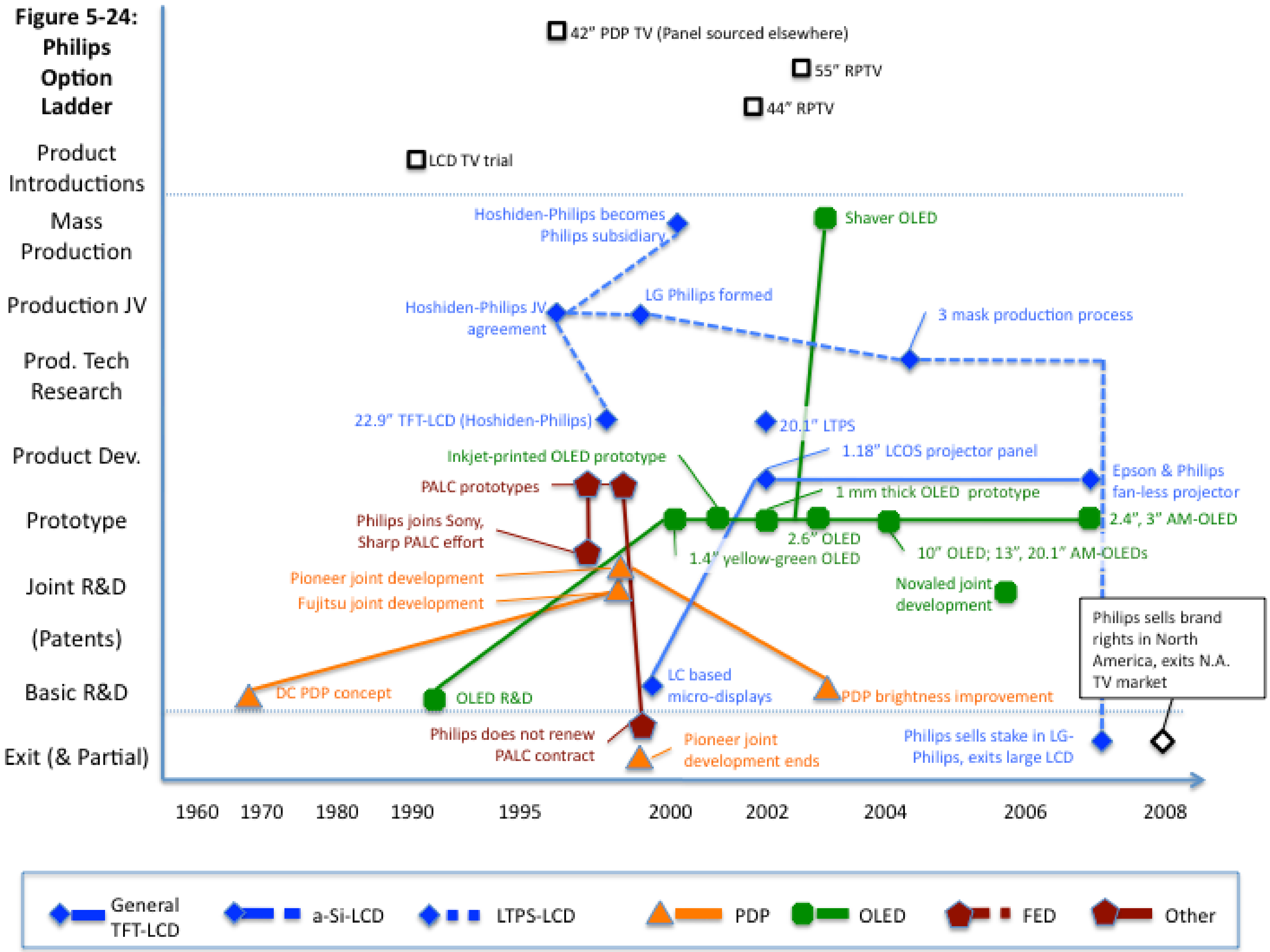
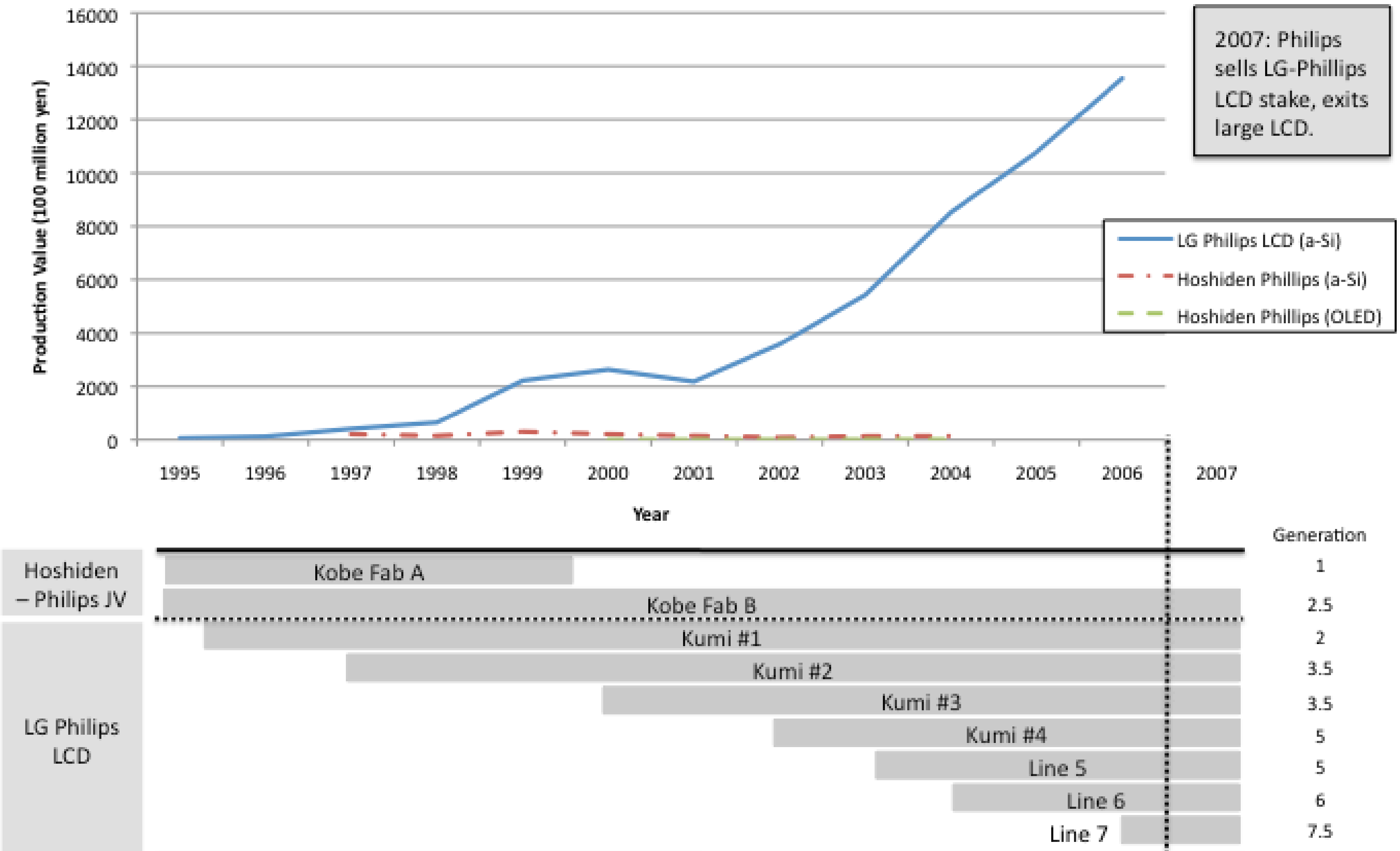


Figure 5-24: Philips Option Ladder

Figure 5-25: Philips Display Panel Production Volume and Flat Panel Lines

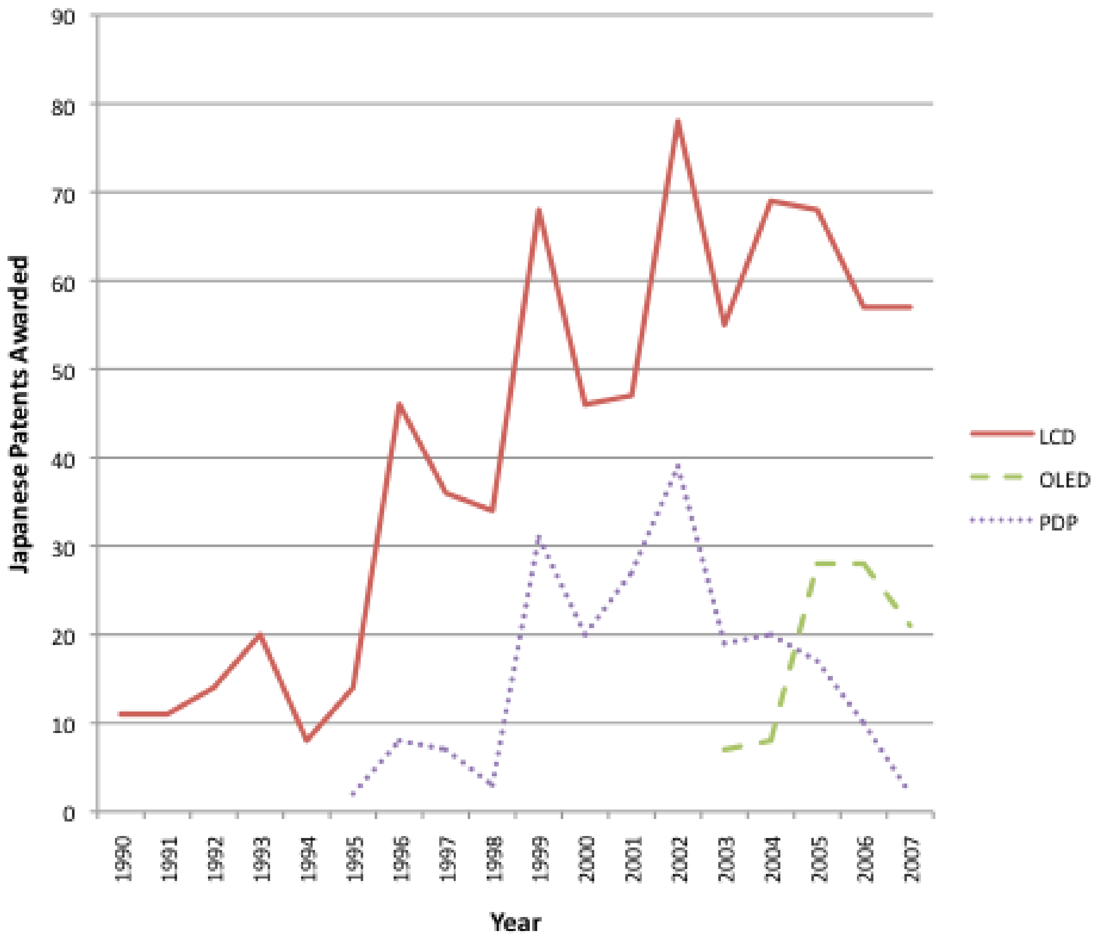


Note: HTPS, LTPS, and PDP values were zero.

Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Philips OLED production has been in house.[2] The displays have been used in shavers, an application where short lifetime PM-OLED would be sufficient. Production investment does not appear to have been substantial.

Chart 5-36: Philips Patents



Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

[2] Hoshiden-Philips was also involved with OLEDs after it became a consolidated subsidiary of Philips and renamed Philips Mobile Display Systems.

Evidence of Option-like investments

Figures 5-24 and 5-25 suggest Philips made small, option-like investments in a variety of different technologies. Philips pursued low cost basic R&D options, on its own (e.g., PDP, OLED) and through participation in joint development projects (e.g., PDP with Fujitsu, Pioneer; PALC with Sharp and Sony). Philips participation in these joint development programs was generally short. At the same time, recurring basic research developments on PDP suggest the firm may have also pursued longer term R&D at modest scales. Patent data agrees with this observation. Taken together, this indicates Philips had a broad portfolio of options, although there may have only been a few that were actively maintained at any given time.

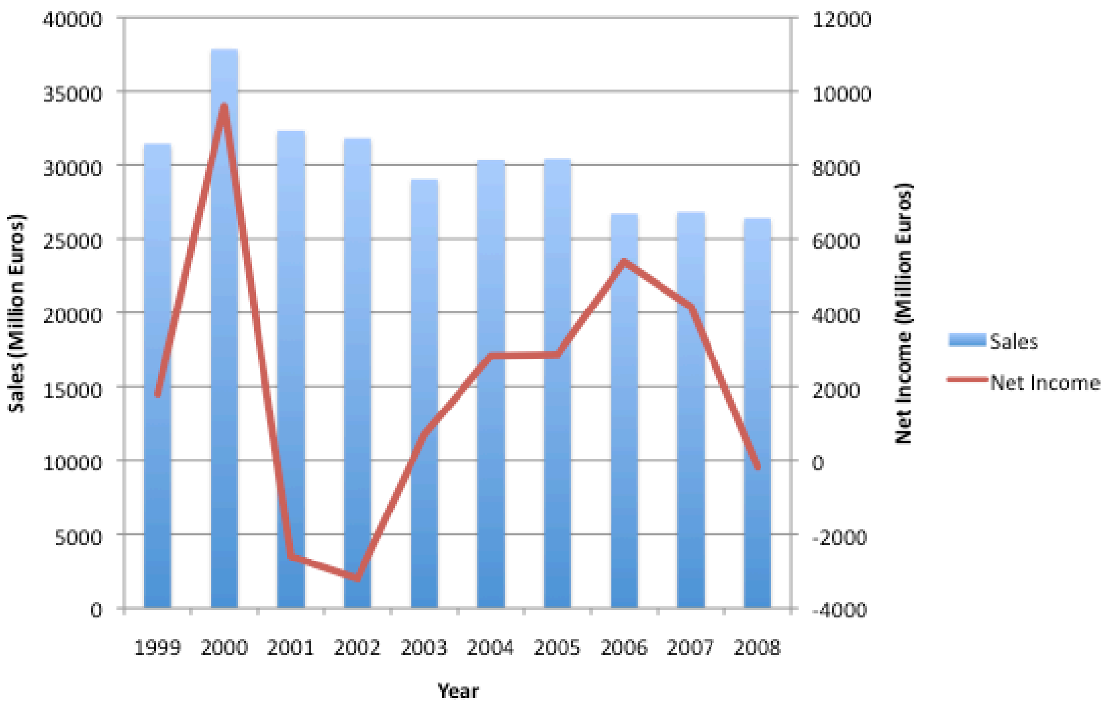
Exercise of options through mass production and market entry was limited. Philips exercised its option on the Hoshiden Philips JV and purchased Hoshiden's stake in the business. Philips also developed and for a time maintained an option in larger LCD panel production through its investment in LG Philips LCD, although it later sold its stake and exited. Philips has exercised options on OLED by beginning production of small PM-OLEDs for shaver applications. This leaves Philips holding options for further OLED development and entry into production of AM-OLEDs in the future.

Philips' Performance

Philips has been decreasing its exposure to LCD TVs. It sold its stake in LG Philips LCD in 2007 (Nikkei BP, 2006 (Gyokai bunseki hen)), and its TV brand rights in North America in 2008 (Nikkei BP, 2008 (Kigyo bunseki hen)).

Philips had high market share in CRT TV sets, and has been able to continue to maintain sizeable market share in flat panel TV as well. Over the period 1998 to 2004, its worldwide unit market share for CRT TV was in the range of 6-7% (Fuji Chimera 1999-2004). Techno Systems lists Philips share of PDP TVs and Monitors at 8.6% and 5.3% for the fourth quarter of 2000 and 2001, respectively. Techno Associates Research (2006) listed Philips share of the worldwide LCD TV market at 11.1%, and PDP TV at 8.4% in the second quarter of 2005. LG Philips was a very large LCD producer. In 2005, the joint venture was the world's largest supplier of LCD TV panels, with 24.2% market share (Techno Associates Research, 2006).

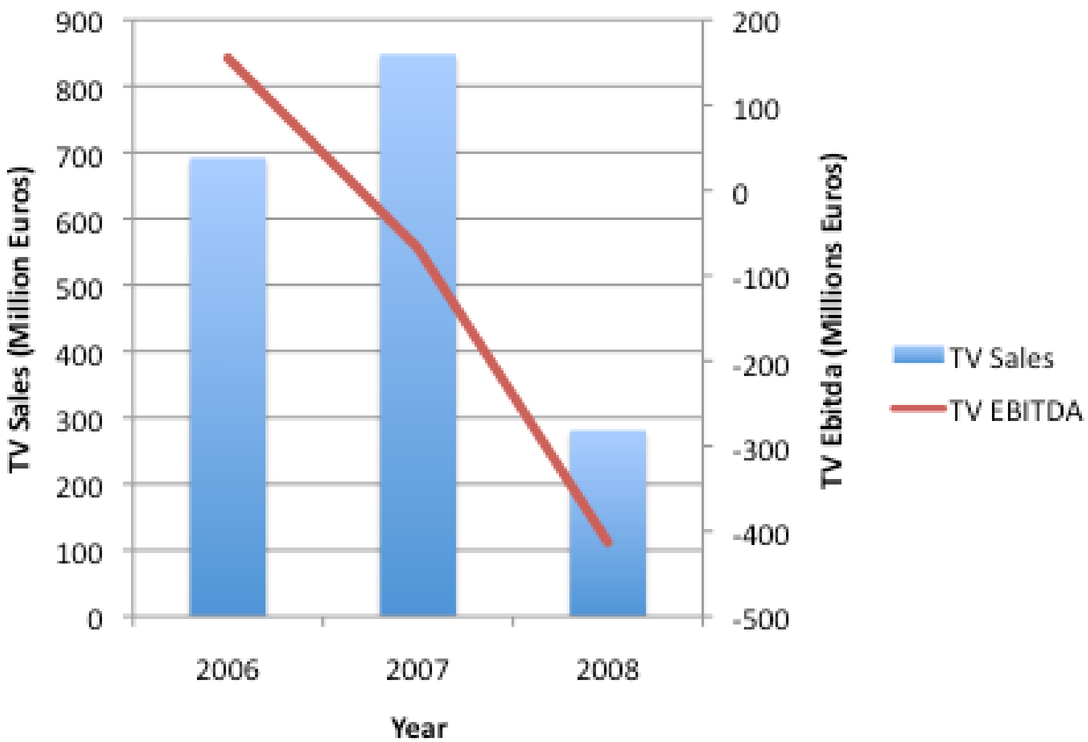
Chart 5-37: Philips Sales and Net Income



Source: Philips Annual Reports

Philips performance was low by a number of other measures. Sales of its Consumer Electronics sector have not been growing. Philips consolidated results reveal a downward trend in sales and volatile net income (see Chart 5-37). Philips has not reported TVs separately in most years. For the three years it was available, EBITDA for TVs was negative for 2007 and 2008, and positive for 2006 (See Chart 5-38).

Chart 5-38: Philips Television Sales and EBITDA



Source: Philips Annual Reports

Thomson

Thomson has had limited involvement with flat panel technologies, and therefore has not been rigorously covered by the Japanese sources. Thomson was a major CRT and CRT TV producer, selling Thomson and RCA brands. Thomson's 2000 annual report lists the company as the 2nd largest producer of large and very large sized color TV picture tubes, with a 20% share of the global market.

Thomson performed some basic R&D on both LCD and PDP, but details are sketchy. The company has not exhibited prototypes at the major trade shows, nor is there evidence of direct investment in production facilities.

Figure 5-26 below shows Thomson's option ladder. Thomson had an LCD subsidiary, however this subsidiary does not appear to have had a significant production capability of its own.[3] Thomson sold it off in 1999 (Thomson Annual Report, 1999). Thomson performed Plasma related research in Moirans, France (Thomson Annual Report, 2000). Thomson has developed a business in licensing LCD and PDP related patents. Some of these were the results of internal R&D (see patent data, Chart 5-39), however Thomson also reports it purchased patents relating to LCD and Plasma, some of which were originally from Xerox's PARC (Thomson Annual Report, 2004).

Thomson has produced PDP TVs. The company began cooperating with NEC on plasma in 1998 (Fuji Chimera, 1999). Thomson used NEC panels in its PDP TVs. In 2001, Thomson and NEC announced plans to form a joint venture to further develop, produce, and distribute PDPs (Sangyo Times, 2002). However, the joint venture was never established (Fuji Chimera, 2002). Thomson also had a joint agreement with LG covering PDP, which started in 2003 ((Sangyo Times, 2004).

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[3] Nikkei BP series lists small and pilot lines even outside of the Asia region, but has not identified one directly owned by Thomson.

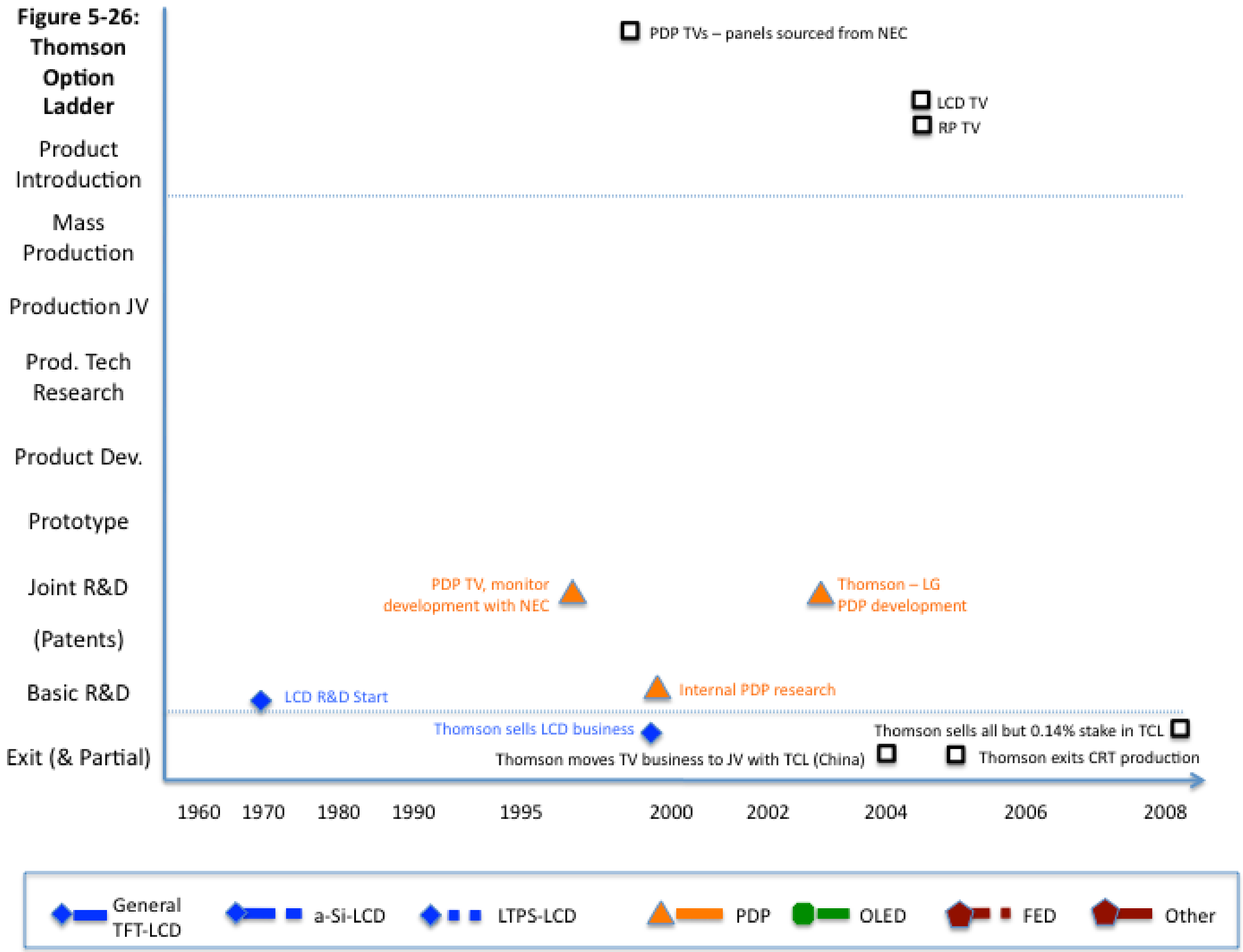


Figure 5-26: Thomson Option Ladder
Product Introduction
Mass Production
Production JV
Prod. Tech Research
Product Dev.
Prototype
Joint R&D
(Patents)
Basic R&D
Exit (& Partial)
PDP TVs – panels sourced from NEC
LCD TV
RP TV
PDP TV, monitor development with NEC
Thomson – LG PDP development
Internal PDP research
LCD R&D Start
Thomson sells LCD business
Thomson sells all but 0.14% stake in TCL
Thomson moves TV business to JV with TCL (China)
Thomson exits CRT production
1960
1970
1980
1990
1995
2000
2002
2004
2006
2008
General TFT-LCD
a-Si-LCD
LTPS-LCD
PDP
OLED
FED
Other

Thomson exited both CRT production and TV set manufacturing. The company sold CRT and related glass activities in 2005, and shut down activities relating to tube components during the 2007-2008 period (Thomson Annual Report, 2008). The company deconsolidated its TV set related business in August 2004. This business was contributed to joint venture with TCL of China called TTE. Thomson originally had a 33% stake in the JV, but later changed this to a 29% stake in TTE's Chinese parent company in 2005. Since then, Thomson has been reducing this stake; it was 19.3% in 2006, 2.4% in 2007, and 0.14% in 2008 (Thomson Annual Report, 2008). Effectively, Thomson has exited the TV set business.

Thomson's Options portfolio and Performance

Thomson developed basic technology options relating to LCD and PDP. Through a cooperative agreement with NEC, it increased its access to PDP technology and panels. However, the firm never developed production capabilities of its own. The levels of investment Thomson put into its options appear to be relatively small compared with the costs of setting up mass production of cutting edge panel production for TV applications. This may have been due to lack of resources or it may have been a strategic choice.

Chart 5-36: Thomson Patents

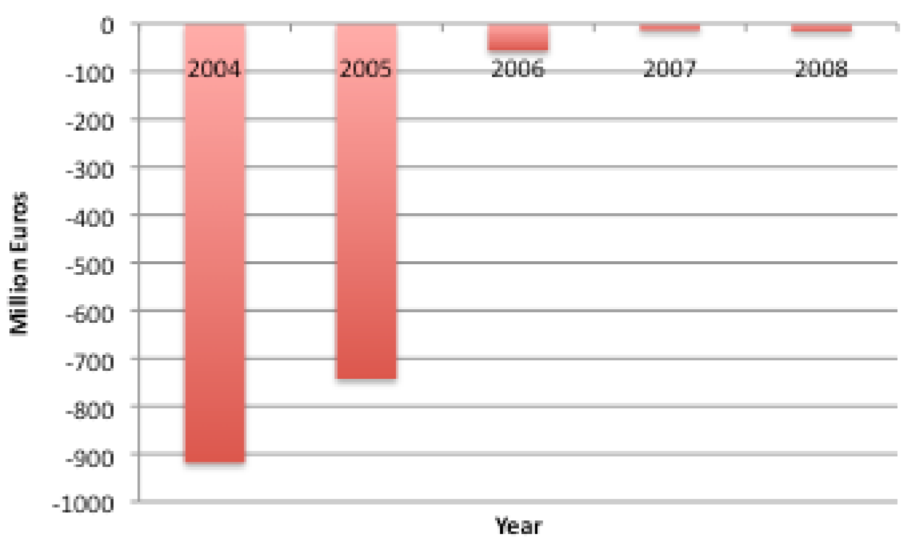
Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

In the early 2000s, it became increasingly clear that flat panel televisions would replace CRT TVs. As time passed, the urgency for Thomson to take action with regard to its TV business must have risen. The company made several LCD and rear projection models during 2004, using panels made by other companies. Of the different flat panel technologies, Thomson developed larger options on PDP than the other technologies.

However PDP was looking relatively less attractive compared with LCD by this point. The joint venture with TCL was an exit strategy.

Thomson has changed its focus over the period, moving away from TV set hardware manufacturing and into media and services areas. In the process of exiting TV, Thomson realized a string of losses stemming from its previous CRT manufacturing business. Chart 5-40, below, shows these losses. From the perspectives of financial performance and survival, Thomson's TV business performance is low.

Chart 5-40: Thomson's Losses Relating to Exiting CRT Production



Source: Thomson Annual Report, 2008.

Firm Level Analysis – IT Firms

Fujitsu

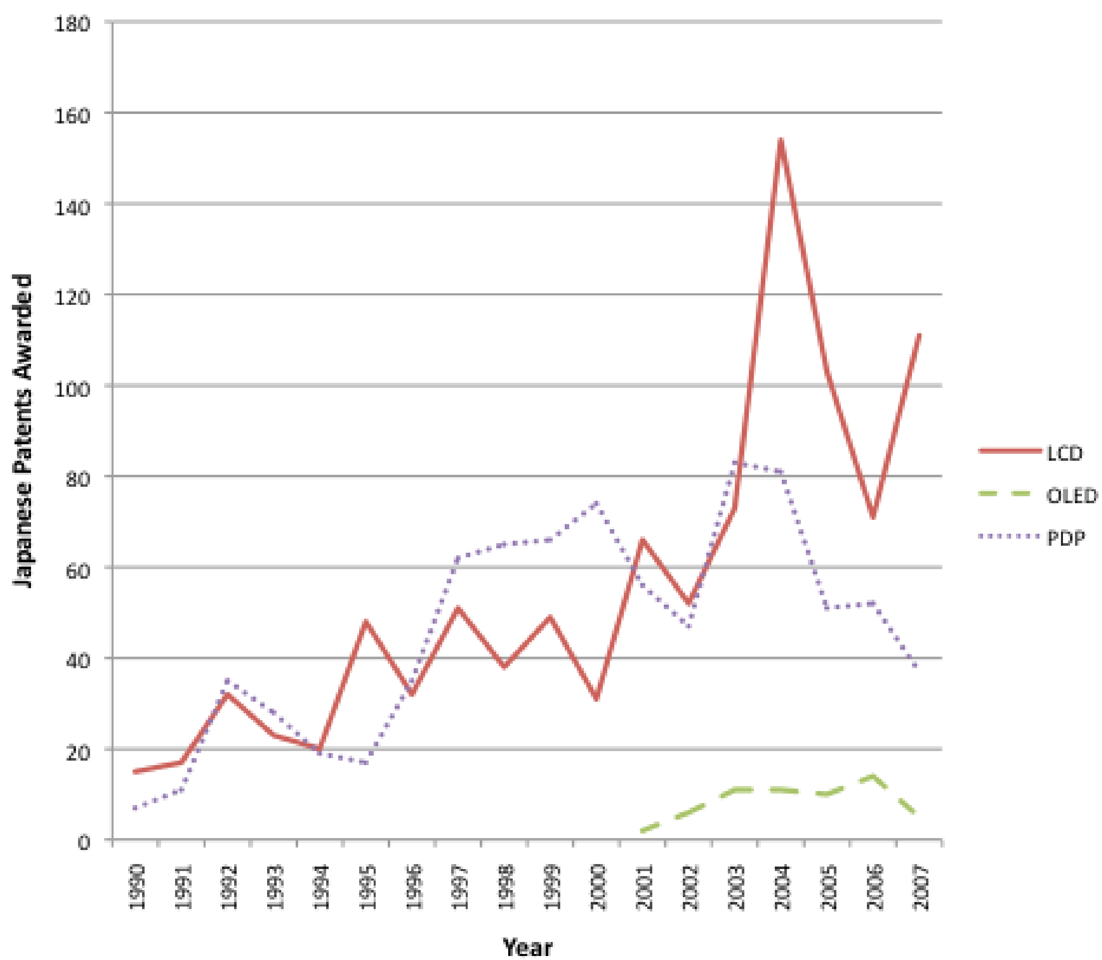
Fujitsu is an information technology firm that has played a significant role in LCD and PDP research and development, although it eventually exited display production in both cases. As a firm without a meaningful TV business, the company is not one of the target companies for this research. However, a brief discussion of the firm is appropriate here because of the technological breakthroughs it achieved. It is also worth considering because Fujitsu is an example of a firm with strong technology options that did not enjoy the full benefits possible from fully exercising these options.

The focus of Fujitsu's development activities was on displays for use in computer, office automation, communication, and factory automation applications, and not for use in entertainment purposes (Sangyo Times, 1994). Nonetheless, Fujitsu was a pioneer in PDP development. The firm played such a prominent role that Japanese national Television broadcaster NHK even produced a documentary on it (i.e., NHK, 2003). It was the first firm to exhibit a video capable color PDP, and it also developed Alternative Lighting of Surface (ALIS), a major PDP technology used later by all major PDP producers. In the area of TFT LCD, Fujitsu was the first to develop vertical alignment (VA), one of the two major LCD modes used in LCD TVs to enable wider viewing angles. It later followed this up with MVA, an improved version that has become widely used in the industry.

Fujitsu did not have a television set business, but is affiliated with another firm, Fujitsu General, that had a domestic Japanese TV set manufacturing and sales business. Fujitsu General was a very small player in the market, both before and after flat panel displays were introduced, but it was an outlet for PDPs when Fujitsu first began production. Fujitsu General became the first company to begin selling PDP TVs in 1996.

As is shown in Figure 5-27, below, Fujitsu began working on PDP before LCD. However, it began producing both technologies around the same time and also exited both in the same year. Patent data shows patenting levels of PDP and LCD were in the same magnitude for most years (see Chart 5-41). Fujitsu formed a joint venture with Hitachi to develop PDP technology, produce and sell PDPs. However it did not work with a partner in LCDs. Fujitsu's investment in LCD production was limited to a pilot LTPS line, and two mass production a-Si lines (see Figure 5-28, Fujitsu Panel Production and Production Lines): one generation 1 and one generation 2.5 line (Fuji Chimera, 1999-2007). These lines used small substrates, and had low production capacities. They would not have been cost competitive for larger displays.

Chart 5-41: Fujitsu Patents



Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

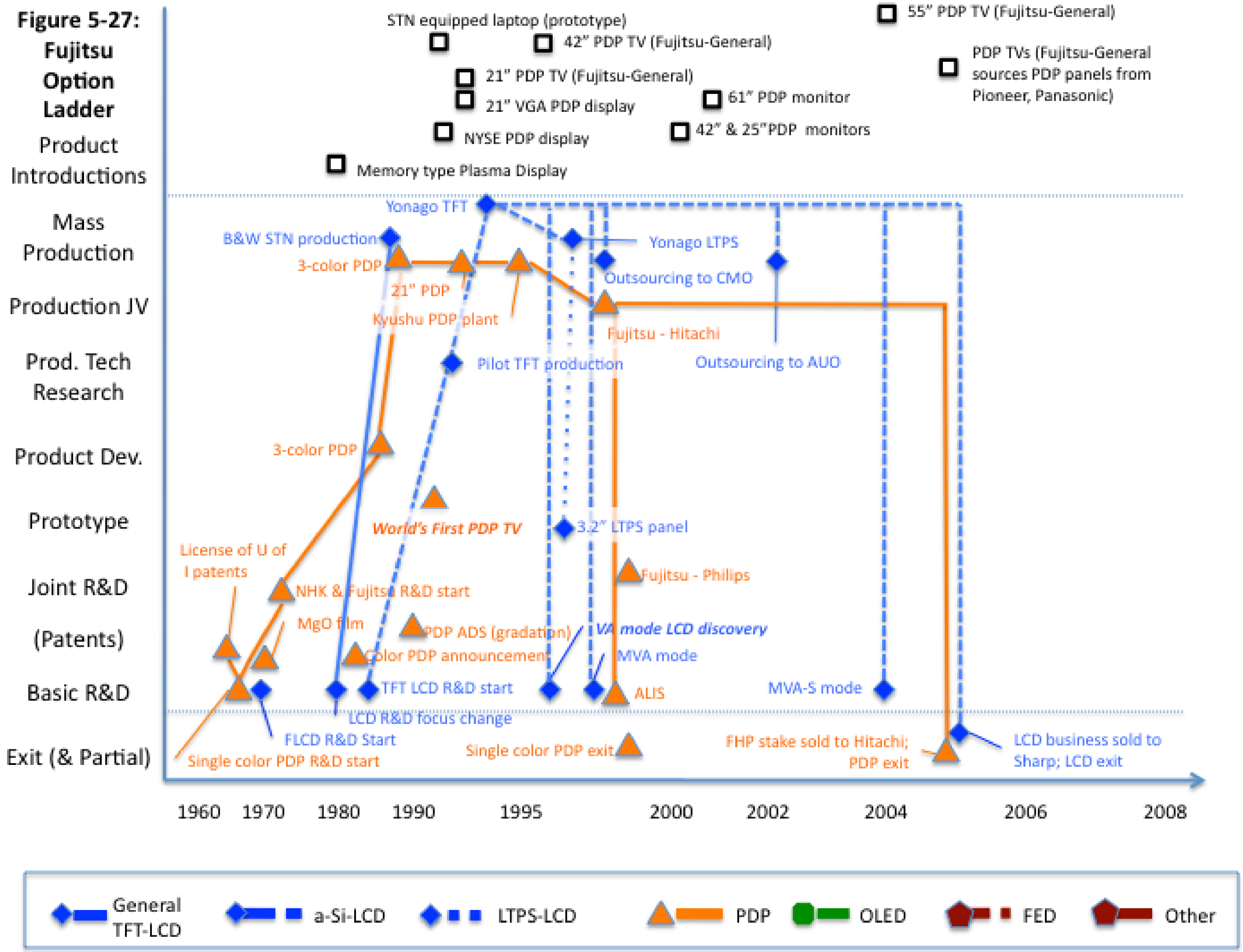
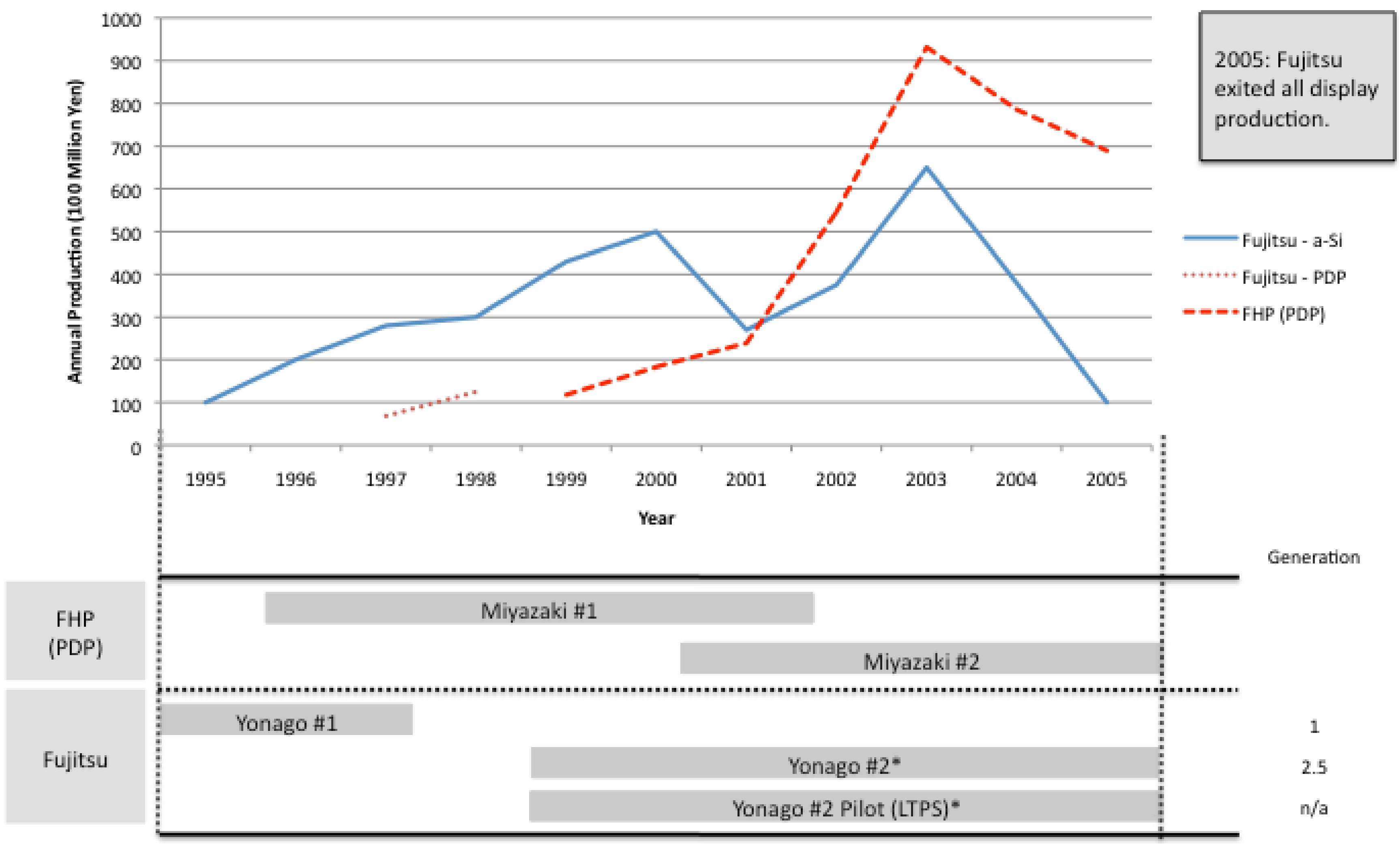


Figure 5-27: Fujitsu Option Ladder
Product Introductions
Mass Production
Production JV
Prod. Tech Research
Product Dev.
Prototype
Joint R&D
(Patents)
Basic R&D
Exit (& Partial)
STN equipped laptop (prototype)
42" PDP TV (Fujitsu-General)
55" PDP TV (Fujitsu-General)
PDP TVs (Fujitsu-General sources PDP panels from Pioneer, Panasonic)
21" PDP TV (Fujitsu-General)
21" VGA PDP display
61" PDP monitor
NYSE PDP display
42" & 25" PDP monitors
Memory type Plasma Display
Yonago TFT
B&W STN production
Yonago LTPS
3-color PDP
Outsourcing to CMO
21" PDP
Kyushu PDP plant
Fujitsu - Hitachi
Pilot TFT production
Outsourcing to AUO
3-color PDP
World's First PDP TV
3.2" LTPS panel
License of U of I patents
Fujitsu - Philips
NHK & Fujitsu R&D start
MgO film
PDP ADS (gradation)
VA mode LCD discovery
Color PDP announcement
MVA mode
TFT LCD R&D start
ALIS
MVA-S mode
LCD R&D focus change
FLCD R&D Start
Single color PDP R&D start
Single color PDP exit
FHP stake sold to Hitachi; PDP exit
LCD business sold to Sharp; LCD exit
1960
1970
1980
1990
1995
2000
2002
2004
2006
2008
General TFT-LCD
a-Si-LCD
LTPS-LCD
PDP
OLED
FED
Other

Figure 5-28: Fujitsu Display Panel Production Volume and Production Lines



Notes: (1) LTPS, HTPS, and OLED production values were zero. (2) * starting year unknown

Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

It may appear puzzling that Fujitsu exited both PDP and LCD businesses given the firm's strong technology development capability.[4] However, these technologies represented growth options for the firm and not strategic options because Fujitsu did not have a major TV business. In other words, Fujitsu's existing businesses were not threatened by display technology uncertainty. The company may not have had sufficient manufacturing know-how to be an efficient producer, or marketing presence to sell its output. Alternatively, continued large investments in production capability may have been unattractive, especially since displays were outside of the company's core business areas. In 2005, Fujitsu sold most of its stake in Fujitsu Hitachi Plasma to Hitachi. In the same year, it sold its LCD operations to Sharp. Fujitsu's 2005 annual report suggests it exited displays where margins were deteriorating rapidly in order to shift resources to its LSI device business that had a more favorable financial outlook.

NEC

NEC is an information technology company that has developed LCD, PDP, and other display technologies. The company had some CRT capabilities before it began working on flat panel technologies. In the past, NEC had a small exposure to TV sets through its consolidating subsidiary NEC Home Electronics. NEC was never a major player in the TV business, and exited the business in 2000. NEC introduced PDP TVs in the late 1990s through this subsidiary prior to exit.

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[4] One informant suggested that several companies, including Fujitsu had gotten into flat panel displays because of strong technology capabilities to find they were out of their league in terms of management capabilities.

NEC has a long history with both LCD and PDP, as is shown in NEC's option ladder in Figure 5-29. It started LCD R&D in 1969, and began producing single color plasma displays in 1971 (Numagami, 1999; Fuji Chimera, 2003). NEC continued to work steadily on plasma technology. In 1981, the company had top market share in plasma displays (Yano Keizai, 1982). As early as 1993, the company was considering establishing a color PDP business (Nikkei BP, 1994). NEC established a display development department in 1987 to focus on developing TFT-LCD for office automation applications (Sangyo Times, 1990; 1993). From this point, it proceeded rapidly, developing TFT displays, building a prototype production line, and investing in a mass production line by the end of 1990 (see Figure 5-30, Production Capacity and Production Volume). It was the first company to sell a laptop with a color TFT screen (Sangyo Times, 1993).

NEC appears to have dabbled with FED for a brief period in the late 1990s, around the time it closed its CRT operations and began work on OLED (Nikkei BP, 1999, 2000, 2005 (Kihon gijutsu hen)). NEC and Samsung SDI later formed a joint venture to develop and produce OLED[5] (Sangyo Times, 2001). In 2004, NEC exited PDP and OLED, selling its PDP operations to Pioneer, and its stake in the OLED joint venture to Samsung (Nikkei BP, 2004 (Jitsumu hen); Sangyo Times, 2005). NEC continues to compete in LCDs. It reduced its exposure to standardized a-Si LCDs through sourcing agreements with CMO (Taiwan) and a TFT-LCD production joint venture with SVA (China) (Sangyo Times, 2003, 2004). With such arrangements in place in 2002, NEC set up a separate subsidiary for its LCD operations, NEC LCD

[5] Samsung SDI was originally a joint venture between NEC and Samsung Electronics established to produce CRTs.

Technologies, and changed focus from office automation displays to high-end niche displays, such as those used for medical applications (Sangyo Times, 2003).

Evidence of Option-like investments

NEC's involvement with PDP and LCD were ongoing and overlapped heavily, and represent options on competing technologies. As NEC was not a major TV producer, options on display technology were not strategic for TV; however LCD and PDP technologies represented strategic options for NEC's substantial CRT monitor business. Patenting data (see Chart 42 below) provides evidence of ongoing R&D investments in the two that are of similar magnitudes.

NEC's options on other technologies were less ongoing. NEC developed an LTPS option early on, but did not produce LTPS during the timeframe for which production data is available; at the same time, evidence suggests it has continued developing the technology. NEC's FED options appear to have consisted of very low cost research on the part of a handful of NEC engineers. The short involvement with the technology was evidently enough to convince the firm the option was not worth further involvement. The relatively rapid increase in option levels relating to OLED suggests NEC was planning to enter the market for OLED displays. However, by establishing a joint venture with Samsung, NEC's investment was option-like with relatively low cost and high flexibility. It was therefore relatively simple for NEC to exit OLED once the decision was made.

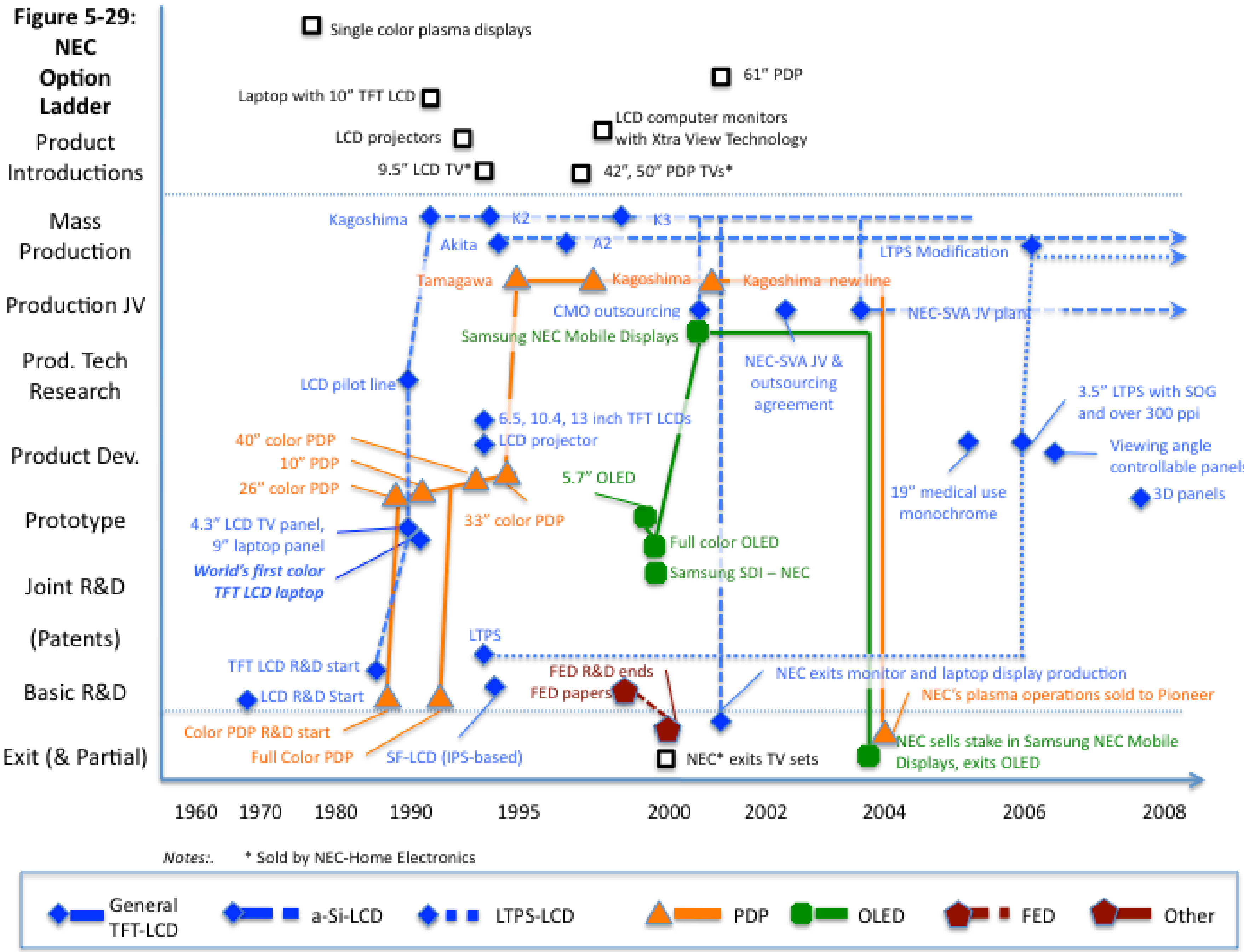
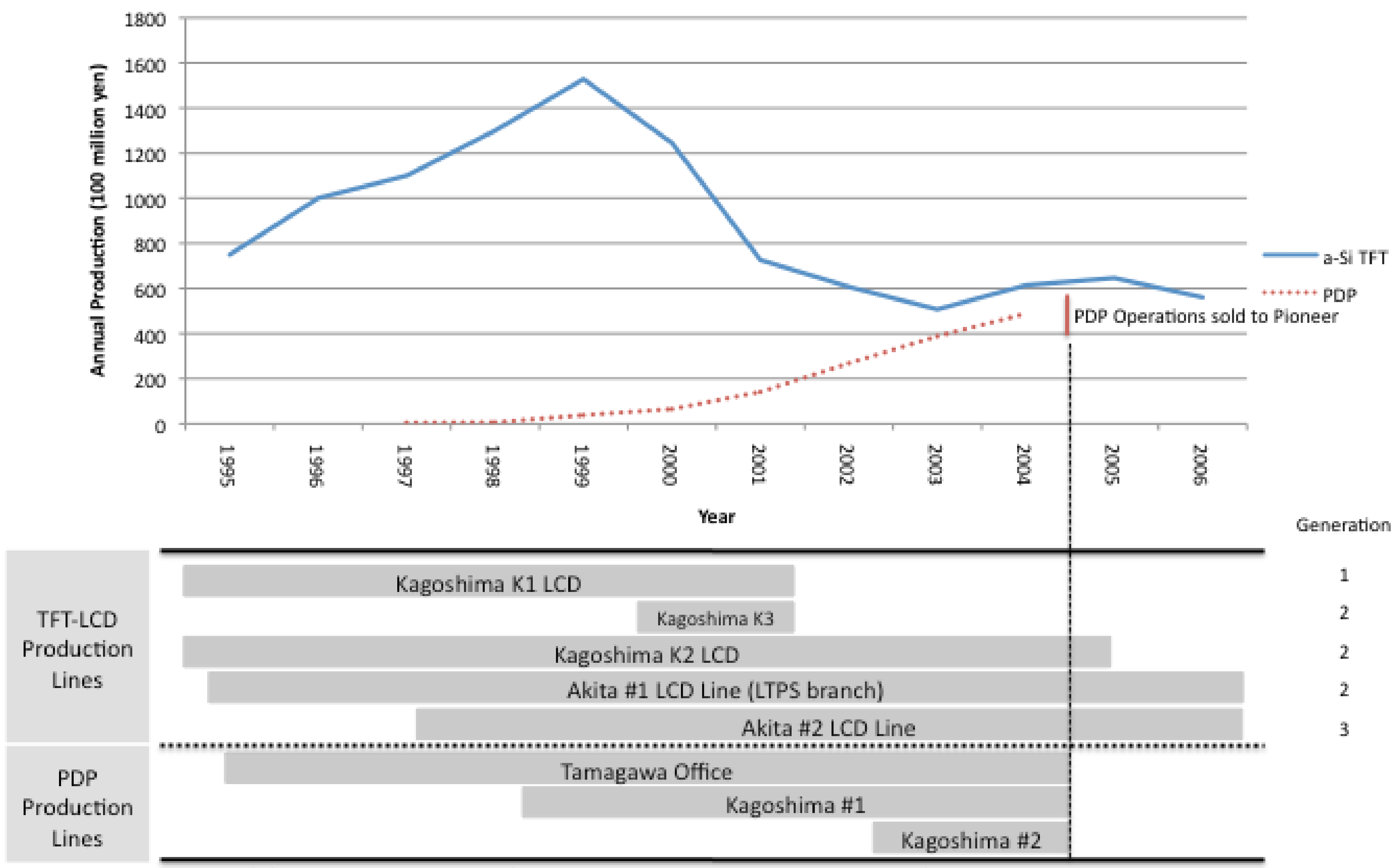


Figure 5-29: NEC Option Ladder

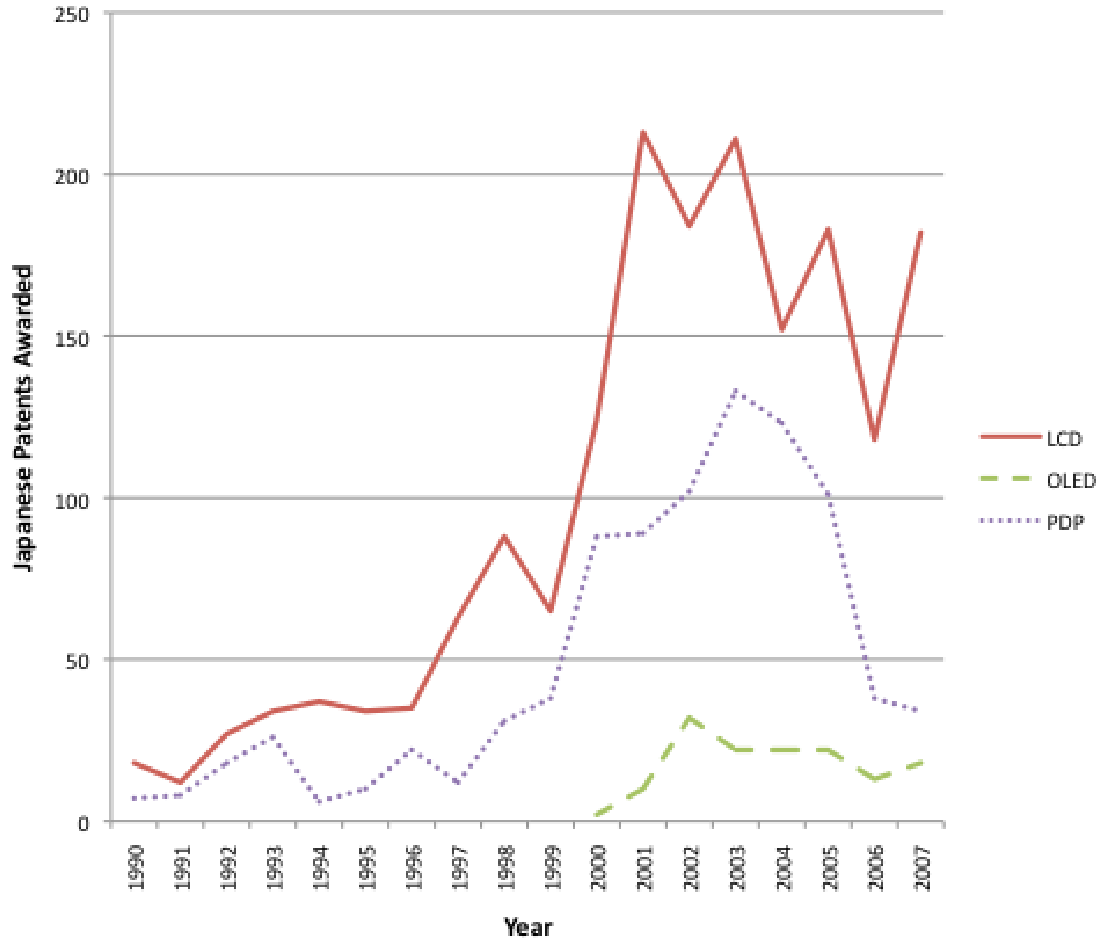
Figure 5-30: NEC Display Panel Production Volume and Production Lines



Notes: (1) HTPS, LTPS, OLED values were zero.
(2) SVA-NEC JV lines and production not included.

Sources: Fuji Chimera, 1998, 2000-2002; 2004-2007

Chart 5-42: NEC Patents

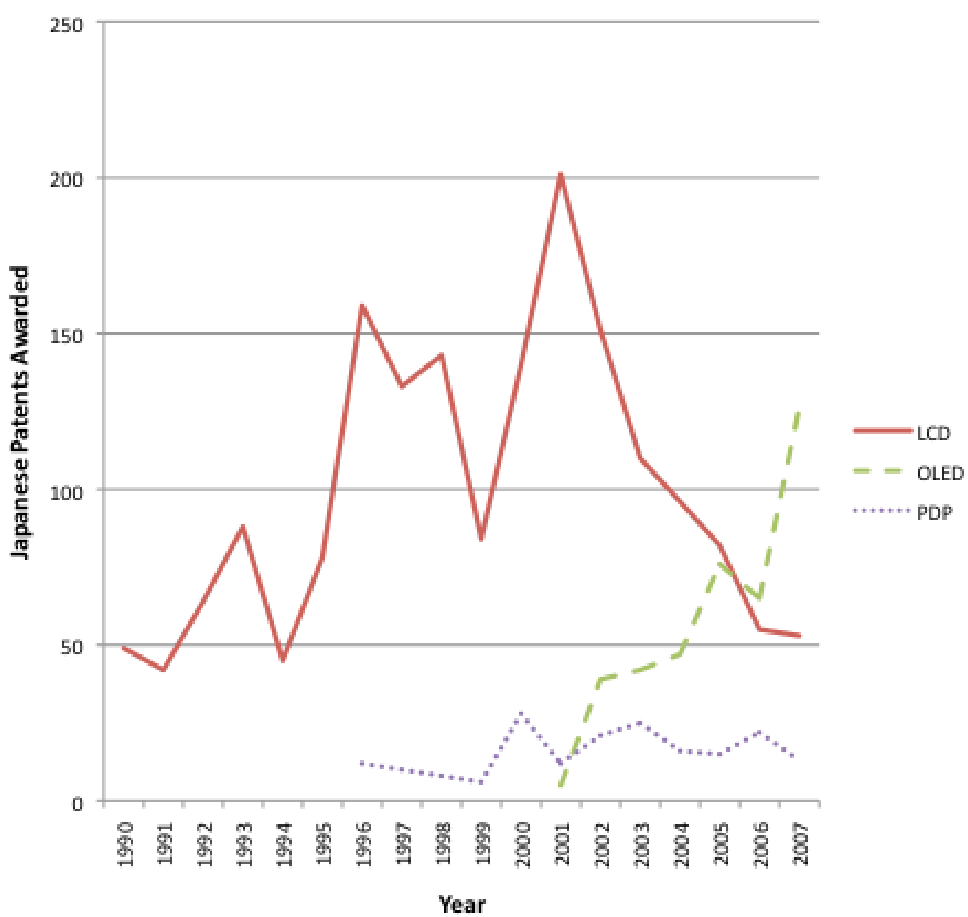


Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

Canon

Canon is relevant to this research because it planned to enter TV manufacturing but did not, even though it developed SED display technology chosen for its suitability for the TV application. Canon has spent substantial time and resources over the years developing display technologies but has yet to build a large-scale production line or make a large-scale market entry using any of them (see Figure 5-31). It is interesting that Canon never developed a TFT-LCD capability despite the fact the firm had knowledge about the mainline LCD technologies. Canon is one of two or three firms producing exposure equipment for LCD production lines (Nikkei BP, 2004 (Jitsumu hen)). Canon's patenting data exhibits a focus on LCD in the past (See Chart 5-43, below). There is a mixture of several things driving this, including the patents related to LCD production equipment, patents relating to their FLCD efforts (likely represented by the middle peak), and potentially patents overlapping from OLED activities.

Chart 5-43: Canon Patents



Note: does not include patents from Joint Ventures.
Source: Extracted from Derwent patent data.

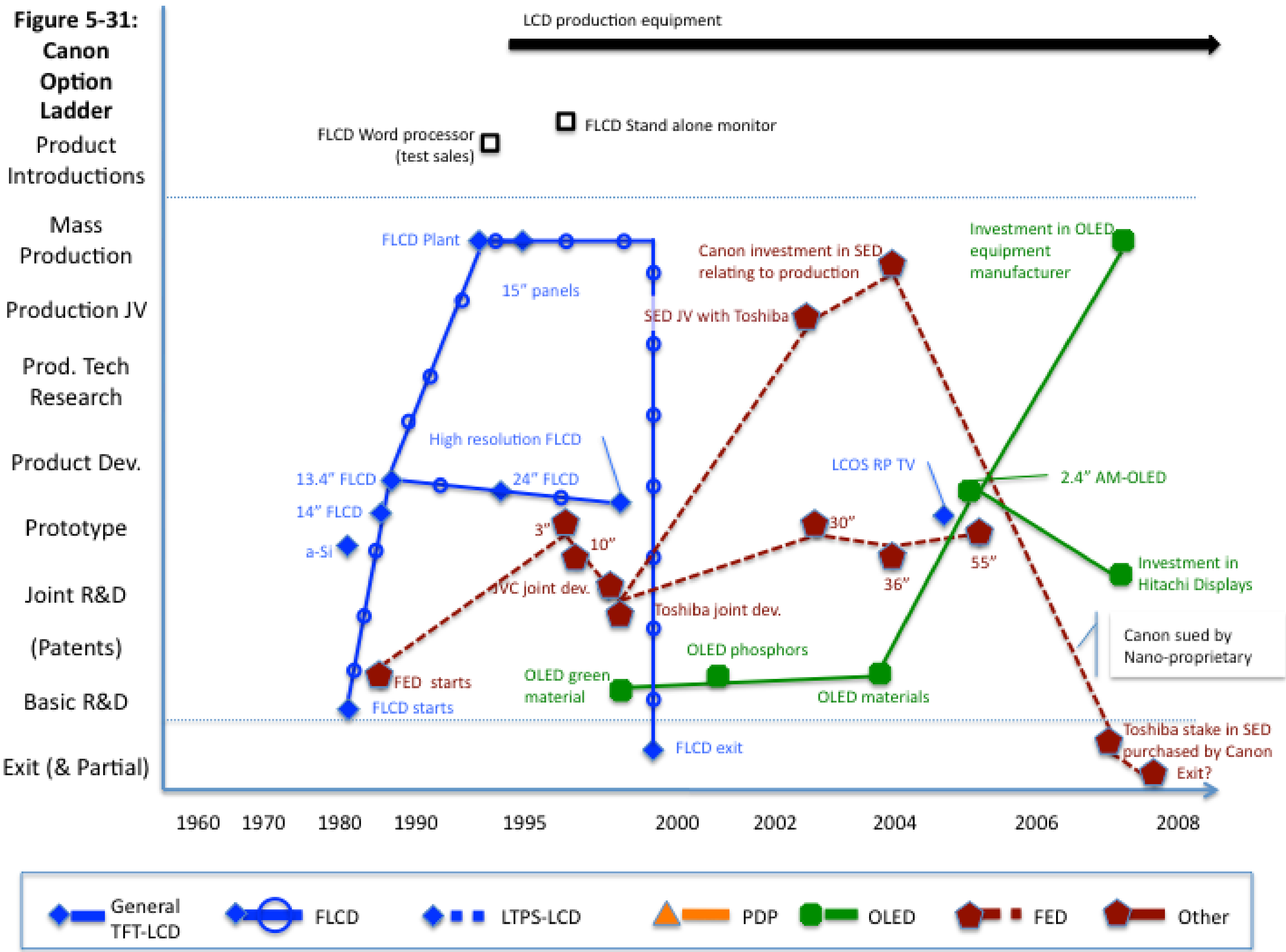


Figure 5-31: Canon Option Ladder

Canon's efforts to develop FLCD technology were aimed at office applications. The goal was to develop a display technology having the benefits of TFT-LCD, but which could be made with lower cost, simpler manufacturing techniques. The display was first used as part of a Japanese word processing system, and was planned for general computer monitor usage (Sangyo Times, 1998, 1999). Canon was successful at producing high-resolution displays with the technology, but it still suffered from short lifespan and limited ability to display gradation (Sangyo Times, 1998; Fuji Chimera, 2000). In 1998, in the face of these limitations together with rapidly declining prices for its competing technology, TFT-LCD, the company discontinued FLCD (Fuji Chimera, 2000).

Canon's experience with SED (surface-conduction electron-emitter display), a type of FED, was focused upon TV applications. Although a number of Japanese firms were interested in FED variants, Canon put more effort into this technology, partnering with JVC, Noritake, and Nippon Sheet Glass, and later Toshiba. Although Canon and Toshiba were able to exhibit a number of successful prototypes, their JV was dissolved after Canon was sued over patent licensing related to the technology. Canon never mass-produced SEDs. Developing SED does not appear to have been a low cost effort; Canon had invested $1.8 billion in SED technology development and manufacturing facilities by 2006 (Consumer Electronics Daily, February 7, 2006).

Canon has also been working on OLED technology. Most recently Canon has started joint work with Hitachi Displays on the technology. Canon's OLED efforts are aimed at small displays.

Canon's efforts to develop these technologies should not be considered to be investments in competing technology options. Investments in the technologies were not parallel, but closer to serial in their implementation. For instance, investment in SED picked up after FLCD had been developed and its future was being called into question. Furthermore, the technologies were not competing for the same (television) application. Although OLED's target is vague, Canon had specific target applications for both SED and FLCD.

Behind Canon's SED development was a strong wish to enter the TV business. Canon CEO Fujio Mitarai stated Canon planned to enter TV manufacturing because of convergence, which would result in the television set being the heart of a networked home. Another reason given was that Canon wanted to leverage its strength in other imaging related products (cameras, etc.) that can be connected to the TVs (Sangyo Shimbun, 2004). Interviewees did not discuss Canon in particular, but did stress the importance of television for consumer electronics companies. They typically believe television is the "face" of the company to consumer households.

Canon had another approach to television that is less well known. Canon is reported to have developed LCOS technology to use in rear projection televisions (Sangyo Shimbun, 2005). Canon exhibited a 64" RPTV in 2005, but stated in 2006 it was reconsidering its plan to enter the market for rear projection television, as the future for RPTV appeared questionable (Nikkan Kogyo Shimbun, 2006). Canon did use the LCOS technology for front projectors – typically for business applications.

Canon's technology options and performance

Canon did not invest in multiple competing display technologies in the face of technological uncertainty. Rather, Canon identified technologies it believed would be optimal for a specific applications, and focused its investments on these. It appears that Canon tried to outsmart uncertainty. Unfortunately for Canon however, both FLCD and SED appear to be failed technologies at this point in time.

Although Canon made use of joint R&D and manufacturing JVs it is not apparent flexibility was the motivation for these arrangements. Rather, it may have been reduction of required investment and or access to capabilities of the partner firms. This interpretation would certainly fit for Canon's partner in SED, Toshiba. With no experience in building a TV set, Toshiba's TV background would have obvious value to Canon.

In Canon's case the relevant performance metric is market entry. Canon failed to enter the TV set market even though it had intended to do so and had specifically developed SED technology for this purpose. Canon's SED bet was unlucky. The firm invested heavily and was unable to commercialize the display technologies it developed or enter the market it had targeted.

Chapter Conclusion

This chapter presented firm level case studies analyzing historical evidence of option-like investments in display technologies by the firms studied. It also evaluated performance data for each of the firms. Although between case analysis is performed in the following chapter, there are several observations that can be made at this point. First, none of the firms focused exclusively on one technology over the study period. Second, although a number of firms appear to have tried to use investments in display technologies to become more prominent players in the industry, this strategy does not appear to have worked over the longer term, with the single exception of Sharp.

The following chapter investigates aspects of the options portfolios held by the firms and searches for evidence of performance implications. It also performs pairwise analysis of several firms of interest. In particular it tries to identify what made Sharp - the only firm to realize long term performance benefits based on its investments in display technologies – different from other firms.

CHAPTER SIX: BETWEEN CASE ANALYSIS

The purpose of this chapter is to compare the firms studied in the previous chapter to uncover patterns of difference and commonality between the firms' option portfolios, commitments, and the outcomes achieved. In examining patterns in the data, this chapter searches for evidence the firms studied as a group did or did not behave as real options logic suggests they should. It also examines performance outcomes coinciding with different patterns of option like investments across firms.

Variation observed between firms studied ranged from the readily apparent to the nuanced. On the most basic level of real option related behavior, one TV set producing firm did not develop any display technology options at all, but rather waited for uncertainty to resolve itself. Three firms developed options on seven display technologies and committed to production of several. The rest of the sample exhibited behavior between these two boundaries.

Option portfolios and management of options differed along several dimensions in the firms studied. Firms that developed options exhibited differences in the breadth (number of technologies developed) and depth (levels in the option ladder) of the options portfolios they developed and maintained. Timing of option development, exercise, and abandonment also differed between the firms.

Single-firm options ladders presented in the prior chapter provide visual representation of options depth and breadth. This chapter develops summarized data based upon that in the prior chapter to allow more ready comparison. The following discussion begins with breadth of the options portfolios, and then building on this, examines depth of the portfolios. Having considered these two dimensions, the chapter discusses the aspect of timing. Timing is considered in terms of option execution timing as well as the pathways followed in developing technology options – serial and parallel. In the process of examining these different aspects of options behavior, breadth, depth, and timing, patterns of performance are searched for and the observed behavior is compared with that predicted by real options logic. Finally, the top incumbent Japanese TV set manufacturers are compared, in pair-wise fashion, with competitors that attempted to dramatically improve their positions in the TV set business through applications of flat panel technologies.

Brief Chapter Summary

Overall, the analysis in this chapter suggests firms behaved as predicted by real options reasoning, however performance benefits were difficult to observe. Target firms of this study developed options on more than one display technology, in agreement with the predictions of real options reasoning. In terms of the breadth of options portfolios, or number of technologies developed, those firms with the broadest option portfolios were also high performing firms. However, other high performing firms had narrower portfolios. If there is a relationship between number of options held and performance, the direction of causality is unclear. Analysis of the depth of options portfolios – deeper options being those including investments higher up on the options ladder – did not uncover a relationship between option portfolio depth and performance. Timing of option exercise was also analyzed, however no relationship between timing and firm performance was identified.

Analysis of outliers found top incumbent firms Panasonic and Sony suffered temporary performance decreases as flat panel TVs started to grow in the market, however both firms were able to regain their positions later in the study. The strong market power of these firms appears to have facilitated their recovery. Pioneer and Sharp were notable challengers to the incumbent top firms. Pioneer committed to PDP technology, and enjoyed a period of strong performance but was unable to compete in the long run and eventually exited PDP and TV set manufacturing. Sharp stood out as the only firm able to turn its technological advantage into a durable performance improvement. Sharp had a significant lead in LCD technology compared with competitors, and also stood out for regularly making large investments in cutting edge production facilities, unlike its Japanese competitors.

Option portfolio breadth

The breadth of options portfolios developed by companies studied varied greatly. On the low end, one firm developed no options. On the high end, three firms developed options on seven display technologies, including different Liquid Crystal related sub-types (e.g., a-Si, HTPS, LTPS, LCOS). These sub-types are related, but differ enough that they should be considered distinct for this analysis. Some knowledge and production capabilities are relevant to more than one of these subtypes, but each requires some distinct knowledge and at least some specialized production equipment. To get a full picture of breadth of technology options held by each firm, two measures are required – one counting each technology and the Liquid Crystal sub-technologies, and another of the total non-liquid crystal technologies. It is possible to have a portfolio of display technology options appear broad in number but entirely liquid crystal-related. On the other hand it is also possible to hold a portfolio of options on display technologies that share little in common. Such a portfolio might include only one or no liquid crystal related technologies. These approaches are different; therefore, the ability to compare the two provides a clearer picture of the relative breadth.

Table 6-1, below, lists both portfolio breadth measures and summaries of performance in TV and display businesses for each of the firms studied. Note that these measures do not provide information about the depth of the options in question, which will be discussed later in this chapter. Also note that some of the options represent very small investments whereas some are very large.

The firms developing the largest number of options by either measure were Panasonic, Sharp, and Sony. Each of these firms has exhibited growth in the TV and display businesses, although in different ways. Sony and Panasonic initially lost market share to other firms that moved more quickly into flat panel TV, however, both firms regained their positions in the market. Sharp was a small player in CRT TV, but has emerged as a major LCD TV player and display manufacturer. Sharp has played a pioneering role in development and growth of LCD TV. It no longer commands the TV market share it did earlier as other firms have entered, or as in the case of Sony and Panasonic, existing firms have greatly strengthened their product offering and branding activities. Nonetheless, Sharp stands out as the only firm in the study that was able to parlay its technological capability into lasting increase in market share.

Table 6-1: Option Portfolio Breadth

Firm	Total display options identified	Non-LC display options	TV market performance	Display business performance
Funai	0	0	Insufficient access to LCD panel supplies	n/a
JVC	2	1	Partial exit	Continued operations
Thomson	2	1	Exit	Exit
LG Group	3	2	Sustained growth	Continued growth
Pioneer	3	3	Partial exit	Exit
Fujitsu	3	1	Short term share increase followed by exit	Exit
Canon	3	2	Failed to enter TV market	Continued development
Hitachi	4	2	Short term share increase, not sustained	Exit from large displays; continued small display operations
Sanyo	4	2	Continued operations, continues to be minor player	Exit
Samsung	5	3	Sustained growth	Continued growth
Mitsubishi	5	2	Continued operations, continues to be minor player	Exit
NEC	5	3	Exit	Exit from large displays; continued small specialized display operations
Toshiba	6	3	Continued operations, continues to be middle ranking player	Exit from large displays; continued small specialized display operations
Philips	6	3	Partial exit	Exit from large displays; continued small specialized display operations
Panasonic	7	4	Short term share loss followed by recovery of market share	Continued growth; Increasing investment in large displays including LCD (IPS Alpha) and PDP
Sharp	7	4	Long term share increase; sustained growth	Continued growth
Sony	7	4	Short term share loss, followed by recovery of market share	Increased involvement. Investment in LTPS/OLED; Production JVs for large LCD

Note: LCOS, HTPS, LTPS, a-Si, DLP, FED, PALC, PDP, OLED, EL considered separately in total display options.

Firms other than these three exhibit the entire spectrum of performance outcomes. Thomson and JVC had relatively narrow options portfolios and exited or partially exited the TV business. On the other hand, NEC and Philips also exhibited similar performance outcomes despite having much broader portfolios. LG Group had a relatively narrow portfolio but has exhibited strong performance in TV and display businesses.

Taken together, firms with the widest option portfolios exhibited high performance, but there is no discernable relationship between option portfolio breadth and performance for the rest of the sample. Also, several high performing firms such as Samsung and LG had high performance with narrower options portfolios than Panasonic, Sharp, and Sony.

The nature of the relationship between option breadth and performance is unclear. Panasonic, Sharp, and Sony may have managed their technology options well and benefitted from the flexibility. On the other hand, it may simply be coincidence that the firms holding the widest portfolios all had high performance. Alternatively, prior high performance may have fueled the ability to develop broader than average portfolios. It appears logical that firms that had suitably-timed options on a-Si technology should have performed well even if their portfolios were not wide. However, Sony's experience questions this line of thinking. Sony only developed access to a-Si production well after the market had already grown and did so through joint venture arrangements. Sony's performance suffered for some time before it entered these arrangements, but appears to have rebounded.

Several other points are worth discussing before proceeding to the next section. First, it is interesting that Sharp should be in the group of firms with the broadest portfolios given its strong commitment to LCD. Sharp's public image as *the* LCD company and its aggressive investments in a-Si production – where Sharp is often the first firm to build a new generation line – would appear to imply the firm is not involved in other display technologies, but this has not been the case. Sharp held options on FED, OLED and PALC, and produced EL displays for a number of years. Second, in contrast to Sharp, Sony's wide portfolio seems to "fit" with its approach to flat panel displays. Sony has been critical of the quality of several technologies including a-Si. Sony has kept its options open. Its investments in a-Si have been limited to JVs, with a clear focus on reliable procurement of high quality LCDs for its TV business. Sony appears to have been actively searching for a display technology superior to a-Si that would also provide it the opportunity to develop and maintain a proprietary capability.

This section examined and compared the breadth of technology options portfolios held by the firms studied. Another important aspect of options is their level, or depth, in terms of their position on the options ladders discussed in the prior chapter. The next section considers the depth of options portfolios held by firms.

Option portfolio depth

The firms studied exhibited large variation in the depth of options portfolios in addition to breadth discussed above. The option ladder graphically depicts the depth levels of options. To allow for ready comparison, the depth data shown in each firm's option ladders must be simplified and summarized. The number of technology options can be measured at a number of different levels on the option ladder. However, counting the number of technologies a firm has invested in mass-producing is a readily interpretable measure of depth when considered in conjunction with the total number of technology options developed by the firm. Table 6-2, below, provides the number of technologies in which each firm invested in mass-production capabilities for (including investments in production joint venture). It also shows how many of the technologies each firm exited production. The total breadth, as well as TV and Display business performance data is identical to that in Table 6-1 and is included to aid interpretation.

There is no readily identifiable pattern between number of technologies mass-produced and performance. Firms with broader options portfolios have opportunities to invest in producing in greater numbers of technology types; accordingly there is some correlation between these two measures. However, high and low performing firms are interspersed without relationship to the relative depth of the options held by the firm in question.

Real options logic suggests firms hold options open under uncertainty, but execute or exit options as uncertainty decreases. As uncertainty decreases, some options lose value and others gain value. Those gaining would be more likely to be executed and those losing would be candidates for abandonment. Through this process, real options logic suggests holding many lower cost options, and executing only a relative few. Real options logic would therefore predict options portfolios be characterized by being broad at the low levels, and deep for only a small subset of the total options the firm holds. Of all the firms holding options, none committed to as many technologies as it held options on. This is in agreement with real options logic. As far as performance goes, however, no pattern could be identified. There was no discernable relationship between the tendency to make commitments and performance.

Table 6-2: Depth of Technology Options

Firm	Total display options identified	Total mass production displ tech. types	Production technologies exited	Partial exits of production technologies	TV market performance	Display business performance
Funai	0	0	0		Insufficient access to LCD panel supplies	n/a
Thomson	2	0	0		Exit	Exit
JVC	2	1	0		Partial exit	Continued operations
LG Group	3	2	0	OLED not at mass production level	Sustained growth	Continued growth
Pioneer	3	2	1		Partial exit	Exit
Fujitsu	3	2	2		Short term share increase followed by exit	Exit
Canon	3	2	2		Failed to enter TV market	Continued development
Mitsubishi	5	2	2		Continued operations, continues to be minor player	Exit
Philips	6	2	1	Retains minor LCD capability	Partial exit	Exit from large displays; continued small specialized display operations
Panasonic	7	2	0		Short term share loss followed by recovery of market share	Continued growth; Increasing investment in large displays including LCD (IPS Alpha) and PDP
Hitachi	4	3	1	Partial exit of additional production tech	Short term share increase, not sustained	Exit from large displays; continued small display operations
Sanyo	4	3	3		Continued operations, continues to be minor player	Exit
Samsung	5	3	0		Sustained growth	Continued growth
Toshiba	6	3	1	Unclear if a-Si exit is complete or partial	Continued operations, continues to be middle ranking player	Exit from large displays; continued small specialized display operations
Sharp	7	3	1		Long term share increase; sustained growth	Continued growth
NEC	5	4	2	Partial exit of a-Si	Exit	Exit from large displays; continued small specialized display operations
Sony	7	5	0		Short term share loss, followed by recovery of market share	Increased involvement. Investment in LTPS/OLED; Production JVs for large LCD

Note: LCOS, HTPS, LTPS, a-Si, DLP, FED, PALC, PDP, OLED, EL considered separately.

The value of an option changes with the level of uncertainty and therefore is not constant over time. In the next section, time will be considered further.

Timing of options

Timing has a large impact on the value of real options. To obtain maximum benefit from developing and maintaining options, firms need to execute them at the most opportune time and in the right scale.

Figures 6-1A and B show building, startup, and shut down of a-Si LCD lines over time by focal firms by line generation. To simplify presentation, middle generation lines were grouped together with the earlier generation (for example generation 7.5 was included in generation 7). Figures 6-2A and B provide similar data for PDP lines of focal firms. Unlike LCD, PDP production lines do not have defined generations. Figure 6-3 shows production start dates of PDP plants by substrate size, providing some indication of production capability. In both LCD and PDP, data on new line startup is publicly available, and final shutdown of production lines is generally clear from the historical record as well. Announcements of construction starts and plant modification are not always made public and are therefore imperfect. Data is limited for a small number of early LCD lines that were started in the late 1980s through 1992. These lines are depicted in a section below Generation one on Figure 6-1A. Such lines were generally prototyping and R&D lines and were not capable of large-scale mass production.

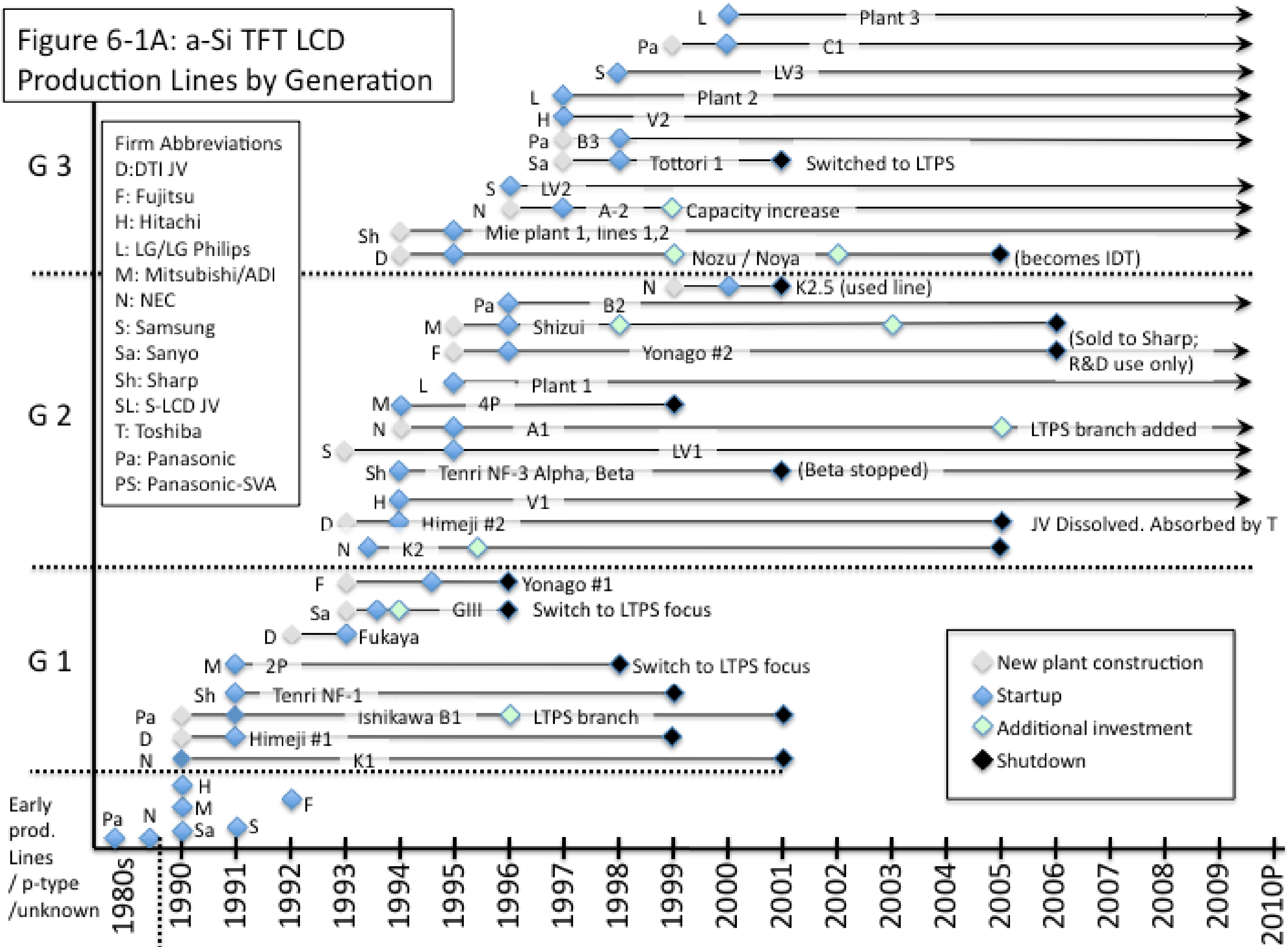


Figure 6-1A: a-Si TFT LCD Production Lines by Generation

Note: intermediate generations are handled as follows: 2.5G -> 2G; 3.5G->3G; 5.5G-> 5G; 7.5G-> 7G.

Figure 6-1B: a-Si TFT LCD Production Lines by Generation

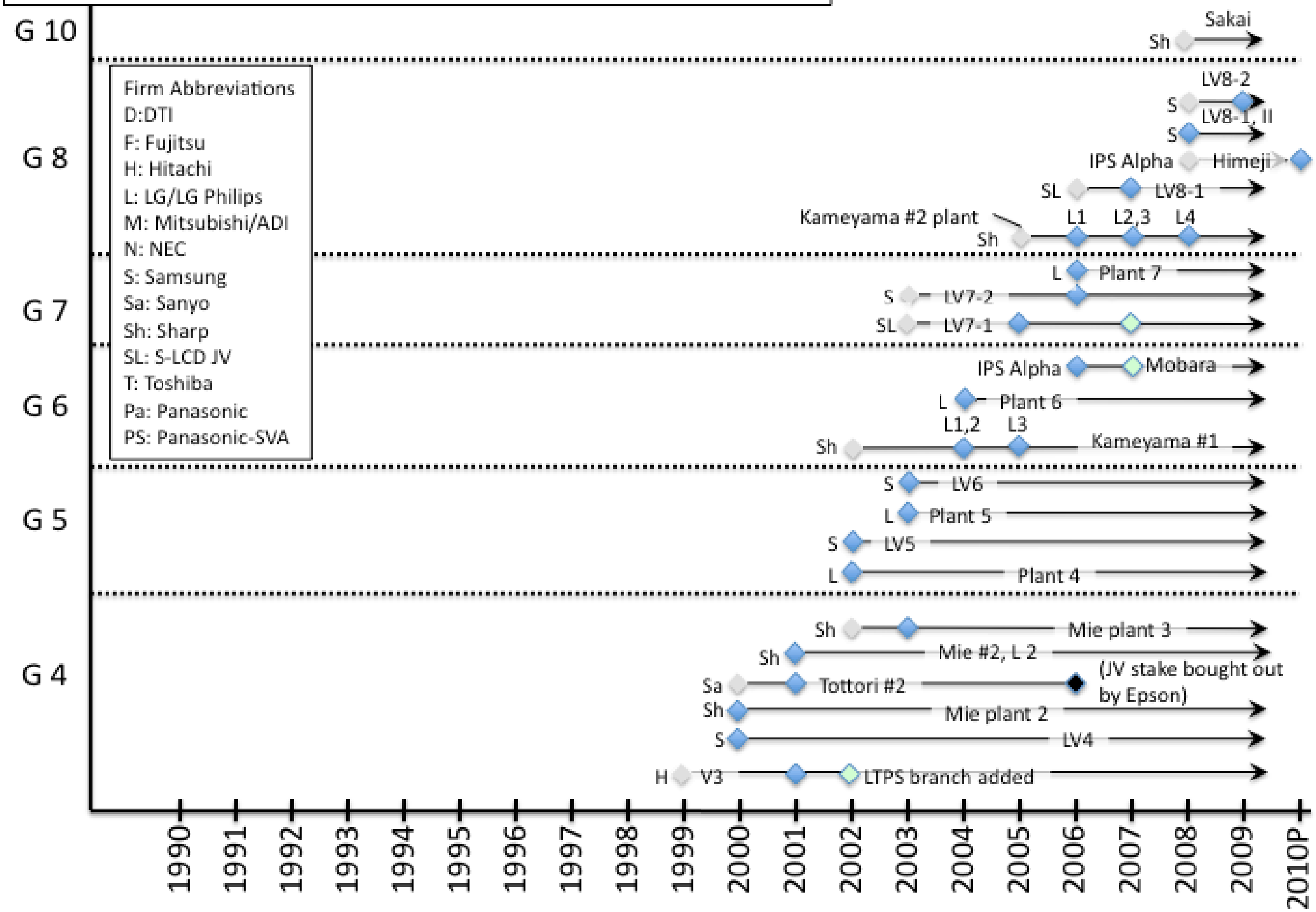


Figure 6-2A: PDP Production Lines

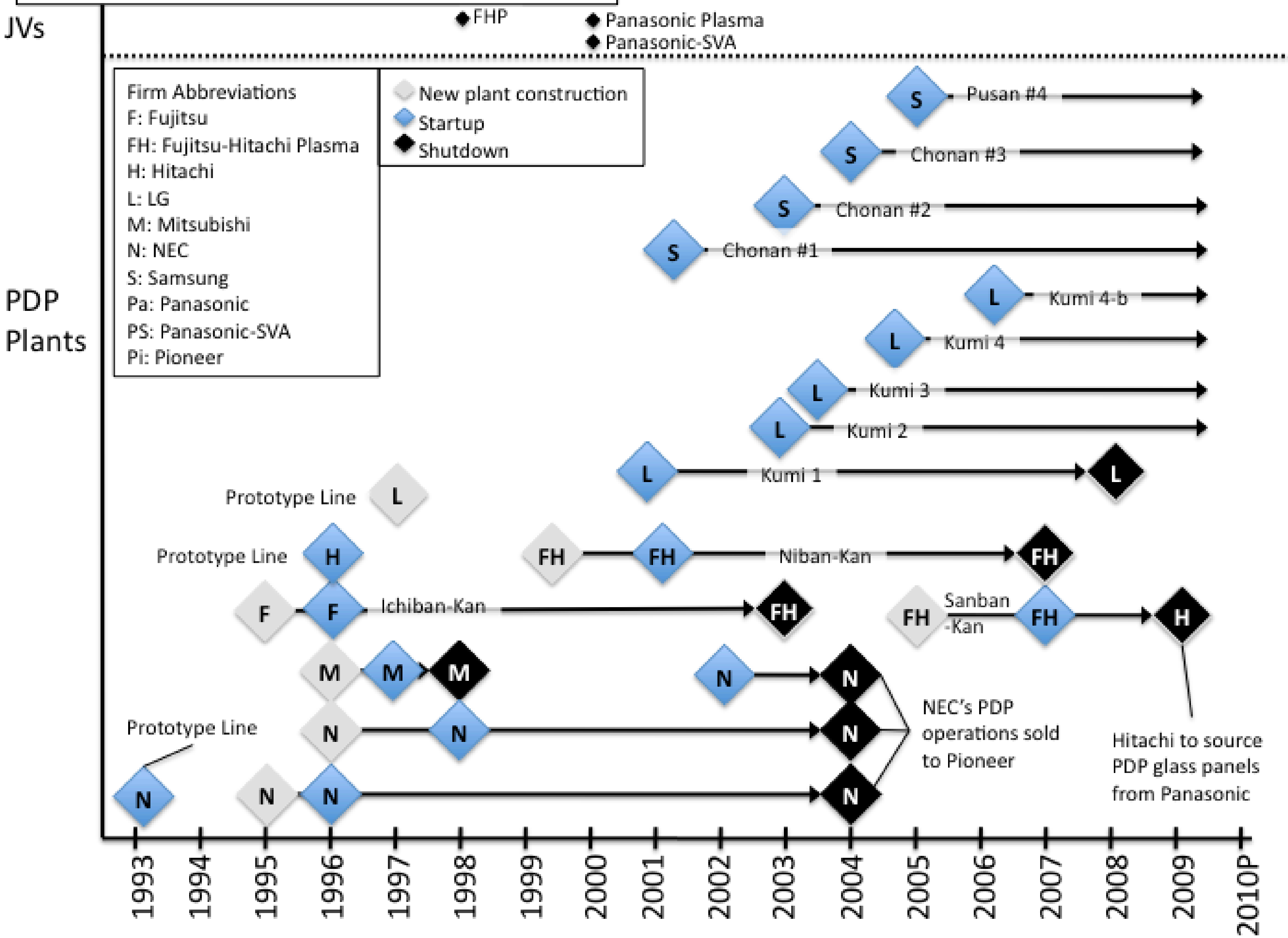


Figure 6-2B: PDP Production Lines

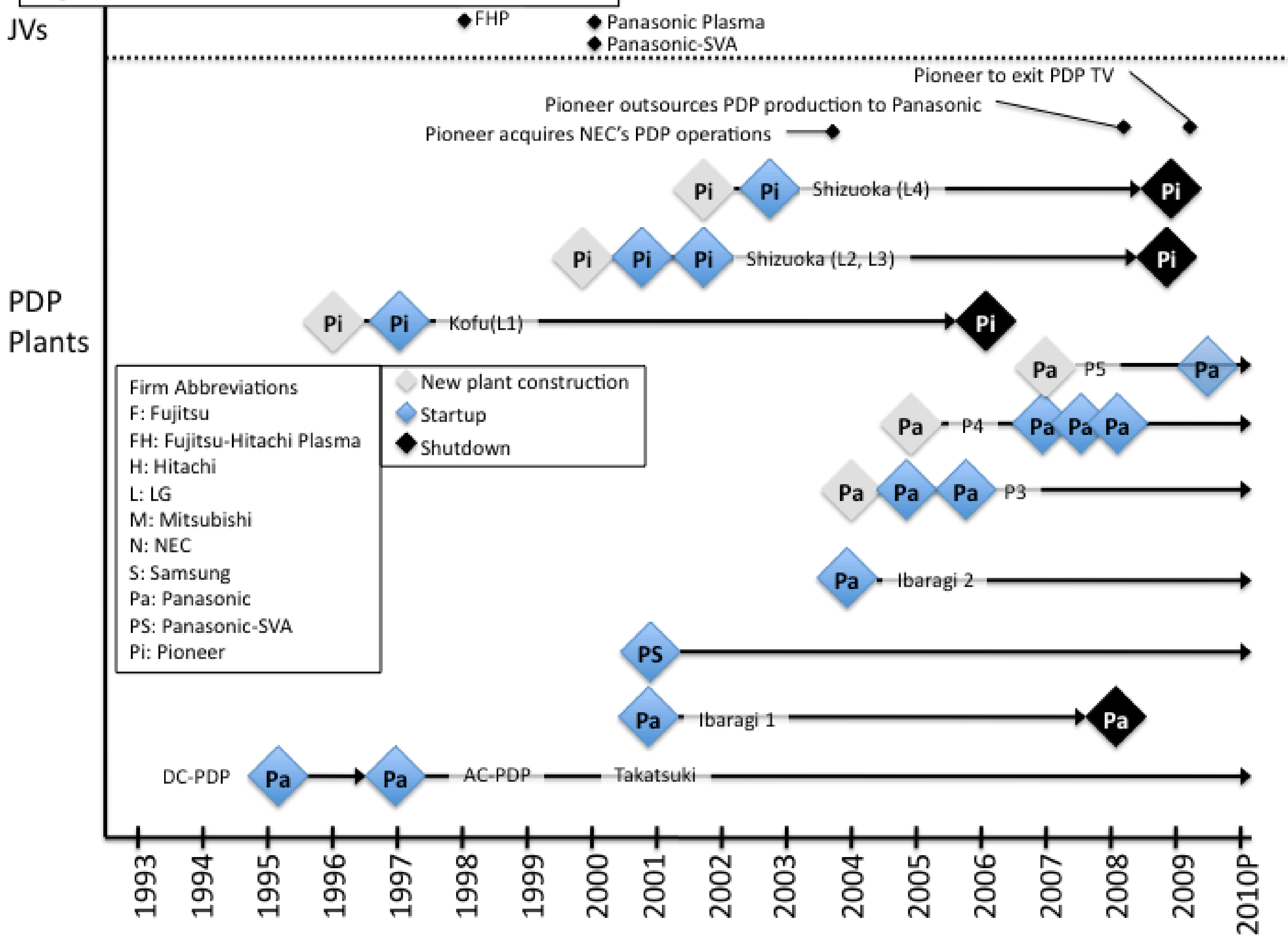
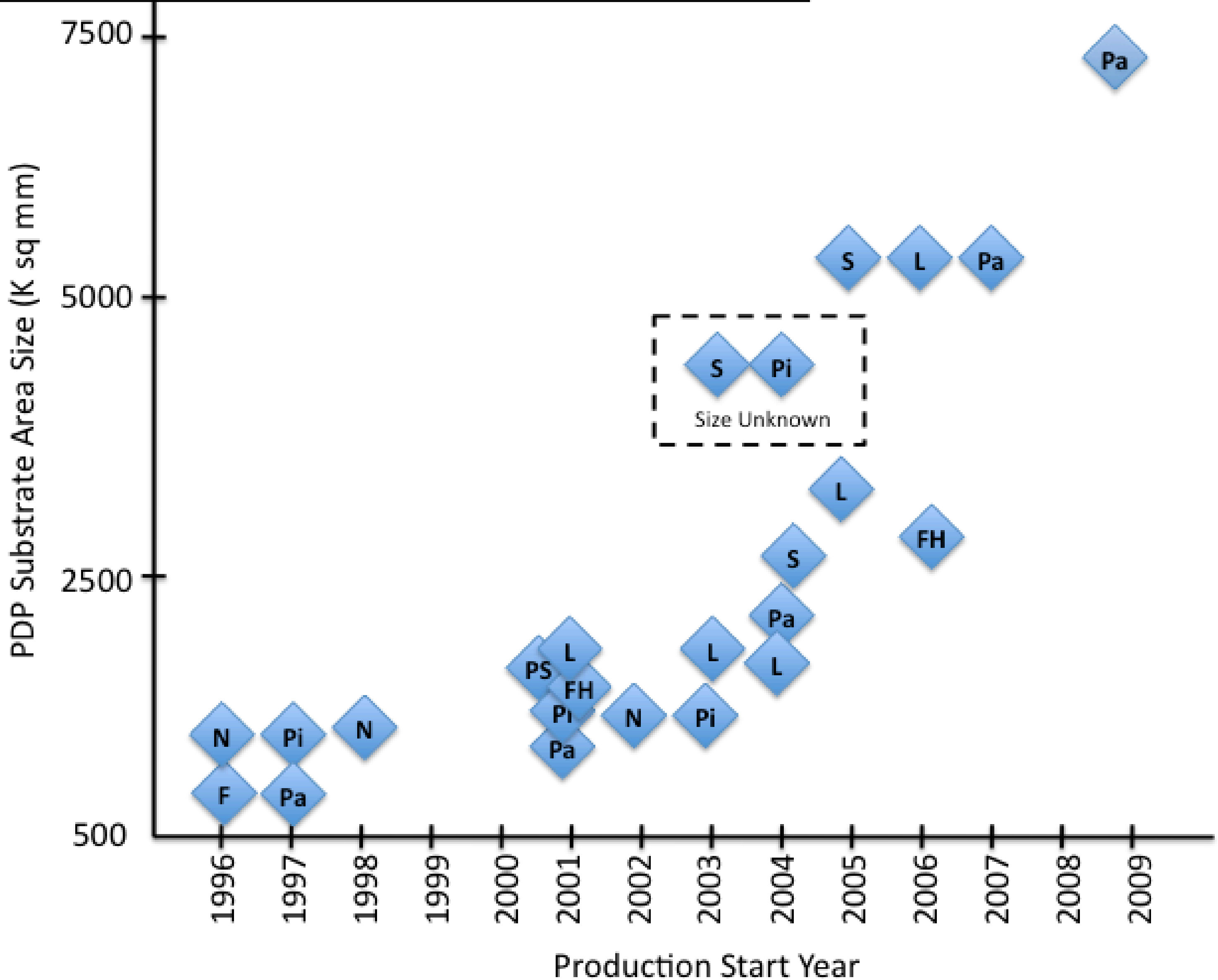


Figure 6-3: PDP Production Lines by Substrate Size



Early LCD entrants were generally from one of two industry backgrounds: IT and consumer electronics. IT firms included Fujitsu, NEC, and Toshiba. These firms were interested in obtaining sources of displays for laptops. Consumer electronics firms appear to have had different reasons for entering; some had longer-term TV aspirations. Several firms were active in both IT and consumer electronics, including Hitachi and Mitsubishi. As the industry developed, panel types used in very large volume, in particular those found in computing applications, became commoditized. Over time, the production of such commodity LCD panels moved largely from Japanese firms to other producers, in particular Taiwanese and Korean firms. The reasons for this shift appear to include both size of investment requirements and willingness to take risk in the face of the crystal cycle. Computing firms have either exited flat panel production or focused upon developing displays that meet the needs of small niche applications.

Early generations of LCD production had option value relating to capability development and product output. Some generations provided more flexibility in potential product markets than others. The earlier generation plants run by Japanese firms were incapable of making large displays. On the other hand, the latest generations using largest substrate are *only* suitable for making very large displays. In particular, generation ten lines are only suitable for TV production.[1] The middle generations provide the greatest variety of potential applications. Investments originally intended for laptop display production were also used to produce displays used in portable TVs, music players, cell phones, navigation systems, and many other applications.

[1] In person interview with Tsuyoshi Numagami, March 13, 2009.

LCD plants up to and including generation 5 provide additional flexibility because they can produce LTPS as well as a-Si panels with modifications. Larger generation plants do not have this flexibility because some of the required equipment has been deemed too large and difficult to make by production equipment manufacturers.[2] While middle generations allow display makers to keep options open in terms of display application markets, later generations are increasingly committed to the TV market. Plants integrating panel and TV set production, such as Sharp's Kameyama plant, are evidence of TV set commitments. These newer generation plants capable of producing with large substrates also require much greater investment than earlier generations.

The only Japanese firms investing in a-Si production capacity past generation 5 were Sharp and IPS Alpha. Korean and Taiwanese firms have invested much more aggressively in newer generations. In the midst of strong competition from Korean and Taiwanese firms, Sharp moved to a closed innovation model with the goal of developing proprietary technologies to reduce production cost.

The historical development overview depicted in Figures 6-3 and 6-4 fails to uncover a clear relationship between investment timing and performance. Many but not all early movers exited the market. Firms surviving in the end were a mixture of early movers and followers.

To further examine the data, firms were placed into three groups based upon timing of a-Si entrance and compared using option data discussed in the sections above. The first group included early entrants into a-Si production defined as those firms that

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[2] Ibid.

invested in Generation one or early production facilities. The second group was comprised of firms that entered a-Si in later generations. The third group of firms did not enter a-Si. Table 6-3, below, provides means of the number of technology options generated and technologies mass produced for these three groups.

The groups differed in a number of ways including the mean number of technology options held, the propensity to produce flat panel displays through joint ventures, the likelihood of exiting production, and performance. Firms that developed or obtained a-Si TFT LCD production capabilities had larger mean numbers of display technology options than those that did not regardless of the measure used. With the exception of Sharp, firms that produced a-Si all had joint venture arrangements relating to flat panel display production.[3] On the other hand, firms without a-Si TFT LCD production were much less involved with joint ventures; Pioneer was the only firm in this group to have related JV arrangements. These arrangements were limited and not central to large flat panel production. Late movers mass produced, on average, more types of display technologies, but were less likely to exit production. The reduced likelihood of exit makes sense as these firms waited until uncertainty levels fell before investing.

Performance in the TV set business and display business of those firms having no a-Si production exposure was low across the board. However, it was mixed for the early and late mover groups. Based upon this data, it is difficult to say what timing would have been ideal even in retrospect. However, the evidence here does *not* suggest early movers outperformed late movers.

[3] At the time of writing, Sharp and Sony have entered into a joint venture agreement, but production has not yet commenced.

Table 6-3: Comparison of Groups with Early, Late, and no a-Si TFT LCD Production Entry

Group	Firms included	Mean total display technology options	Mean number of non-Liquid Crystal options	Mean total mass production display types	Mean number of production technologies exited	Mean of production technology exits / total mass production types
Early mover (a-Si)	Fujitsu, Hitachi, Mitsubishi, NEC, Panasonic, Samsung, Sanyo, Sharp, Toshiba	5.11	2.67	2.78	1.33	0.50
Late mover (a-Si)	LG Group, Philips, Sony	5.33	3.00	3.00	0.33	0.17
No a-Si exposure	Pioneer, JVC, Thomson, Canon, Funai	2.00	1.40	1.00	0.60	0.50

The PDP story is different from a-Si. PDP has been capable of large applications (those requiring around 50” diagonal size) from the early days of production, however the number of applications it is suitable for is also limited because it is not effective at smaller, high resolution applications and has higher energy requirements than a-Si LCD. Although several firms briefly made large computer monitors using PDP displays, these were always niche products. The only two applications PDP was really suited for were TV sets and public information displays such as those found in airports, railway stations, and hotels.

From a real options perspective, PDP had less option value than LCD because the potential market applications were more limited. LCD technology was potentially valuable in many market applications; if it proved to be unsuitable for one it would still have value in another. Even in earlier stage single color segment type panels, LCD’s potential for low power, portable applications was clear. In the 1970s LCD became a calculator display technology. As the technology progressed it was used in an increasing number of low power, portable applications (see Chapter Three). What probably could not be foreseen was LCD’s entrance into applications where size and power consumption mattered less, such as automotive displays and pachinko machines. Since LCD was suitable for more markets, the total market uncertainty it faced was lower than was the case for PDP. The large number of potential applications meant it offered greater flexibility and therefore had higher value. This is not to say it was clear that LCD was more or less suited to TV set usage than PDP at any point in time. Rather, the flexibility offered by the technology made it a palatable investment even in the event it should not work out as a TV display.

The PDP production line investments depicted in Figures 6-4 A&B show firms developing options on low volume prototype lines and executing production options by follow up investments in mass production lines. Points denoting the start of joint ventures are shown at the top of these figures.

Table 6-4 compares mean numbers of options, technologies produced and exited for early movers into PDP production with those for late movers and firms that never had a PDP production capability. Early entrants were defined as those having a production capability running by the end of 1996. No pattern of performance is apparent between the different groups in Table 6-4 with respect to either the TV business or the display business. Late movers exhibited a lower rate of production exit than the other groups, as was the case in the above analysis of the a-Si TFT LCD groups.

Theory emphasizes the relationship between timing and the value of options. However, the analysis above failed to identify a relationship between long-term performance and the timing of option exercise (entry into mass production). Failure to uncover such a relationship does not mean that it does not exist. The relationship may be complex or it may not be discernable without controlling for other factors. The question of timing will be reconsidered in the pairwise comparison of cases appearing later in this chapter.

Table 6-4: Comparison of Groups with Early, Late, and no PDP Production Entry

Group	Firms included	Mean total display technology options	Mean number of non-Liquid Crystal options	Mean total mass production display types	Mean number of production technologies exited	Mean of production technology exits / total mass production types
Early mover (PDP)	Fujitsu, Hitachi, NEC, Panasonic	4.75	2.50	2.75	1.25	0.46
Late mover (PDP)	LG Group, Mitsubishi, Pioneer Samsung	4.00	2.50	2.25	0.75	0.38
No PDP exposure	Canon, Funai, JVC, Philips, Sanyo, Sharp, Sony, Thomson, Toshiba	4.11	2.22	2.11	0.89	0.45

Serial and Parallel Options Pathways

Another aspect of timing has to do with how options are developed and maintained, either in serial or parallel. Canon's option ladder (Figure 6-32) in the prior chapter shows a clear serial pattern. One display technology option is pursued and abandoned, to be followed by another. Other firms studied exhibited more parallel options maintenance than Canon. While development may not be undertaken simultaneously on multiple display technologies, most firms keep more than one technology "in-play" at a time.

Serial options pathways, where one technology is abandoned before the next is invested in, have less flexibility compared with parallel pathways. Part of the value of the abandoned option may be retained, but it cannot be easily executed once abandoned. When uncertainty is high, then, real options logic suggests parallel paths to be superior to serial. Most firms developed and maintained options in parallel. Canon's serial pattern was unusual.

Canon made bets on one technology at a time. In effect, Canon appears to have thought it could outsmart uncertainty, but it did not. Its resulting performance has been poor with regard to TVs and display technology in general. Although the company announced its intention to enter the TV business several times since the year 2000 it has yet to do so. It has also not become a major display producer.

Integrating Options Pathway Type and Strike Timing Aspects

Investments required to enter mass production of flat panels are large by any measure, including requirements for managerial and engineering talent as well as financial resources. Parallel development of technologies at lower levels requires fewer resources than those needed to build new production capabilities simultaneously. Keeping options open at lower levels on the option ladder is easier than doing so at higher levels, suggesting that parallel pathways should be prevalent at lower level. Investments at higher levels should be more serial in nature. This is not to say firms should not or cannot invest in production capabilities associated with more than one display technology; rather, they should not attempt to simultaneously build new production capabilities for two alternative technologies. Although building two capabilities at the same time might increase flexibility of the firm, at the same time it would put extreme pressure on the financial and managerial resources of all but the largest firms. For example, limitations to financial resources might result in building production capabilities inferior to competitors across multiple display technologies. In this case, the new production capabilities would begin with a handicap. Another possibility is that stress on managerial attention and technological capabilities would limit the speed and effectiveness of development of the production capability, in which case the firm would fall behind competitors focusing on single technologies. Interestingly, two firms that pursued simultaneous development of two new production capabilities were also, for a time, cutting edge developers of PDP and LCD technologies, Hitachi and Fujitsu.

Hitachi and Fujitsu played key roles in developing LCD and PDP technologies. Hitachi was the first to successfully develop the In-Plane Switching mode of LCD, and Fujitsu discovered Multi-Domain Vertical Alignment (Sangyo Times, 1995, 1998). These two modes were breakthrough improvements allowing increased viewing angles and therefore increasing the suitability of LCD to TV applications. Both firms also had leading PDP technologies. Fujitsu developed Alternative Lighting of Surface technology, which became widely used in PDPs (Nikkei BP, 1998).

Despite having the technologies at early stages, these two firms exited large panel display production and neither became a major player in the TV business. The inability to focus on a single technology at the right time has been suggested as a reason for the poor performance. To paraphrase the comments of one informant: “We have a lot of resources compared with other firms, but we can’t support more than one large display technology development and production in house… They (Hitachi) wouldn’t be able to do a good job of that either.[4]”

Samsung and LG appear to have followed a similar path to that of Fujitsu and Hitachi but with very different results. Two things make the experiences of these Korean firms different from Hitachi and Fujitsu. First, the technologies were more mature when the Korean firms entered, increasing the availability of know how and other resources outside the firm. Second, the Korean groups did not pursue multiple new display technologies simultaneously inside the same company. Samsung SDI, a Samsung group company with experience in CRTs, concentrated on building a PDP capability. Samsung Electric, a focal group company with experience in LCDs, focused upon LCD

[4] In person anonymous interview: March 27, 2009.

capabilities. These made sense from the standpoint of leveraging existing capabilities as PDP uses phosphors like CRTS and LCD production shares communalities with semiconductor production. Similarly, LG group divided LCD and PDP between different group companies. Fujitsu and Hitachi, on the other hand, built the capabilities first internally and then made separate entities. The Fujitsu Hitachi Plasma display joint venture integrated capabilities the firms already had. Another difference between Fujitsu and Hitachi and the Korean firms was branding and marketing capability. Neither Fujitsu nor Hitachi can be considered to be major consumer electronics brands (Hitachi is arguably strong in consumer appliances in Japan). LG and Samsung have built stronger brands and better market positions than Hitachi and Fujitsu.

Pairwise comparison

The purpose of this section is to compare several dramatically different cases in the sample to isolate variation and mechanisms that are difficult to observe when all of the cases are considered simultaneously. To achieve this, the two top incumbent Japanese TV set manufacturers, Sony and Panasonic, are each compared against a company that attempted to dramatically improve its position in the TV set industry through exercise of display technologies options. Table 6.5 below divides the focal firms by the tier they belonged to in the TV set industry before flat panel TV became prevalent and at the end of the study. Of the firms attempting to improve their place in the industry, Sharp and Pioneer exhibit the greatest variance in outcomes. Furthermore, when compared with the larger group of firms studied, Sharp and Pioneer are particularly salient because they have been regarded as leaders in the display technologies they specialized in during the period flat panel TV was becoming prevalent.[5] Sharp is of particular interest because it is the sole firm that was able to leverage its display technology capability into a long-term performance improvement in the TV set industry. As Sony has focused its flat panel TV set business primarily on LCD technology, Sharp and Sony form a suitable comparison. Pioneer's case is interesting because it was considered by critics to have the best screens and TV sets in the business. As Pioneer and Panasonic both focused primarily on PDP technology for their TV set businesses, these two firms form the second pair for analysis.

Table 6-5: Japanese TV Set Makers by Tier

Tier	Prior to FP TV	After FP TV
Tier 1	Sony, Panasonic	Sony, Panasonic, **Sharp**
Tier 2	**Hitachi, Mitsubishi**, Toshiba	**Hitachi, Mitsubishi**, Toshiba
Tier 3	**Pioneer**, Sanyo, **Sharp**	Sanyo
Exit		**Pioneer**

Note: Firms in bold are those attempting to use technological capability to improve position in TV set industry.
Sources: Author analysis based upon Fuji Chimera (1998-2007), in person interviews anonymous informants (Interview dates: November 4, 2008; March 11, 18, 19, 27, 2009) and an in person interview with Tsuyoshi Numagami (March 13, 2009).

[5] Fujitsu and Hitachi were known for key technological breakthroughs, these achievements occurred earlier.

Sony and Panasonic had been the top two Japanese TV set manufacturers for many years before flat panel display technologies became feasible for use in TV sets. They had developed strong market power, strong brands, and highly effective distribution networks. By comparison, Sharp and Pioneer were not strong players in the industry before flat panel TV. Sharp had built a third tier TV business that relied on others to supply cathode ray tubes for set production. Pioneer was a small niche player in the TV industry prior to entering flat panel TV.

Although the strengths of Sony and Panasonic did not directly reduce the market uncertainty faced by these firms, the market power they held reduced uncertainty about these firms' future positions in these markets. Furthermore, past performance in the CRT TV market is evidence these firms had developed powerful ways of ascertaining customer needs accurately and meeting these needs effectively. While other firms may have had superior display technology options, those may have not provided sufficient advantage to successfully challenge Sony and Panasonic, given their existing strengths.

Sharp-Sony comparison

Prior to the introduction of flat panel television, Sharp was far behind Sony in the TV set industry. While Sony had market power, Sharp did not. This difference in market power meant that Sharp needed to have a major advantage over Sony in technology in order to actually compete. Evidence suggests LCD technology provided such an advantage in this case.

Sharp entered flat panel television early with its 8 and 10-inch models in 1995 (Sangyo Times, 1995). It released a bold new line of LCD TVs in 2000 under the sub-brand “Aquos” (Sangyo Times, 2001). Sony, on the other hand, was slow to enter flat panel television. Sony first used an LCD in portable a video tape player in 1990 (Sony web site). While Sony released a PALC based TV in the late 1990s, this was not mass-produced (Sangyo Times, 1997). First evidence of a consumer LCD TV by the brand was the release of a 15” wireless model in 2000 (Nikkei BP, 2000). In 2002, Sony began selling LCD TVs using its main TV sub-brand, Wega (Sony web site). Trying to identify exactly how far behind of Sharp Sony was is tricky. Sharp’s first consumer LCD TV went on sale a full five years before Sony’s. Furthermore, Sharp already had a dedicated LCD TV brand in 2000, but Sony only began adding flat panel products to its main TV line in 2002. Sony introduced its Bravia sub-brand for flat panel TVs in 2005, a full five years after Sharp had similarly developed a FP TV brand (Nikkei BP, 2005 (Jitsumu Hen)).

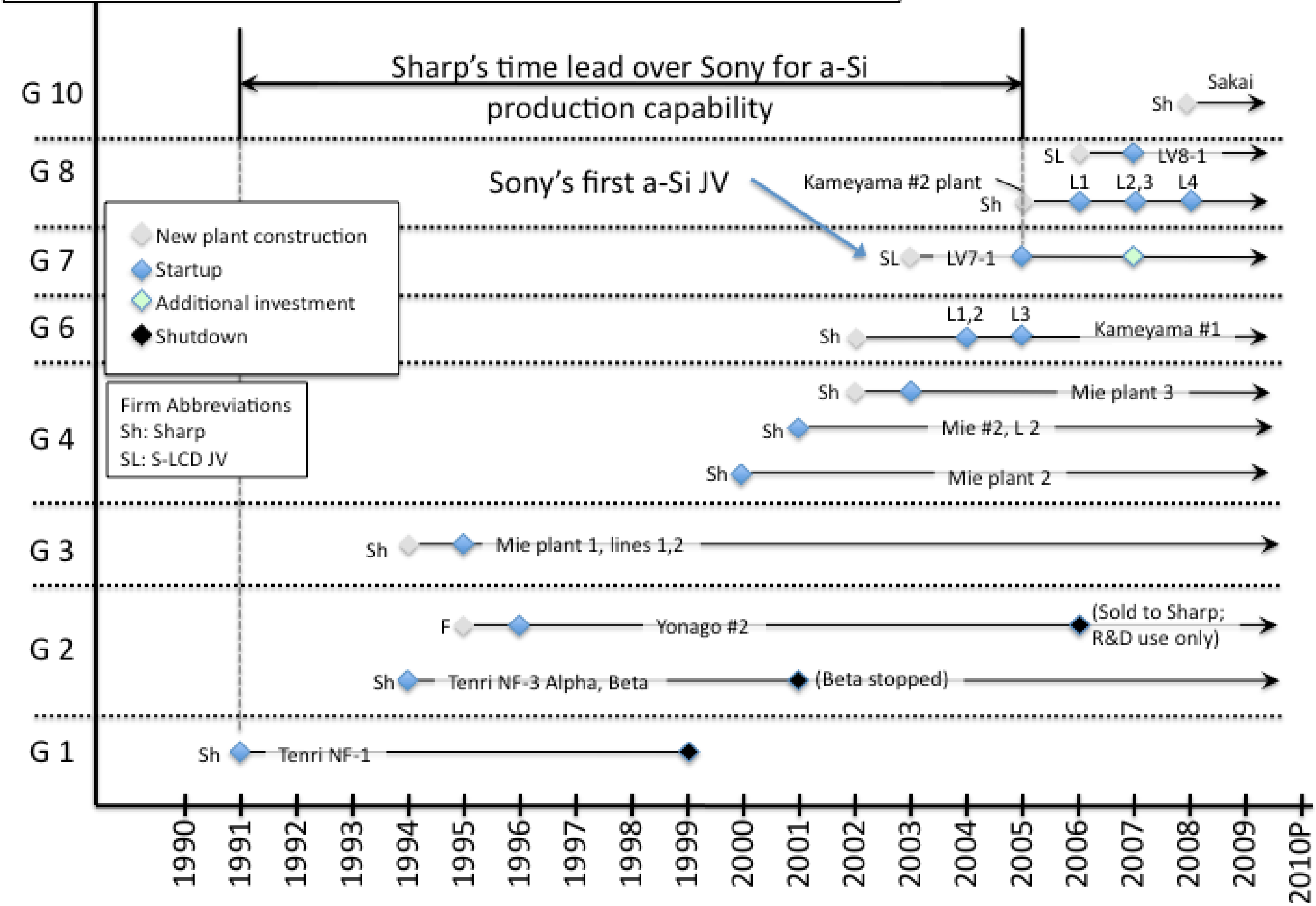
As flat panel TV grew into a meaningful part of the TV market, Sony lost share to competitors, including Sharp and others that leapfrogged it into flat panel TV. However, Sony was able to recover its position a number of years after changing its TV focus to flat panel. Sharp was an early winner in flat panel TV and maintained a much stronger position than it held previously, even after Sony (and its rival Panasonic) reestablished their strength in the market. How was this possible for Sharp when other companies with strong display capabilities failed to maintain positions in the TV set business?

Figure 6-4 below compares the timing of entry into a-Si LCD mass production between Sharp and Sony. Sharp began producing a-Si more than 10 years before Sony.

Chart 6-1 depicts the cumulative number of Japanese patents on LCD technology held by Sharp and Sony beginning in 1990. This data shows a large and expanding gap, with Sharp far in the lead ahead of Sony in patenting. Chart 6-2 examines the total TFT-LCD production of Sharp and Sony. Comparison of a-Si production does not provide much additional information over what was shown in Figure 6-6, as Sony entered a-Si only recently and only through a joint venture. Accordingly, the data used for the comparison covers LCD technology relatively broadly. Again, this data shows Sharp years ahead of Sony across the study time frame.

The different data comparing Sony and Sharp all suggest that Sharp had a very large lead on LCD technology compared with Sony. This lead gave Sharp the time it needed to build its brand and establish a strong place in the industry.

Figure 6-4: Sharp and Sony comparison – a-Si facilities



Note: intermediate generations are handled as follows: 2.5G -> 2G; 3.5G->3G; 5.5G-> 5G; 7.5G-> 7G.

Chart 6-1: Sony and Sharp - Cumulative LCD Patents Starting 1990

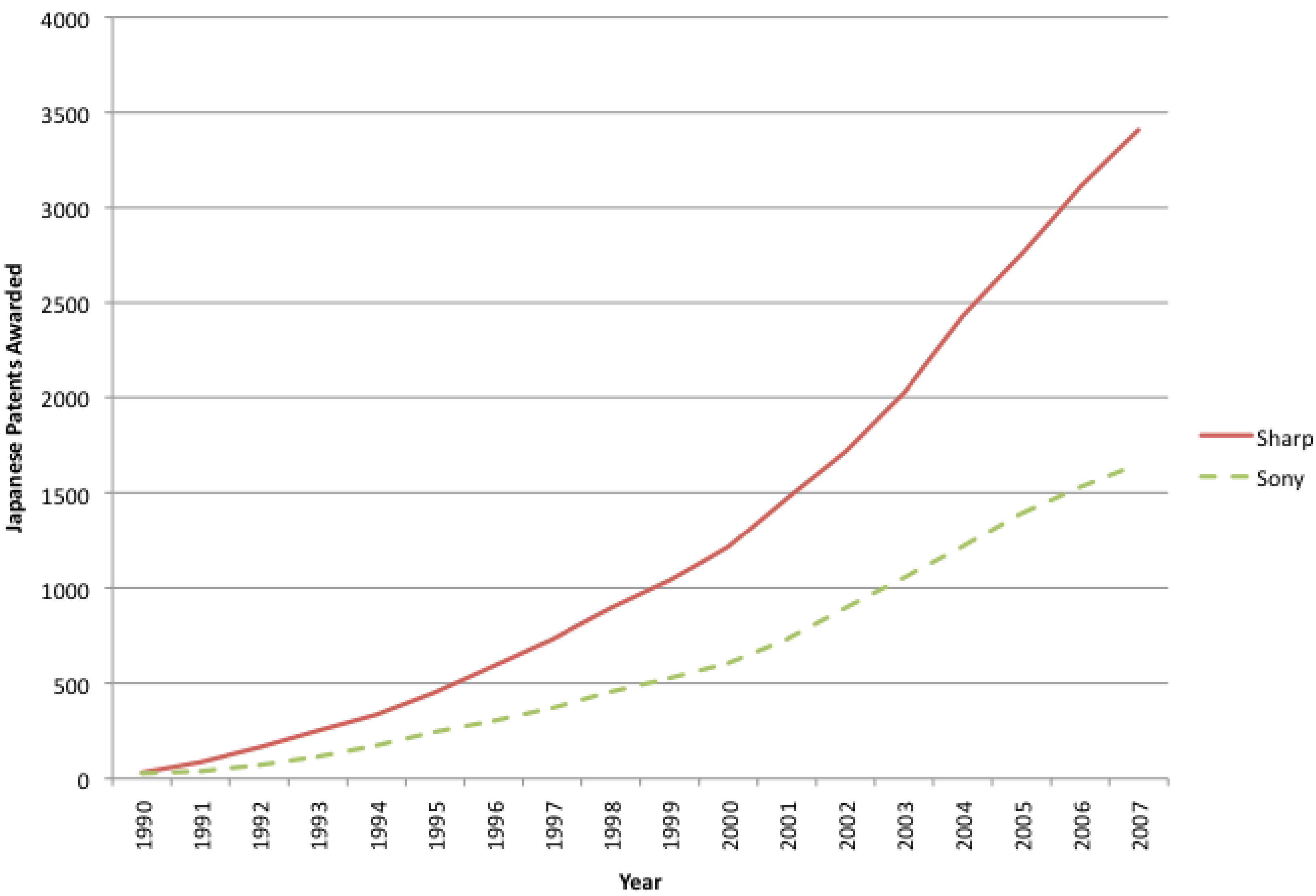
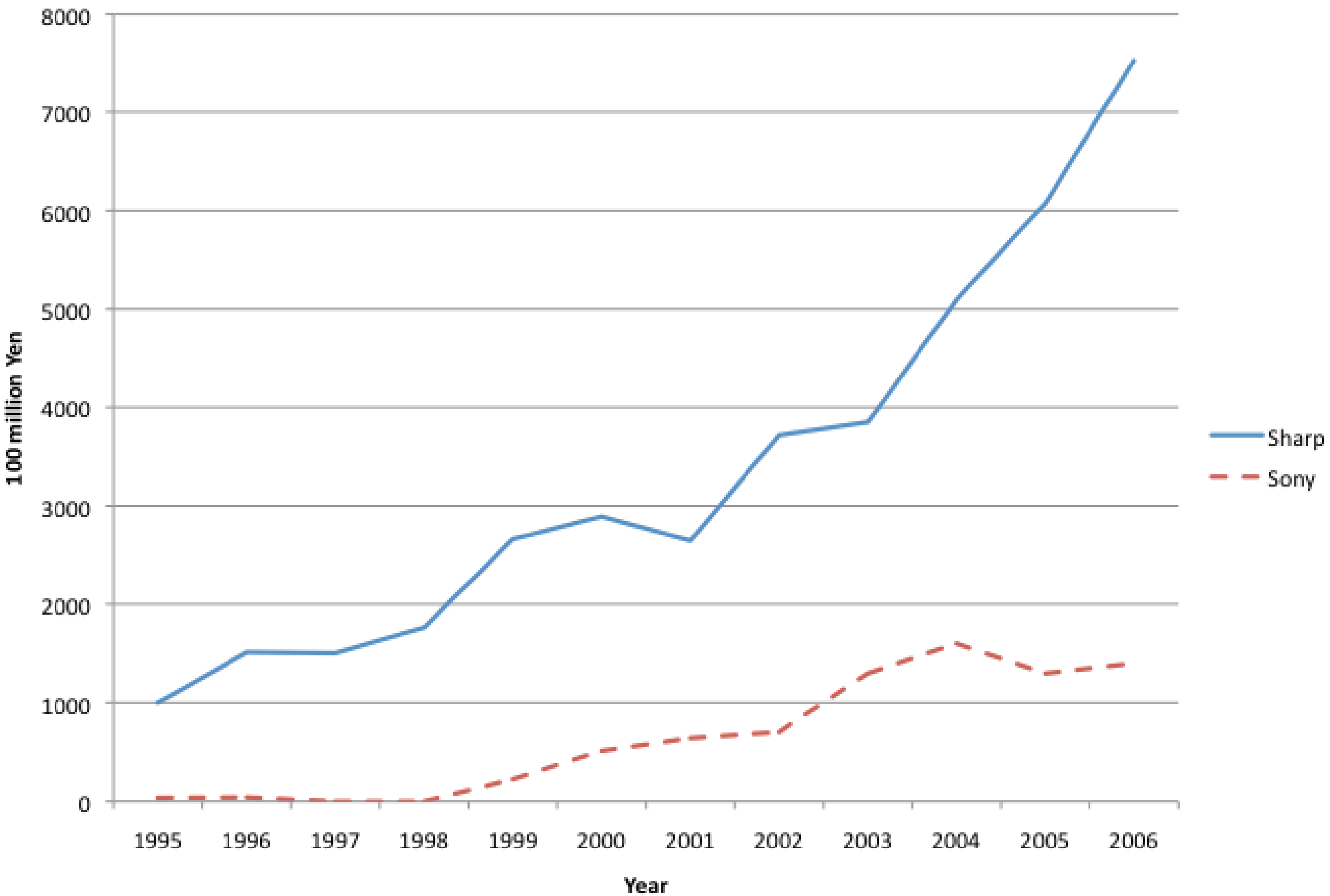


Chart 6-2: Sony and Sharp – Annual LCD Production Value, All TFT Types



Pioneer – Panasonic Comparison

Like Sony, Panasonic had a strong market position in CRT television. Panasonic has historically focused on cost efficiency and wide distribution. Although Panasonic's brand may not have been as strong as Sony's, Panasonic was arguably stronger than Sony in these other areas. Like Sony, Panasonic had strong market power. Its strength and control in the Japanese domestic distribution network was unparalleled by competitors. This had virtually guaranteed sales, reducing the risk of production investments compared to that faced by competitors.

Like Sharp, Pioneer was highly regarded for its flat panel display technology. However, the Pioneer story is quite different from that of Sharp. Pioneer's PDP TVs were lauded by experts for having deeper blacks and generally better picture quality than TVs made by other manufacturers. However, the empirical evidence in this study does not suggest Pioneer actually had a large lead on Panasonic in PDP technology. Indeed, Panasonic appears to have entered into mass production of PDP before Pioneer (See Figure 6-5), although Pioneer and Panasonic began releasing PDP TVs in the same time frame, around 1997-1998. Data on cumulative Japanese patents on PDP technology for the two companies suggests Pioneer lagged Panasonic in terms of PDP patents over the entire study period (See Chart 6-3). Chart 6-4 examines cumulative PDP production by the two firms. Here, it appears Pioneer produced more than Panasonic early on, but was overtaken by Panasonic. It is difficult to say whether Pioneer initially benefited from proceeding along the learning curve in front of Panasonic, however any advantage it might have had does not appear to have been major, and was certainly short-lived.

Panasonic's approach to the TV market was to fill different TV size needs in the market using display technologies suited for them. As the technologies matured, the size ranges each covered changed. This strategy initially divided the market into three groups: small LCD TVs, mid-size CRT TVs, and large PDP TVs. Panasonic produced all three.

Panasonic was not one of the first into the LCD TV market, but not one of the last either. In 1999, it introduced a 15-inch LCD TV and in 2000, a 22-inch model (Sangyo Times, 2001). Panasonic's market entry was after Sharp, but before Sony.

In comparison, Pioneer limited its approach to large sized TVs; it did not attempt to become a full line TV manufacturer. The emphasis on larger sized TVs may have contributed to Pioneer's poor performance as it reduced Pioneer's chance of reaching Panasonic's scale and the resulting cost competitiveness in non-production activities.

Altogether the data suggests Pioneer never had a significant lead against Panasonic, and may have trailed it the entire study time frame. To be successful in competing with Panasonic, Pioneer would have needed a large enough advantage to compensate for its relative weaknesses in other areas such as distribution and efficiency. This was not the case.

Figure 6-5: Panasonic and Pioneer PDP Production Lines

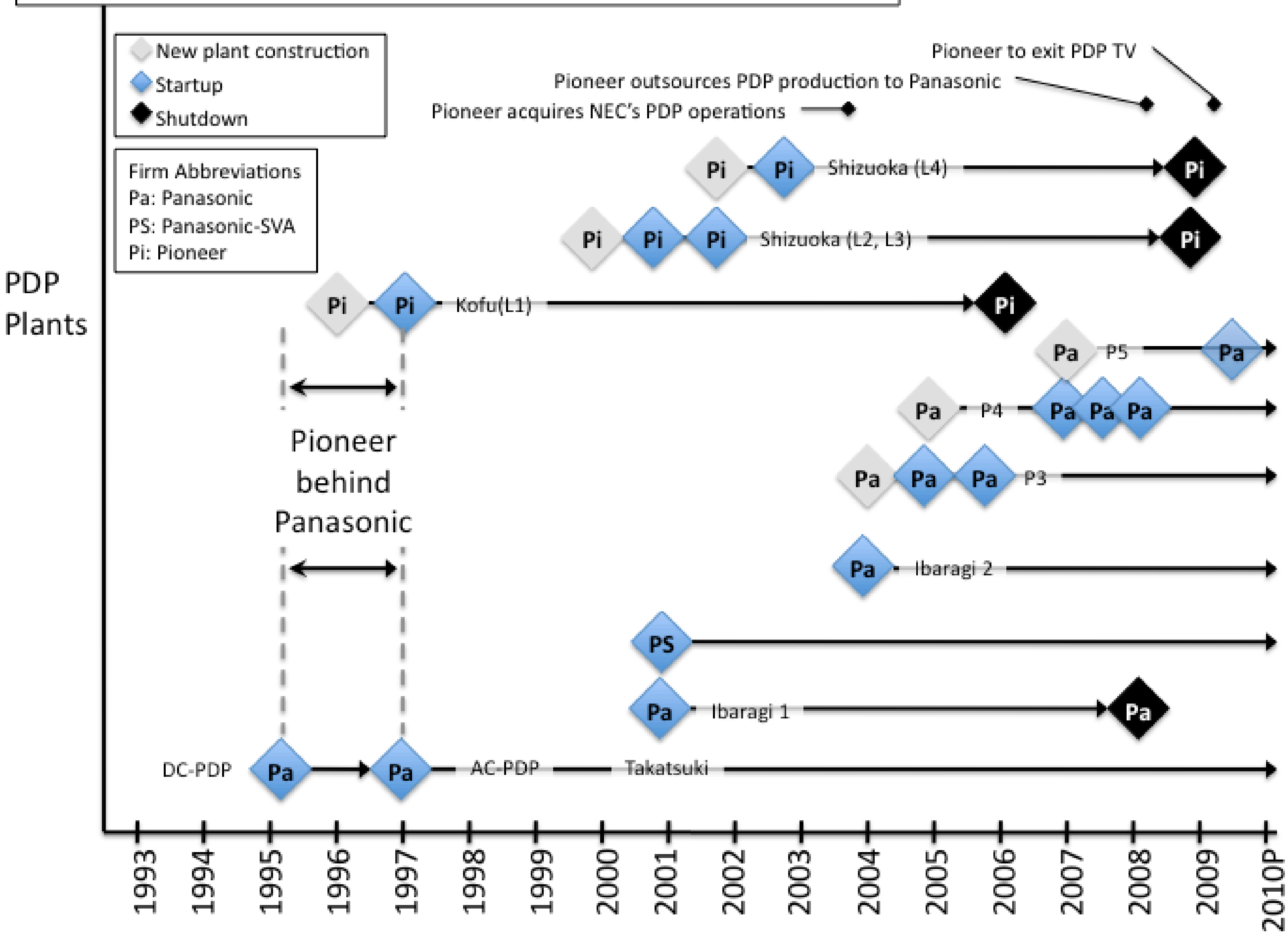


Chart 6-3: Pioneer and Panasonic - Cumulative PDP Patents Starting 1990

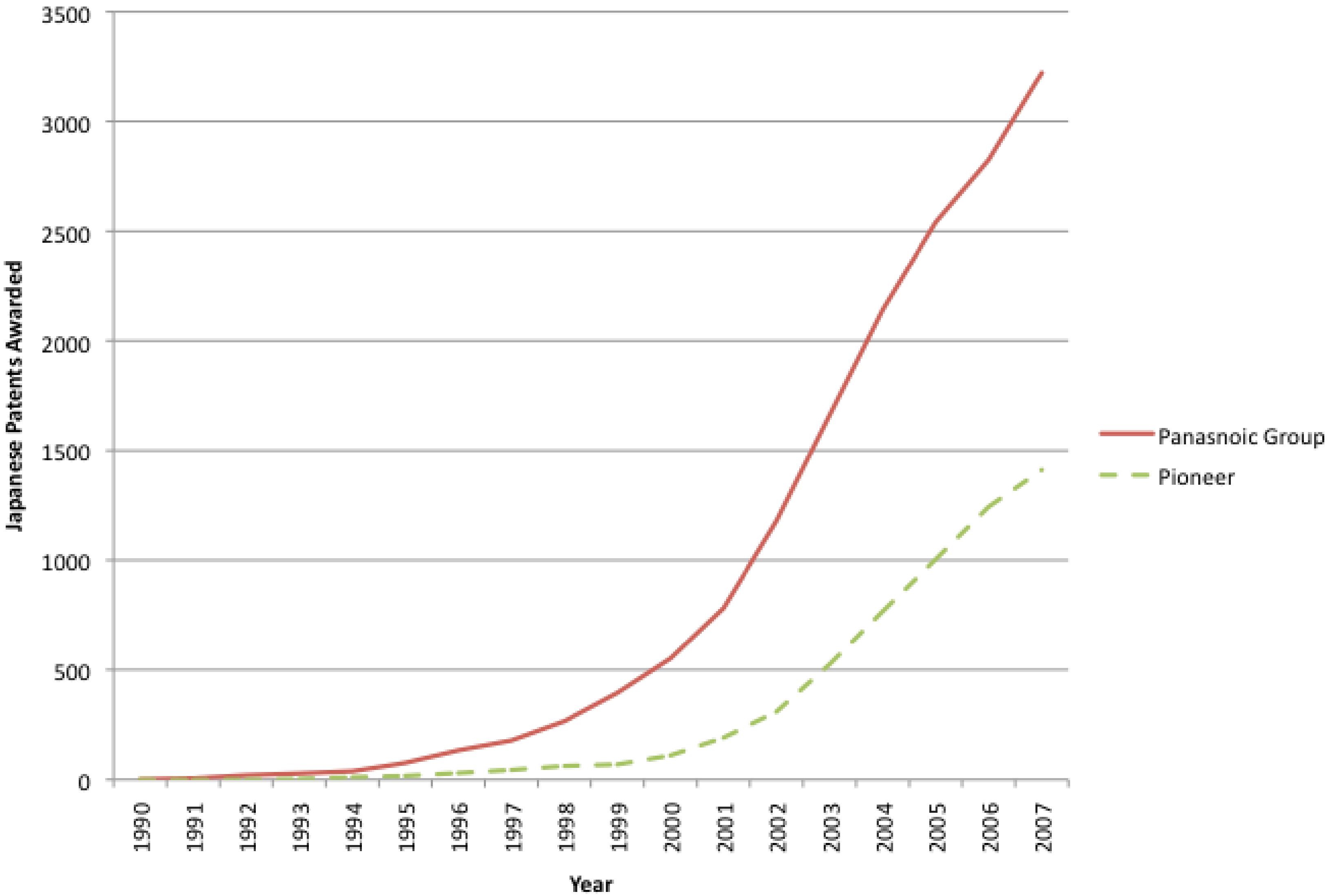
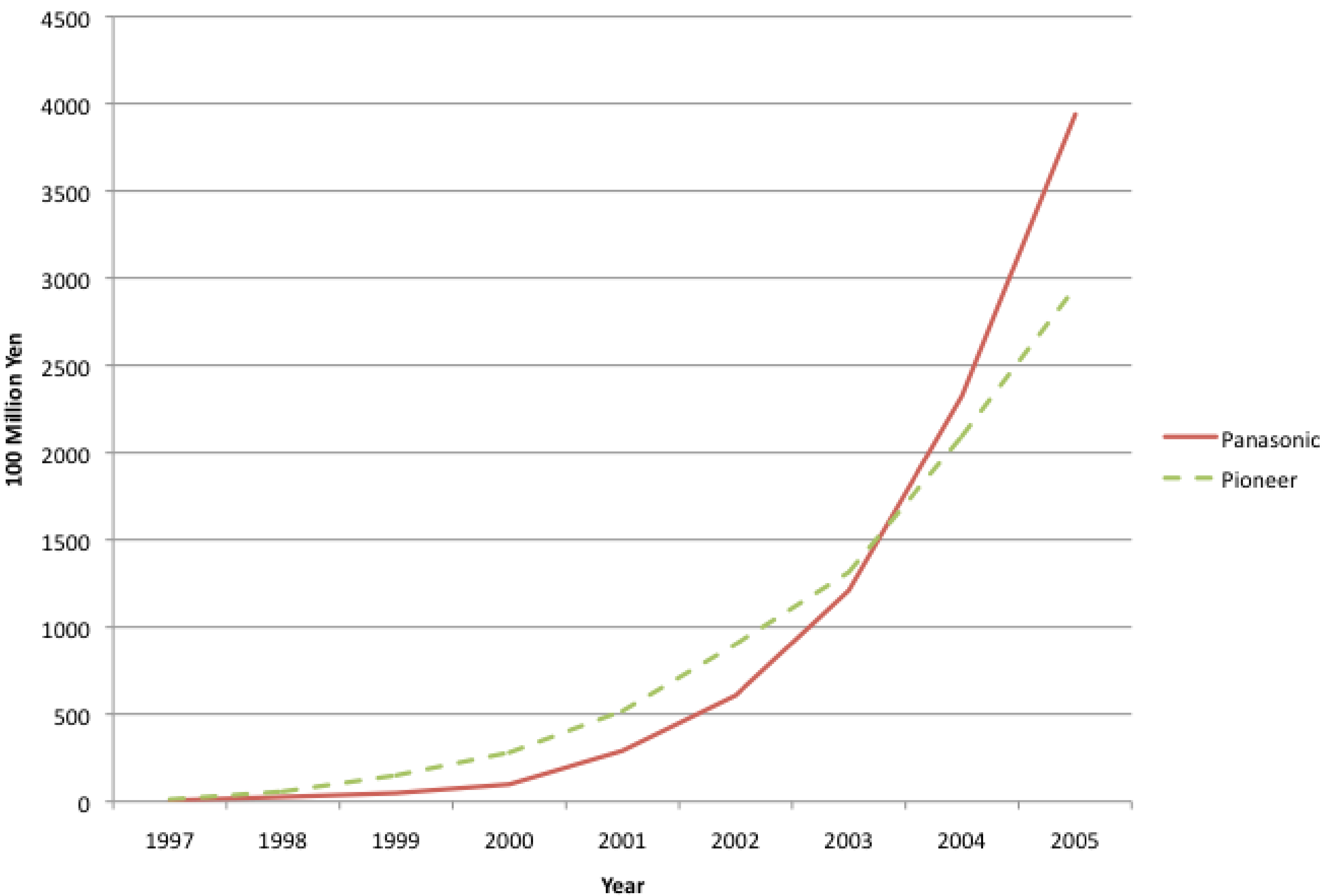


Chart 6-4: Pioneer and Panasonic – Annual PDP Production Value



Panasonic, on the other hand, had sufficient market power it did not have to rush into large scale adoption of a new display technology. Its sales might be reduced temporarily if it did not have suitable investments in the newly dominant technology, but market power bought it time. By comparison, smaller firms gaining a significant position in the TV industry may have been able to launch successful niche products, but building sufficient market share and scale was difficult and took many years if even possible. However, with such strong market power, and large market position, a firm such as Panasonic could make rapid, bold commitments in production capacity as uncertainty decreased. Panasonic's investments in PDP plants with the world's largest capacities (see Figure 6-3) and purchase of a controlling stake in IPS-Alpha, are evidence of such commitments.

Comparison between Sharp and Pioneer

Sharp's approach to LCD differed from Pioneer's approach to PDP in several ways. Perhaps the most important was the way Sharp reduced its total exposure to market uncertainty by developing a variety of adjacent markets for LCD displays. The number and variety of products incorporating Sharp-made LCDs is truly astounding[6]. Examples include laptops and computer monitors, portable game machines (e.g., Nintendo DS), commercial pachinko machines, cars, cell phones, PDAs and many more. By comparison, Pioneer PDPs were really only suitable for two major applications: TV and public displays such as those used in airports and train terminals.

[6] Evidence suggests Hitachi followed a similar approach early in LCD's development (1970s – mid 1980s), but this did not continue. Other focal firms may have started with similar intentions, but later focused on certain display size ranges or sub-technologies.

Sharp's approach allowed it to commit resources on LCD knowing that it held or could develop market options in a large number of different application markets. In effect, by holding a large number of market options, Sharp was able to reduce its total exposure to market uncertainty to a greater degree than its competitors.

Pioneer's PDP focus limited its ability to reduce the total market uncertainty it faced because PDP had few other potential applications beyond TV and public displays. Coupled with the lack of a significant technological lead, this may have made it difficult for Pioneer management to make the continued large investments required to build and maintain a strong position in the industry. Given the situation, it most likely would not have been reasonable for Pioneer to try to continue to maintain these large investments.

Pioneer would not necessarily have done much better if Panasonic had put its main emphasis on LCD instead of PDP. Pioneer might have enjoyed a short-term technological advantage that could have given it some time to increase its efficiency, build its brand, and develop its distribution. However, in the longer term, it is questionable whether Pioneer would have been able to become competitive enough fast enough to match the already strong firms focusing on LCD, especially as LCD costs and sizes improved so rapidly over time.

The Relevance of Options and Uncertainty for Panasonic, Pioneer, Sharp, and Sony

Although the exogenous uncertainty faced by these firms may have been the same, the potential impact of this uncertainty differed amongst the firms. Prior to the development of the flat panel display technologies discussed here, none of the players would have known which technology would become dominant. They also could not have known if holding options on the dominant one would necessarily translate into competitive advantage. However, the potential impact of holding or not holding options was different between the firms.

Panasonic and Sony had established positions in the market. Technology options represented a way to defend these established businesses. In the end, the advantages these two firms had – other than display technology – were strong enough they could return to high performance even after failing to invest heavily in the technology that became dominant. Neither Panasonic nor Sony had made big bets early on a-Si LCD; Panasonic even transferred most of its LCD capability to a JV majority controlled by Toshiba, effectively increasing its emphasis on PDP. Later, after uncertainty declined, Panasonic bought its way into control of IPS Alpha to obtain a production capability for large a-Si LCDs. Panasonic managed to rebound despite having guessed wrong.

Sony appears to have been searching for a display it could use to differentiate itself as it had done with the Trinitron in CRT TV. It did not develop a large-scale a-Si production capability, and has relied on sourcing from other firms and joint ventures with competitors. Like Panasonic, it has bought access to a-Si production.

For Sharp, LCD was a technology suitable for a broad variety of applications, and one it had unusually strong capabilities in. The TV set industry represented an opportunity for Sharp to further apply this capability. Sharp had a goal of becoming a strong, respected TV producer. However, when it bet on LCD, Sharp was making a much more general bet – that LCD would be an attractive display technology for a variety of different applications. Sharp's position as an "also ran" in TVs meant that it had little to lose in this respect. Where LCD was concerned, Sharp would have probably continued to bet on LCD even if it were clear it would not work in TVs.

Although most of Sharp's investments in display technology were related to LCD it developed a few other display technology options. Paradoxically, developing these options may have increased Sharp's awareness of LCD's capabilities and Sharp's strong position with regard to LCD technology.

Pioneer, on the other hand, was clearly betting on TVs when it invested in PDP technology. Public displays were the only other application PDPs really worked for, although they were briefly sold as computer monitors. Pioneer had been a small producer of TVs, relying on other firms for tubes, and focusing on large sized sets. It had not been involved in industries that used PDPs for other applications. PDPs represented a way for Pioneer to enter the mainstream TV industry if the bet worked for them. Note that Pioneer's bets in OLED were made by a subsidiary firm and were focused on small displays. OLED output used in house went into producing car stereos. Pioneer's bet relied on several things going right. First, PDP had to become a dominant display technology for TV sets, and second Pioneer had to be able to become a competitive PDP producer in terms of quality, efficiency and distribution.

Performance revisited

The interpretation above presents the opportunity to reevaluate the performance question within a more nuanced understanding of the options held. Both Pioneer and Sharp were third tier TV producers that attempted to use flat panel display technologies to improve their position in the industry. Although both firms had options on more than one display technology, when it came to a display to use in televisions, they had far fewer options. Pioneer was betting exclusively on PDP for TVs; Sharp had a long history developing EL and subsequent brief work on FED and PALC, in addition to its strong commitment to LCD.

When it comes to TV displays, Sharp and Pioneer had narrower options portfolios than Sony or Panasonic. Further, the investments made in production capabilities made by Sharp and Pioneer represented much larger bets for them than would have been the case of similar investments by Panasonic and Sony, which were much larger firms. In other words, production investments that might have been option-like for Panasonic or Sony may have been closer to commitments for Pioneer and Sharp.

Put in this context, Sharp could be considered as "lucky" and Pioneer as "unlucky." The technology Sharp bet on became dominant, and the technology Pioneer bet on did not. Theory suggested firms with narrow portfolios were likely to exhibit more extreme outcomes than those with wide portfolios. This reevaluation of performance is in agreement with theory.

However, there appears more to this than luck. Certainly, Sharp was lucky that LCD became dominant in the TV set application. However, Sharp had also been adept at reducing its overall uncertainty by developing a large variety of alternative applications. In the case where technological uncertainty was high and market needs uncertainty low, real options theory suggested firms should hold technology options and commit to market needs. This is what Panasonic and Sony did. Both firms may have been slow to recognize the change in the market and switch over from CRT to flat panel, however they both had broad technology options portfolios.

Sharp and Pioneer did not follow real options logic in the same way as Panasonic and Sony. Sharp, it appears, did something near the opposite of what theory suggests. Sharp committed to LCD and developed options on a large number of product markets for LCDs. In some, it competed on the level of finished goods, and for others was a panel supplier. Pioneer meanwhile, took the risky approach of committing to both a product market it was weak in, TV sets, and an unproven technology it did not have a lead in, PDP.

Chapter Conclusion and Implications for Real Options Reasoning

This chapter analyzed differences of breadth and depth of options portfolios held by firms, and timing of options exercise. It searched for patterns and relationships between option-related behavior and performance outcomes. It also performed pairwise analysis of four firms exhibiting large variance in the sample.

The firms with the broadest options portfolios were all high performing firms. This observation does not suggest causality; indeed, these firms may simply have had enough resources to pursue more options. Other analysis presented here were unable to identify any relationship between options portfolios or timing of exercise and performance. While it appears that firms in the industry generally behaved as expected by real options reasoning, they did not necessarily benefit from developing and maintaining options on alternative technologies. Top-tier incumbent firms suffered short-term performance decreases despite holding large portfolios of technology options. Market power enabled these firms to regain their positions once they obtained access to sufficient production capability. Second and third-tier incumbent firms, with the single exception of Sharp, were unable to turn investments in leading display technology into durable improvements in their market positions. This was true both for those following a more commitment-like investment approach such as Pioneer as well as those with broader portfolios such as Hitachi.

The following chapter discusses the findings of the study in terms of theory and the propositions developed in Chapter one. Additional theorizing took place over the course of the research and analysis. Post hoc analysis relating to this theorizing is also included in the following chapter.

CHAPTER SEVEN: RELATING STUDY FINDINGS TO THEORY

This chapter has two purposes: first it weighs evidence from the study regarding the propositions developed in Chapter one. Second, it performs post hoc analysis based upon theorizing that occurred over the course of this research. This post hoc analysis considers broadly how and whether firms dynamically react to discontinuous changes to uncertainty levels. Whereas the prior chapter examined the data broadly, the emphasis of this chapter is on considering specific questions.

Option-related Behavior

One question this research asked was: do firms behave as real options logic suggests they should? The flat panel TV set industry studied herein was characterized by low market needs uncertainty and high technological uncertainty. In an environment with this profile of uncertainty levels, real options logic suggests firms should hold options on technologies. P1 argued that in the face of technological uncertainty, firms will develop and hold technology options. Display screens are considered key devices in TV sets. Historical analysis of the industry suggests that firms with strong display screen technologies have been able to leverage this to effectively differentiate their products or reduce costs in the past. Accordingly, if there is a high level of uncertainty regarding which display technology will be used in television sets in the future, real options reasoning suggests firms should hold options on more than one display technology.

The evidence from this study is in agreement with P1. All focal firms developed and held options on more than one display technology[7]. Amongst the non-focal TV set producing firms, Funai Electric, a firm that never had its own display mass production capability to begin with, was the single exception. There was variation in the number of technologies firms invested in. Several firms developed as many as 7 technologies. Furthermore, these technology options were developed and held largely in parallel and therefore represented competing options on multiple technologies.

Although not a TV set producer, Canon is worthy of note because it was the only firm in the study that did not develop display technologies in parallel. Canon developed them in serial form, giving up on one before starting work on the next. Other firms with minor or no TV set production capability held options on multiple competing technologies. This suggests in the face of high technological uncertainty but a large certain potential market (TV sets), firms generally hold options on multiple alternative technologies, as predicted by real options logic.

Moving beyond P1 but continuing with the same general question of behavior, real options logic implies firms should not commit to all of the technologies they develop options on. Compared with low cost, easily reversed investments like R&D, investment in mass production capabilities is less option-like in that it is more costly and may be less reversible. Accordingly, if real options logic accurately predicts how firms act, firms should develop and hold options on more technologies than they develop mass production capabilities for. The analysis contained in Chapter six found that none of the firms entered mass production of all of the technologies which they held options on.

[7] Some of the display technologies developed may not have been intended for TV applications, as was the case with Pioneer's OLED development.

Therefore, in this case as well, the firms studied behaved as real options logic would predict. Post hoc analyses were performed to ascertain if firms changed their options portfolios dynamically in response to significant changes in uncertainty levels, as real options logic predicts they should. This analysis is contained at the end of this chapter. Some observations included in the analysis agree with the predictions of real options reasoning, and some are ambiguous. No findings appear to contract theory, however.

Altogether, these different analyses discussed above find general support for the behavioral predictions of real options logic. In the next section, the research questions related to performance predictions of real options logic are examined.

Performance and options

Performance implications of option-like investment were also proposed in Chapter One. The general notion of P3 and P4 is that in the face of technological uncertainty, firms making commitments to single technologies will experience extreme performance outcomes, whereas those holding options on numerous alternative technologies will not exhibit such extreme outcomes.

This logic argues that some firms would make a winning bet by committing to a single technology, and obtain a high payoff without the cost of developing and holding multiple options. However, when the firm did not place a winning bet, it would exhibit low performance. Although both high and low performance outcomes are expected in general, the odds of identifying both outcomes are not symmetrical. A very large sample may be required to find "lucky" firms that made singular commitments that turned out to be winning bets, and obtained high performance. Accordingly, failure to identify a high performing firm making the “winning” bets does not invalidate the theory but fails to offer support.

The industry studied has a relatively small number of competitors and they generally held options on multiple technologies. Given this situation, it first appears that P3 and P4 cannot be evaluated using the data herein, but with some interpretation and adjustment it is possible to evaluate the general line of thinking involved in these two propositions.

Initial analysis indicated all of the focal firms developed and held options on display technologies. In this sense, no firm was identified as having a pure commitment. On the other hand, subsequent additional analysis of Pioneer suggested its development of OLED, taken on by a subsidiary and focused on small displays for car audio, and later cell phones, could be considered as a separate operation without specific relevance for Pioneer’s TV set business. Reconsideration of other firm’s portfolios failed to uncover other firms making commitments similar to Pioneer.

However, it is also possible to commit while still holding options. In other words, a firm may make a major commitment to a single technology while developing and holding options on alternatives. This is what Sharp did. Sharp committed to LCD technology, investing heavily in LCD and numerous liquid crystal related display technologies. Over the study period, it also developed, maintained, and in most cases abandoned options on alternative display technologies.

Amongst the focal firms, Sharp and Pioneer stand out as making commitments. Other firms made major investments, but these weren’t commitments in the face of uncertainty to the extent of those made by Sharp or Pioneer. For example, Panasonic has made large investments in PDP production; however early investments were small given Panasonic's size and later commitment-like investments were made as uncertainty declined.

The performance of Pioneer and Sharp exhibit both high and low extremes. Pioneer has experienced significant financial losses relating to its PDP and TV set businesses. It has already exited PDP and is in the process of exiting the TV industry altogether. As such, it serves as an example of extreme performance by a firm committing to a single technology.

Sharp's case is more nuanced, but supports the notion that firms committing to winning bets will have high performance. Sharp had a strong, historical commitment to LCD. Sharp used the technology (or produced it for other firms) for every application it was suitable for. Sharp also had options on other display technologies, however many of Sharp's options were on variants of LCD, and the relative size of the commitment to LCD and its variants was overwhelming in comparison to the size of the investments it made options on alternatives. Sharp was lucky in the sense that LCD became the dominant flat panel TV display technology. On the other hand, given the number of non-TV applications Sharp's LCDs successfully competed in, Sharp would probably have exhibited respectable performance even if LCD had lost out in the TV set business. Sharp can be considered as a high performing firm with a large LCD commitment.

Altogether, the findings are in agreement with P3 and P4. The data do not offer perfect examples of commitments to single technologies used in theorizing behind the propositions, however both Sharp and Pioneer clearly made commitments to display technologies, and exhibited performance extremes.

The implicit idea behind real options logic is that firms should - on average - enjoy performance benefits through practicing it when compared to those that do not practice real options logic. Firms making commitments in the face of uncertainty would have the highest performance if they made the winning bet, but accompanying this would be long odds. Firms holding options might not have such high performance, but theory suggested they would be less likely to exhibit very low performance, or exit.

However, with the exception of the performance outliers Sharp and Pioneer, one thing striking about the industry is how little technology options portfolios seem to have mattered to performance of the other players. While some players attempted to use technology to improve their positions, Sharp was the only one to gain durable improvement.

Hitachi kept options open in both LCD and PDP, even investing in production facilities for both. Despite the fact Hitachi's technology was advanced it was unable to improve its place in the TV market. Canon tried to outsmart uncertainty investing in SED as its plan to enter the TV business. SED never entered mass production and Canon failed to enter the market. In terms of the TV industry, both Hitachi and Canon remained essentially on the same trajectory as they had been prior to the development of flat panel display technology. This was also the case for the other firms in the study.

This section discussed evidence relating to propositions developed in Chapter one. Evidence was in agreement with real options reasoning's predictions of firm behavior under uncertainty. Evidence regarding the performance implications hypothesized was also supportive with some interpretation. The section below on post hoc analysis returns to the question of whether firms behave as predicted by real options reasoning, but with a more dynamic viewpoint.

Post Hoc Analysis

This section contains post hoc theorizing and analysis regarding changes to uncertainty levels as antecedents of changes in options portfolios. The analysis contained here makes opportunistic use of data gathered in the course of conducting research for this dissertation.

One of the broad, central questions of this dissertation was: do firms behave as real options reasoning predicts? Analysis focused on relatively static observations of firm option portfolios. Although firms' technology options portfolios were charted over time in Chapter Five, to facilitate further analysis these options portfolios were simplified in terms of width and depth in Chapter Six.

The purpose of this section is to consider whether firms behaved as real options reasoning predicts in a more dynamic way. In other words, to evaluate whether firms changed their options portfolios in response to changes in uncertainty levels, as predicted by real options reasoning.

Several notable changes to uncertainty levels taking place during the study period are identified below. Uncertainty of market needs changes with feedback. R&D outcomes may change technology uncertainty levels. Evidence regarding subsequent changes to options portfolios of firms in the industry is presented and discussed.

Real options logic suggests that firms should adjust their options portfolios in response to changes in the level of uncertainty. Firms are expected to hold options under uncertainty, but to execute or abandon them when there is little or no uncertainty. It follows there must be some adjustment process as firms modify their options portfolios in response to changes in uncertainty levels.

Increases and decreases to uncertainty levels can be slow and continuous or rapid and discontinuous in nature. Technological uncertainty may increase slowly as a technology emerges to compete for a particular application resulting from incremental R&D. Similarly, incremental R&D can reduce technological uncertainty over time if one technology starts to gain a lead on alternative technologies over time. A sudden major breakthrough, on the other hand, may result in a rapid, discontinuous change in uncertainty. Breakthroughs can increase or decrease uncertainty. If the breakthrough strengthens the dominant technology, overall technological uncertainty is reduced as the dominant technology becomes more certain. If the breakthrough strengthens a competing technology, overall technological uncertainty is increased.

As uncertainty increases, the value of flexibility rises. Accordingly, holding options becomes more attractive. Events increasing technological uncertainty can be expected to lead to increases in the number of technological options developed and maintained.

On the other hand, when uncertainty is resolved, some options lose relevance and become “out of the money.” The costs associated with maintaining options further reduce their net value over time. Although real options do not have a clear expiry date, they in essence do expire as at some point even when uncertainty remains high as the cost to maintain and hold them eventually exceeds the benefit from the flexibility they provide. When uncertainty levels fall, this point is reached earlier as the benefits from flexibility decrease due to the change in uncertainty.

As dominant technologies emerge, the value of options on alternative technologies lose value. When a technology's chance of achieving dominance increases, so do the value of options on it and therefore investments in it. At the same time, competing technologies become less attractive. Events that reduce technological uncertainty through strengthening the dominant technology can be expected to be followed by increases in options held on that technology and decreases on the options held on competing technologies.

Changes to Technological Uncertainty Levels Over the Study Period

Over the study time frame, the level of technological uncertainty regarding flat panel displays changed both incrementally and discontinuously. Incremental improvements in display technologies were evident throughout the study period and were discussed in Chapter Three. Discontinuous changes to technological uncertainty were also observed for LCD and PDP during the study period.

A number of drawbacks to TFT-LCD technology made it initially unsuitable for TV applications. Generally, these drawbacks were reduced through incremental improvements over time. For example, for many years, LCDs could not be produced in sizes large enough for typical living room TV usage. Gradual improvement and introduction of newer generation production facilities supporting larger substrates gradually eliminated this drawback. Some of the technological progress was less incremental in nature. In particular, the invention of MVA mode and IPS mode increased viewing angle dramatically, making a large step towards elimination of another drawback of LCD for TV applications.

Hitachi was the first to make commercial grade IPS panels, with small production beginning in 1996 and mass production after (Nikkei BP, 2004 (Jitsumu hen)). Fujitsu was the first to develop MVA, shipping monitors in 1997 (Sangyo Times, 1999). These events dramatically reduced LCD's technological uncertainty as a TV display. Evidence relating to firm investment in LCD following these developments was ambiguous. It does not show any discernable pattern of firms increasing or decreasing the weight of their investments in LCD vis-à-vis the other technologies.

PDP also exhibited discontinuous changes in its technological uncertainty. Although there have been a number of breakthroughs in PDP development, none stands out to the same degree as IPS or MVA. The largest single discontinuous change to technological uncertainty was not an invention, but rather the failure of a technology to perform well in a large-scale trial.

Japanese broadcaster NHK was involved with development of DC-PDP for TV applications, and used the Nagano Olympics as an opportunity to highlight the technology by setting up locations throughout Japan with PDP TVs connected to live feeds of Olympic events. Although intended to gain customer interest and help launch PDP TV in general, NHK's promotion also served as a trial of DC-PDP technology in a real world TV application. The displays rapidly failed and had to be constantly replaced during the promotion time period. Prior to the Olympics, technological uncertainty had existed between two kinds of PDP. Many firms had worked on developing both DC-PDP and AC-PDP. DC-PDP's failure during the Olympic promotion reduced technological uncertainty by documenting DC-PDP's weakness. Poor performance reduced the value of DC-PDP options and increased those of AC-PDP. Real options logic would suggest increasing the weight of AC-PDP options, which is in fact what happened. All firms dropped DC-PDP development (Weber et al., 2008). As uncertainty between DC and AC versions of PDP was resolved, the level of technological uncertainty relating to PDP in general was reduced. Faced with this reduction in uncertainty, more expensive less flexible option like investments become increasingly attractive. Evidence of investments made after Nagano appears to agree generally with the prediction of real options logic. Firms increased their level of commitment to the technology. Two manufacturers entered mass production of PDPs in 1998, and two more in 1999.[8]

Changes to Market Needs Uncertainty Levels Over the Study Period

The discussion above focused on changes to technological uncertainty. Similar patterns of changes to options portfolios can be hypothesized for changes in market needs uncertainty. Most relevant to this research is the reduction in market needs uncertainty resulting from market feedback to early product introductions. As market needs uncertainty for a specific value proposition are reduced, the value of options on the technologies embedded in that value proposition increase.

[8] It should be noted that one firm exited in 1999.

Although the level of market needs uncertainty was low in the TV set industry, several specific developments reducing it during the time frame were identified. In particular, set makers lacked data on how much consumers would value flat screen over CRT. How much more would they be willing to pay? Perhaps consumers would balk at high prices needed in the initial stages of production. It was possible that FPTVs could end up a niche item for many years if consumers weren't willing to pay a significant premium to CRTs. The events reducing consumer needs uncertainty were evidence, through market reactions to FPTV product introductions, of how consumers valued flat panel TVs.

Sharp's unexpected success with its "window" line of LCD TVs in 1995 (Sangyo Times, 1995), demonstrated that demand existed for LCD TVs even if they were small and expensive. Other manufacturers had sold LCD TVs before the "Window," but they were small gadgets, whereas this was a more useable set. Sharp's case is interesting because they misjudged demand for their 10.4-inch sets at first and ended up selling out of their entire production run in three months despite the relatively high price of 150,000 yen, approximately $1600 US at the time (oanda.com, 2009; Sangyo Times, 1995). Sharp's experience was evidence that consumers valued the flat panel models even though small and expensive. Evidence from this time frame suggests continuing investment in R&D and new plants throughout the target firms. Although Sharp was increasing its focus on LCD TV at the time, evidence of rapid entry into LCD TV from other firms could not be identified. Taken together, this data is ambiguous – it neither supports not calls into question the predictions of real options logic.

The announcement of successful early PDP sales circa 1998 provided feedback on market needs similar to the introduction of Sharp's "Window" line. The sets introduced early on were large and expensive. However, they found receptive audiences with organizations needing large information displays and wealthy individuals. Customers, primarily industrial users, reacted positively despite high pricing (Fuji Chimera, 1999). This reduction of market needs uncertainty should have increased the relative attractiveness of more expensive less flexible option like investments (higher levels on the option ladder). As discussed above, several firms entered mass production of PDPs in 1998 and 1999. This evidence is in agreement with the predictions of real options logic.

Table 7-1 below summarizes the changes to uncertainty levels and evidence regarding changes to options portfolios discussed above. Much of the data is ambiguous. Several of the events occur nearly simultaneously, further complicating interpretation. None of the data appears to refute the predictions of real options logic, however it does not strongly support it either.

Post Hoc Analysis - Discussion

This dissertation includes theory and analyses regarding the question of whether firms behave as predicted by real options logic. Both the theory and data analysis are relatively static in nature. This static analysis has generally found firms develop and maintain options as predicted by theory. The purpose of the analysis presented here was to further consider this question but by looking in a more dynamic manner. Changes in uncertainty levels were identified over the study time frame, and evidence of modifications to options portfolios following such changes were searched for.

Table 7-1: Changes to uncertainty levels and changes in options portfolios

Technology	Year	Event	Relevance	Observation	Evaluation
LCD	1995	Sharp's "Window" LCD TV launch	Reduced market needs uncertainty on LCD TV	Sharp increases LCD TV focus, others do not	Agrees with theory
				No observable change in pace to investment in LCD R&D, fabs	Ambiguous
LCD	1996	Hitachi's breakthrough in IPS-mode	Hitachi successfully makes commerical grade IPS panel, reducing LCD uncertainty	No observable change in pace to investment in LCD R&D, fabs	Ambiguous
LCD	1997	Fujitsu's invention of MVA mode	Fujitsu first to develop MVA, reducing LCD technological uncertainty	No observable change in pace to investment in LCD R&D, fabs	Ambiguous
PDP	1998	Market feedback to introduction of early PDP TVs	Reduced market needs uncertainty on PDP TV	Number of firms entering mass production of PDP increase	Agrees with theory
PDP	1998	NHK PDP promotion in Nagano Olympics	Reduced uncertainty on PDP due to DC-PDP's failure to perform	DC-PDP eliminated by all firms, AC-PDP becomes single focus	Agrees with theory
				Number of firms entering mass production of PDP increase	Agrees with theory

In several instances, observations were found to be in agreement with theory. However as a group, evidence was inconclusive. No evidence contrary to theory was uncovered.

The data used for this analysis was gathered in the course of performing research for this dissertation. Accordingly there were several drawbacks in its use, especially the similar timing of numerous uncertainty-reducing events.

Chapter conclusion

This chapter consisted of two sections. The first section weighed evidence regarding propositions developed in Chapter one. The evidence supported the notion firms generally behave as predicted by real options logic. With interpretation, it also agreed with theory that firms making commitments to single technologies under uncertainty would exhibit extreme performance outcomes.

The second section of this chapter discussed post hoc theorizing centering on the question of whether the way firms react to changes in uncertainty over time agrees with what real options logic would predict. Findings either agreed with the predictions of real options or were ambiguous in nature.

The following chapter further discusses the findings of this research overall and presents implications for managers. It also presents limitations of this study and opportunities for future research.

CHAPTER EIGHT: DISCUSSION AND CONCLUSION

This chapter discusses the findings of the study and develops implications for theory and practitioners. It presents the contributions of this research, examines limitations, and offers opportunities for future efforts. The discussion section below first considers the behavior of firms studied then moves on to develop an understanding of the performance implications uncovered by the study. It also addresses the aspect of timing and how national culture and values may impact the way and degree options are developed and pursued.

Discussion

The industry studied in this research was chosen because it exhibited high levels of technological uncertainty while simultaneously appearing to have low levels of customer needs uncertainty. Real options reasoning predicted firms would hold options on technologies in the face of technological uncertainty. The results of this study are in agreement with this prediction. The focal firms in this study all held options on more than one display technology [9].

There are costs associated with developing and holding options in addition to the benefits gained from increased flexibility and reduction of risk. Theory suggested firms that made commitments to technologies instead of holding options would exhibit extreme performance outcomes. Those betting on a losing technology would have poor performance whereas those guessing correctly would have the benefit of the technology

[9] Although in Pioneer's case, OLED options may have not represented alternative to PDP as discussed in Chapters six and seven.

without the costs associated with developing and holding additional technological options. Because the firms in this study held options on alternative technologies, testing this notion required further interpretation. Pioneer and Sharp were found to have made commitments, even if they held options in addition to the commitments.

Analysis of Pioneer and Sharp uncovered performance extremes predicted by theory. Pioneer exhibited very low performance. After sustaining significant losses, Pioneer exited PDP production and is in the process of exiting the TV set industry altogether. Sharp, on the other hand, stood out as the only firm in the study able to leverage its investments in flat panel display technology into a lasting improvement in its position in the TV set industry.

While these findings are in agreement with theory presented, the details behind them do not necessarily fit with theory well. Both Pioneer and Sharp took betting strategies theory did not recommend for an environment such as the flat panel TV industry. Pioneer committed to both a market need, TV sets with large flat screen and high image quality, and simultaneously also committed to PDP. Theory suggests this to be a long odds wager, and Pioneer did not make the winning bet.

Sharp committed to a technology and developed market needs options. By developing options on a large number of applications (markets) for LCD, Sharp was able to reduce its overall exogenous uncertainty. Sharp's high performance in the TV industry was in large part due to its "lucky" bet on LCD. Sharp's lead in LCD was what allowed it to move from an "also ran" TV producer building a durable major position in the TV market. However, Sharp would likely still have exhibited strong performance even if

LCD had not become the dominant TV display because of the large number of opportunities LCD provides it.

Returning to the question of performance discussed above, Sharp's approach was arguably different from that which theory suggested the "lucky" high performer would follow. Theory suggested the lucky firm would commit to a technology and customer needs for TV sets. By not spending money on other options, theory argued, firms would invest less in total than those developing options portfolios including technologies later abandoned. Sharp essentially made a major commitment but also developed a few display technology options distinct from LCD. The cost advantage argument, therefore, has limited relevance in Sharp's case. Instead, what made Sharp's strategy successful was its ability to develop LCD capability and decrease the total uncertainty it faced by applying LCD in many product markets.

When compared with competitors, Sharp had a major lead in LCD according to numerous measures, however Sharp's ability to continue to make large scale investments in modern LCD production capacity is particularly salient. Each new facility brought significant risk and exposure to falling LCD prices; at the same time, cutting edge LCD plants always had better economic performance than plants one or more generations old. Sharp was the only Japanese firm willing to regularly make these investments, allowing it to maintain advantage in cost and panel size.

One can view these investments as a series of commitments to LCD on the part of Sharp. Note that *only* Sharp's most recent G10 plant is completely dedicated to LCD-TV panel production.[10] Although the Kamayama plants had integrated LCD TV production, the LCD output from these plants could have been sold for a variety of different applications. Cutting the LCDs into panel sizes needed by different applications was feasible for these plants.

These extreme performance cases of Pioneer and Sharp aside, the relationship between options portfolios and performance was not clear. In the study, firms with high performance generally developed and held large numbers of options, although this was not the case for all high performers. Multiple potential interpretations exist, however the idea that organizational slack enabled high performing firms to develop more options is particularly salient. Generating and maintaining real options is costly (Reuer & Tong, 2007). Firms with past high performance may have had sufficient resources to enable investment in many different display technologies, even those that may have appeared at the time to have had low likelihood of succeeding. If this is the case, prior performance may have been a predictor of options portfolio width. Accordingly, the performance outcomes of these firms cannot be attributed to options management on their part.

There may be a minimum price of entry to enable options generation that any firm with more than a certain level of resources can achieve (e.g., McGrath & Nerkar, 2004). However, the observations of firms' option portfolios do not suggest the firms studied were below such a level. However, examination of the data suggests that there is not a single threshold of resources that, when met, will allow all firms to develop the any of the options in question, and when not met, not to develop any. Smaller firms may have been limited to which options they could take. For example, while JVC could afford to work

[10] The substrate is so large that it is not economical to cut panels smaller than TV size from it. Source: interview with professor Tsuyoshi Numagami, March 13, 2009.

on LCOS, a-Si LCD would probably have been too costly for it to become very involved with. With this observation in mind, the options portfolios held by firms seemed to have at least as much to do with their resource levels and past performance as they did with subsequent performance. Accordingly, this study cannot argue there were performance benefits associated with developing and holding options on display technologies in this industry.

Given how much change has occurred in the TV set industry over the study period, it is surprising how little has changed about the relative positions of the players in it. Even though this industry experienced a period of high technological uncertainty and dramatic change from CRT to flat panel, the relative rank and performance of the firms in it have not changed drastically. The strongest Japanese firms, Panasonic and Sony, continue to be very large players. Smaller Japanese players including Toshiba, Mitsubishi, Sanyo are still in the industry but have not become major players. Korean firms Samsung and LG were on a growth trajectory and have continued on it through the period of uncertainty. Philips and Thomson were on a shrinking trajectory and remained on it.

Although display technology was the source of high uncertainty, it was not the only source of major technological change to occur in the industry over the study period. Digital technology and standards were adopted across the industry replacing analog technologies of the past. This migration from analog to digital technologies was a very large change for the industry. It increased the importance of electronic and digital devices while it decreased the importance of nuanced analog engineering and manufacturing (Osada, 2006). Whereas seemingly minor aspects of TV set design, such as the positioning of wiring inside the set, could have major impact on the quality of analog sets, digital either worked or it did not. Accordingly, technological capabilities required for success in digital were very different from those needed in analog. Electronic and digital device production also required larger investments in plant and equipment and had much larger minimum efficient scale of production than that required for analog TV set assembly. One might expect these changes to shake up the industry, giving advantage to firms like Toshiba that had significant information technology capabilities and experience in device production. However, as stated above, surprisingly little changed. Toshiba, for example, was unable to take its digital capabilities and turn them into durable market share gains in the flat panel TV market.

Extrapolating this to the larger industry, the rapid technological development in FP TV made it difficult for most firms to develop and maintain leads in flat panel display technologies. Not only was the market uncertainty low for flat panel televisions, it was certain that the market size, once the right feature mix and pricing was achieved, would be very large. The size of this market increased its attractiveness to potential entrants, and increased technological investment and competition between firms. In an environment characterized by such strong technological competition, Sharp's early strength in LCD made it an outlier. Differences between technological abilities of other players at any point in time were small by comparison. If technology had a small impact on differentiation, the importance of existing market position and branding grew, giving the leading incumbent players a strong position.

The development of the digital photography industry shares some aspects in common with that of FP TV. Many firms with some relation to photography or consumer electronics could tell with certainty there would be a large market for digital cameras, well before the technology was developed. Perhaps not surprisingly, many firms developed digital photography options and later entered the market. Not only did traditional camera companies target digital photography, firms from other areas including film manufacturing, consumer electronics and information technology entered into the market. Prior to the switch to digital, Canon and Nikon were the top incumbents. As digital technology grew to take a larger place, the market appeared unsettled and up for grabs. Today, after it has matured substantially however, Canon and Nikon remain the top players. Other players have changed their positions in the industry somewhat, however not a single firm was able to leverage options on digital photography technology to move from being an "also ran" into a major position in the digital camera market.

Timing Implications

One of the difficulties behind using real options as a heuristic is the problem of when to exercise. In order for the value of options to be realized, the firm must at some point commit. Theory suggests options portfolios adjust as uncertainty levels change over time. Evidence uncovered in this study is limited as far as this is concerned; while data does not disagree with this notion, it does not strongly support it either as discussed in Chapter Seven.

Several additional observations about exercise timing can be made from this research. First, in this industry, firms with very strong market power were able to postpone making technology commitments until uncertainty declined. Panasonic made continuing investments in PDP over the years, but as technological uncertainty declined, Panasonic dramatically increased the size of its commitments both to PDP and, through its investment in IPS-Alpha, in LCD. Sony, on the other hand has managed to largely reclaim its position in the TV industry without building its own a-Si LCD production capacity.

Second, it is difficult to see a pattern between exercise timing and performance, leaving open questions such as: what is a good time to commit and how should firms know when they arrive? Interestingly, there seems to be an almost herd-like rush into initial production in LCD and PDP, but follow on investment was varied. In the flat panel display industry, firms need to make ongoing large-scale commitments in order to stay in the game. In LCD in particular, the newest production technology always has the lowest unit production cost. At the same time, each subsequent generation has dramatically larger production scale. Each new cutting edge plant can flood the market with production, causing price erosion, particularly where the more generic panel types are concerned. The dynamics behind this has resulted in a game theoretic feel to investment in production capacity in the later LCD generations, especially G5 and later.

Investments in LCD production have specific economics that differ from investments in many other industries. Accordingly, the impact of exercise timing may be largely industry specific in nature. Arguably, semiconductors, in particular memory chips, may exhibit similar dynamics.

Finally, there is a question of what time should firms switch from a real options logic heuristic to a focused commitment heuristic. Several firms simultaneously developed mass production capabilities for multiple display technologies. In other words, they maintained a real options reasoning heuristic into the mass production stage.

Hitachi and Fujitsu both developed LCD and PDP production capabilities, however, their long-term performance in both displays and TV sets was poor. Each of these firms were trying to develop two production capabilities simultaneously using the same set resources (and attention). Korean firms LG and Samsung were able to develop strong capabilities in both LCD and PDP. However, in each of these cases, the Korean organizations put PDP and LCD capabilities into different Chaebol group companies. In a sense, the separate companies could each commit to one technology, but the group held options. This organizational approach is in agreement with the prescriptions of Raynor (2007). This analysis suggests that while ideal commitment timing may not be identifiable, maintaining the option heuristic for too long may harm performance unless the option can be moved to a related, but separate organization.

National Culture and Real Options Reasoning

The study covered an industry that is primarily Japanese. Japanese firms may be more likely than firms from other, especially non-Asian, countries to develop and hold options. Japanese culture has been characterized by strong uncertainty avoidance (Hofstede, 1991). Therefore Japanese managers may be more inclined to hold options than managers from other countries. There are additional reasons why Japanese firms may develop and hold more technological options than Western firms, discussed below.

Japanese firms often exhibit more involvement of middle and lower hierarchical levels in decision-making processes than their Western counterparts (Nonaka & Takeuchi, 1995). Low cost R&D investments may begin organically and spontaneously as lower and middle level managers commit small amounts of resources to options they and the engineers they work with identify. While this is not restricted to Japanese firms (3M is well known for bottom-up investments of this type), this phenomenon is more common in Japanese firms than Western firms. This may increase the number of low cost R&D options held by Japanese firms.

Although some observers note that lifetime employment is becoming less common in Japan, it is still clear that Japanese society expects firms to provide stable employment. Laying off workers is frowned upon. The need for firms to reduce uncertainty around their ability to provide employment may have broad impact on options holding and exercise. Indeed, one informant in this study suggested the need to maintain the employment of Japanese workers at a CRT-TV plant as a major reason the firm decided to enter FP TV when it did.

Governance of Japanese firms may also increase the likelihood they hold onto options when compared with western counterparts. Stockholders are less important to Japanese firms than to their western counterparts. Shareholder militancy is rare and the market for control very limited in Japan. Japanese firms have little reason to pursue profit maximization to satisfy shareholders. Other stakeholders such as employees, banks, and group companies have more clout than shareholders and these stakeholders are more interested in stability than profitability.

There is reason to believe that Japanese firms (and firms from some other East Asian countries) may retain greater option value from abandoned technologies than their Western counterparts. Research on the Hard Disk Drive (HDD) Industry found Japanese firms tended to retain engineering talent after abandoning technologies, whereas talent in the U.S. tended to move outside the firm in such situations (Chesbrough, 2003; Christensen, 1997). Japanese firms could later apply this talent if and when the firm decided to resuscitate the technology option in question or invest in technologically related options, whereas Western firms may have already lost the capability in question by such a time. In this study, Canon is an exemplar of applying options from abandoned technologies. Canon abandoned its development of FLCD display technology, however it later was able to apply knowledge developed through the FLCD efforts in digital radiography[11]. This suggests good reason for Japanese firms to develop options more broadly than their western counterparts.

However, Japanese firms are not generally good at exiting businesses or closing operations, and therefore may have tendencies to overinvest in an existing option or to maintain it even after it loses value. Indeed, it often takes a crisis or the appointment of a leader with significant non-Japanese experience for firms to take on such restructuring. For example, Canon's president Fujio Mitarai, an executive with long experience in the United States, became well known precisely because he dramatically reshaped Canon, closing or exiting unattractive businesses and increasing profitability (Nihon Keizai Shimbun, 2004).

Whether using a real options approach is more or less suitable for a Japanese firm than a Western one is difficult to say. On one hand, the ability to retain option value may make investment in technology options by Japanese firms relatively more attractive than would be the case for their Western counterparts. On the other, the inability to rationalize

[11] With regards to Canon's display technology development however, no evidence was found suggesting engineers formerly working on abandoned technologies were involved in subsequent display development.

unnecessary activities related to options that are out of the money may be a significant drag on financial performance.

This consideration of national culture concludes the discussion section of this chapter. Next, limitations are presented.

Limitations

This research has a number of limitations. First, there are limitations to its generalizeability. This study focused on an industry in an environment characterized by high levels of technological uncertainty and low levels of market needs uncertainty. Accordingly, it is not generalizeable to industries that do not exhibit these attributes. Theory developed in the second chapter discussed other combinations of technological and market needs uncertainty, however, this study was only able to address one. This was a conscious tradeoff made in favor of depth and quality in this study.

Real options reasoning is a managerial heuristic. There may be more or less effective ways to apply it. One limitation of this research was the inability to uncover more or less effective ways of applying real options reasoning.

Market power had an effect on long-term performance outcomes in this industry. Accordingly, another limitation of this research is the ability to completely isolate the impact of technology options from market power in the industry studied.

As discussed in the previous section, the industry studied in this research is primarily Japanese. This represented a strength of the study but at the same time may have limited its generalizeability to other geographies, especially those beyond East Asia. Japanese firms may have systematic tendencies toward developing and holding more options than their Western counterparts.

The data used in this study also had several limitations. First, available financial performance data did not always align well with the industry segments of interest. Firms in this industry were large and diversified. As a result, financial data covering only the flat panel display and TV set parts of the business were not available in most cases. Segment reporting changed over time, limiting the possibility of long-term analysis. Additionally, available data on TV set market shares were limited. In particular, data on firms with smaller market shares were frequently included in the "other" category of available data. Although private sources of high quality market share data do exist, the cost of obtaining access to this data was prohibitive.[12] Finally, panel specification data was not available for all years of the study.

Lastly, the post hoc analysis of firms' reactions to changes in uncertainty levels also suffered from limitations. First, the situations chosen for analysis were not ideal for this type of analysis. In particular, several developments reducing uncertainty for alternative technologies occurred nearly simultaneously, aggravating interpretation of subsequent events. Second, the data used were not as fine grained as desirable for such a study and were not available for several important years.

Next, while I have taken a variety of measures to ensure data quality and reliability as discussed in Chapter Two, this study is undoubtedly affected by my prior

[12] Academic researchers studying this industry in Japan typically use the same sources as this dissertation for this reason.

beliefs and experiences due to its qualitative nature. I present the statement of reflexivity below to alert the reader to the potential areas where my background may have influenced this research.

Reflexivity statement

I am a white American male and have spent over 8 years living in Japan although not all at once. Shortly after beginning my study of Japanese over 20 years ago, I moved in to the home of a Japanese host family, where I remained for 3 years. My exposure to Japan at this point was as a young adult foreigner however I learned about the country and language much the same way as a child, by watching others and tentatively trying to use things I had observed. Since the point I moved away my host family, I have spent years as a management consultant working in the Japanese language both in Japan and overseas. Many of my clients were Japanese firms or Japanese subsidiaries of non-Japanese firms. As the result of these experiences, I find I have a mixture of Western and Japanese attitudes and values.

In my experience, Japanese managers have a tendency to emphasize rigor and quality of factual data and are somewhat uncomfortable about what they view as speculating beyond what can be seen in the data. Through my experience working with these managers, I may have developed this tendency. As a result, my research may put more emphasis on data and less on interpretation moving beyond the data itself. This bias may be considered as one instance of a general tendency to avoid risk common in Japanese society. Here again, through my exposure to Japanese firms and the society at large, I have developed the tendency to consider uncertainty avoidance and reduction as prudent. In this research, this may have translated into a bias in favor of firms that sought to hedge their bets through investing in multiple technologies.

This study may have been shaped by my long held interest in technological development. I generally have a positive view of firms that are considered technological leaders.

It is possible this study has been impacted by my prior experience with companies in it. As an amateur photographer, I have been a customer of Canon cameras for many years. It would not be surprising if my positive opinion of the firm's cameras had some impact on my analysis of their efforts in other areas. I have also had a professional consulting relationship with one of the tier two Japanese TV firms, although I cannot disclose which because of a confidentiality agreement. While the work I conducted with the company had nothing to do with displays or televisions, the relationship may have caused me to form preconceptions about the firm's capabilities.

Additionally, I have friends who currently work for or have in the past worked for Canon, Panasonic, and Sanyo. Although none had any relationship with displays or TV sets, it is nonetheless possible accounts of their work experiences have had some effect on my research.

Maintaining the above limitations and he potential for bias in mind, contributions and managerial implications are discussed below.

Contributions

This research contributes to the real options logic literature through theory development and empirical examination. The real options literature includes many theory papers but few empirical studies. This study contributes to the real options literature by empirically studying real options under uncertainty.

This research studied the question of whether firms behave as real options logic would predict. It finds support for the notion that firms keep options open in the face of uncertainty, and behave in accordance with the predictions of real options reasoning.

Following calls from extant literature, this research developed real options reasoning theory under multiple types of environmental uncertainty. It proposed and tested performance outcomes of holding and not holding technology options in the face of technological uncertainty. The identification of a low performing firm which had made commitments in the face of uncertainty serves as evidence of the downside of not holding options. Beyond this, the study failed to identify performance improvement associated with holding options. Analysis of the Sharp case, a pattern of investment and high performance not predicted by theory, contributes by adding to existing theory.

In terms of methodology, this research contributes by introducing the concept of an options ladder to visually present and analyze options at different levels of investment and reversibility. This analytic method can be used in future qualitative empirical studies of real options.

This research also contributes to the academic literature through its study of the flat panel TV set industry. This contribution is novel as little work on this industry has been published in academic press on management (Mathews, 2005). Furthermore, extant research on the development of display technologies, including academic and practitioner, has been focused primarily on LCD. Through its inclusion of multiple, competing display technologies over time, this research contributes to the literature on the development of display technologies.

Finally, this research contributes by developing data based upon original Japanese sources. Comparison of Japanese and Western sources uncovered significant limitations to Western coverage. Not only does the quality of this study benefit from using the Japanese data, its usage is novel for a dissertation written in English. The timeline data in the appendix, in particular, allows English readers access to this data.

Managerial Implications

This research found evidence that firms in the flat panel TV industry behaved as predicted by real options reasoning. However, the study did not identify clear-cut performance benefits of developing and maintaining options. Given these findings, is real options logic valuable to managers?

In the case of the flat panel TV industry, applying real options reasoning may have reduced downside risks for firms, but it not have additional positive impact on performance. In industries similar to FP TV, managers can use real options reasoning as a defensive measure. Based upon the findings of this study, managers should not expect applying real options reasoning will increase the likelihood of improving their firm's position in the industry.

This study suggests there are serious difficulties in effectively applying a real options reasoning heuristic regardless of whether performance benefits exist or not. One crucial problem relating to display technologies is that in order to benefit from prior option like investments, the firm at some point in time must make a large commitment to production capacity. However, there is no heuristic to tell the manager when to do so. If he waits until uncertainty has largely declined, the benefits of the investment may dramatically decrease. On the other hand, early commitment does not agree with real options reasoning.

To make matters worse, one can imagine the difficulty a single manager might have in making a decision to switch heuristics as they are almost polar opposites. Can the cautious manager who wants to keep options rapidly change to a commitment mindset? Perhaps the answer lies in different levels of management – one layer could be more inclined to keep options open while another commit. But this, too, presents its own difficulties. In the Japanese sample, it appears the R&D groups almost naturally analyze and develop technology options. Higher level managers decide to make commitments based upon output from R&D. However, as Raynor (2007) points out, to effectively hold competing options at higher investment levels, such as mass production capabilities, the options need to be held in separate group firms or subsidiaries. Hitachi and Fujitsu serve as examples of the downside of not following this prescription. For real options reasoning to work as it should at higher levels then, substantial organizational changes may be required.

Managers can learn several things from the Sharp case. The Sharp experience emphasizes the importance of using multiple mechanisms to reduce overall uncertainty. Sharp was able to lower its total uncertainty, which in turn facilitated decisions to make large, ongoing investments, and maintain a competitive lead. Sharp reduced uncertainty relating to LCD by aggressively identifying and competing in applications for LCD technology, regardless if the end product was made by Sharp or not. This reduced Sharp's reliance on any single product market, but also built a larger base for sales. Sharp could make large plant investments because it knew where the new production would go. Its competitors may not have been able to do so precisely because they did not know in advance. Sharp consistently invested in LCD in more ways than just production capacity however, and the outcome of these investments was a major, long term technological lead in LCD. Together, Sharp could identify new markets for LCD and enter them before competitors had the ability to compete. One could say that investing more in LCD reduced Sharp's uncertainty level because it helped the company maintain a significant competitive advantage. Not many firms will find themselves with advantages as large as Sharp in LCD, however, the Sharp experience does serve as an example of the potential benefits of extending a capability across multiple application markets. A relatively small and unattractive application market may provide substantial uncertainty reduction if several such markets are developed.

The potential for use in multiple application markets should also be given thorough consideration when making investment decisions between different technological options. Although there have been many supporters of PDP technology in general and Pioneer's application of this technology, PDP ended up becoming a less important display technology than LCD, and Pioneer was forced to exit the market. One major difference between PDP and LCD was that due to advantages and disadvantages of the two technologies, LCD appeared to have nearly endless potential applications, while PDP's were very limited. LCD could be made in many sizes, had low energy requirements, and was reliable, making it suitable for a large variety of applications.

PDP on the other hand was difficult to produce in small sizes and consumed a great deal of energy; few display applications existed for this combination. PDP development, for this reason, arguably faced higher levels of uncertainty than did LCD. When making investment decisions between alternative technologies, managers should thoroughly consider possibility for applications of these technologies outside of the target application for which investment is being made.

Another managerial implication from this study is that in industries where technological development is hyper-competitive, non-technological advantages may play a larger than previously expected role in success. In the case of a new to the world product types, technological advantage may play a large role. However, for industries where technological uncertainty is high but customer needs uncertainty is relatively low, strong existing commitments to the customer needs, including those represented by brand and market power, may contribute more greatly to competitive advantage than the difference in technological options held. Accordingly, managers of firms with low market power should exercise caution when considering opportunities to leverage technological capabilities into improved standing in markets characterized by low customer needs uncertainty.

Firms with strong technological capabilities but limited market power may have systematic decision making biases that result in a tendency to over invest in technological development in industries characterized by low market needs uncertainty. Faced with a potentially very large market, engineers may systematically overestimate the firm’s technological capability relative to the importance of other factors, including market power and minimum competitive scale requirements, in being successful in the market.

If this is the case it would not be surprising to see firms develop and hold low level options even if they do not have what it will take to be successful in the market once technological uncertainty is resolved. As technological uncertainty is resolved and the market grows, managers with business backgrounds (as opposed to engineering backgrounds) are likely to play a larger role in decision-making. Such managers may be less concerned about the technology and be more concerned about business issues such as investments required for efficient scale production and requirements for building market presence.

The biases discussed above are consistent with observations of this research as well as interviewee comments. In this study, firms with strong technology options but limited market power often stopped making follow-on investments in market development or cutting edge production capabilities required for cost competitiveness. Managers of firms with low levels of market power should be careful not to overestimate the potential for new technologies to provide opportunities to gain large positions in markets characterized by low market uncertainty. Accordingly, even in the face of technological uncertainty, investments in technology options may be inappropriate for firms significantly lagging strong incumbents in an established marketplace.

Opportunities for Future Research

A number of opportunities for future research exist based upon this study. First, this study focused on an industry characterized by high technological uncertainty and low market needs uncertainty. A tradeoff between depth and breadth of this research was made, with the result that while propositions for industries with low technological uncertainty and high market needs uncertainty were proposed, such an industry was not investigated. Accordingly, one research opportunity is to perform a similar study on an industry of that nature.

Another opportunity is to examine the situation in an environment characterized by simultaneous high levels of customer needs uncertainty and technological uncertainty. Such research would be complex but offers the potential for rich exploration.

The flat panel TV industry was characterized by very rapid technological development and very large potential market size. It is possible that performance due to developing and maintaining options in an industry with similar uncertainty to FP TV but smaller market size and lower competition may differ from this study. Accordingly, future research should identify and investigate such an industry.

As noted above, national culture may play a role in options related behavior. Firms in Japan may maintain option value of R&D more readily than western firms because engineering talent does not often leave the firm. Risk aversion is another factor that varies according to national culture and may play a role in the tendency of managers to make commitments of hold options. Future research should further develop and test cultural drivers of option related behavior.

In addition to the main study, the post hoc analysis of firms reactions to changes in uncertainty levels suggests opportunities for future development as well. Future research should identify and analyze dynamic changes in options portfolios relating to specific changes in uncertainty levels. Isolating one change in uncertainty from others is difficult if, as in this case, the changes occur in rapid succession. To offer easily interpretable results, future studies should consider one time, discontinuous changes in uncertainty because they are often readily identifiable. Ideally, such studies should include several different types of uncertainty changes occurring in different industries.

Conclusion

This dissertation studied real options reasoning under technological uncertainty in the flat panel TV industry. An underlying question in this research has been: is it possible to "outsmart" uncertainty? Based upon this research, firms appear to try to do so in one of several ways. First, they try to make "smarter" decisions. Canon developed technology options in serial. Reading past interviews of Canon managers, it appears each time that Canon was convinced they had logically arrived at "the best" technology for the application. As discussed in the firm level case of Canon, they were unable to outsmart uncertainty in that way. Pioneer is probably another example of this approach.

A second approach firms took was to hold options. While firms doing this didn't often build large investments in technologies that were abandoned, evidence of positive outcomes from this approach was not identified.

The third approach was to decide to drive uncertainty out through action. This was not discussed in detail in the dissertation for a number of reasons. However, Panasonic seems to have been using this sort of a thought process at least some of the time. As uncertainty relating to LCD declined, Panasonic actually escalated its commitment to PDP. Through market power and financial strength, Panasonic appears to have been able to force PDP to work. This kind of a strategy is only possible for a very limited number of firms with extraordinary resources. This research did not seek out firms with such an approach nor was it designed with them in mind. Whether and under what circumstances it might work are a topic for further investigation.

Sharp's approach represents another alternative. Sharp found a technology it had real competitive advantage in, LCD, and committed to it while also developing technology options on alternative display types. Rather than facing one large uncertainty – will LCD become competitive as a TV display – Sharp's approach searched for potential LCD applications across many different product categories. Although each category had uncertainty associated with it, as a group, the diversified applications reduced uncertainty around LCD for Sharp. The lower uncertainty, in turn, made it easier for Sharp to continue to make further LCD related investments.

Of these four approaches, the first two failed to outsmart uncertainty in this study. The third approach, taken by Panasonic, remains a question mark, however its potential usefulness appears very narrow even if it is effective. Finally, Sharp's way of managing uncertainty is interesting, but appears only useful to a few firms having particularly strong technological capabilities. If the flat panel TV industry is at all representative, there is no simple way to outsmart uncertainty, although real options reasoning offers a way to limit the downside potential. A few firms may be able to use strategies followed by Panasonic and Sharp, however the nature of resources required to pursue these strategies suggest they will not be feasible for most firms.

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APPENDIX ONE: ETHICS APPROVAL

IVEY

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Use of Human Subjects – Ethics Approval Notice

Principal Investigator:	Rod White	Review Number: 023/08(BREB)
Re:	PhD student Derek Lehmberg	
Protocol Title:	Commitment & Real Options Logic: an investigation of how firms manage uncertainty between competing technologies in the flat-panel television industry	
Approval Date:	October 1, 2008	End Date: October 1, 2009

This is to notify you that the Ivey School of Business Expedited Research Ethics Board (BREB) has granted expedited approval to the above named research study on the date noted above.

The BREB is a sub-REB of the University of Western Ontario's Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB), which is organized and operates according to the Tri-Council Policy Statement and the applicable laws and regulations of Ontario.

This approval shall remain valid until the end date noted above assuming timely and acceptable responses to the BREB's periodic requests for surveillance and monitoring information.

No deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the BREB except when the change(s) involve only logistical or administrative aspects of the study. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the BREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely effect the safety of the subjects or the conduct of the study.

If these changes require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information must be submitted to this office for approval.

Members [redacted]s in research studies, or declare a conflict of interest, do not partici[redacted]en they are presented to the BREB.

Signature: [redacted]
Craig Dun[redacted]esearch
Chair, Bus[redacted]EB)

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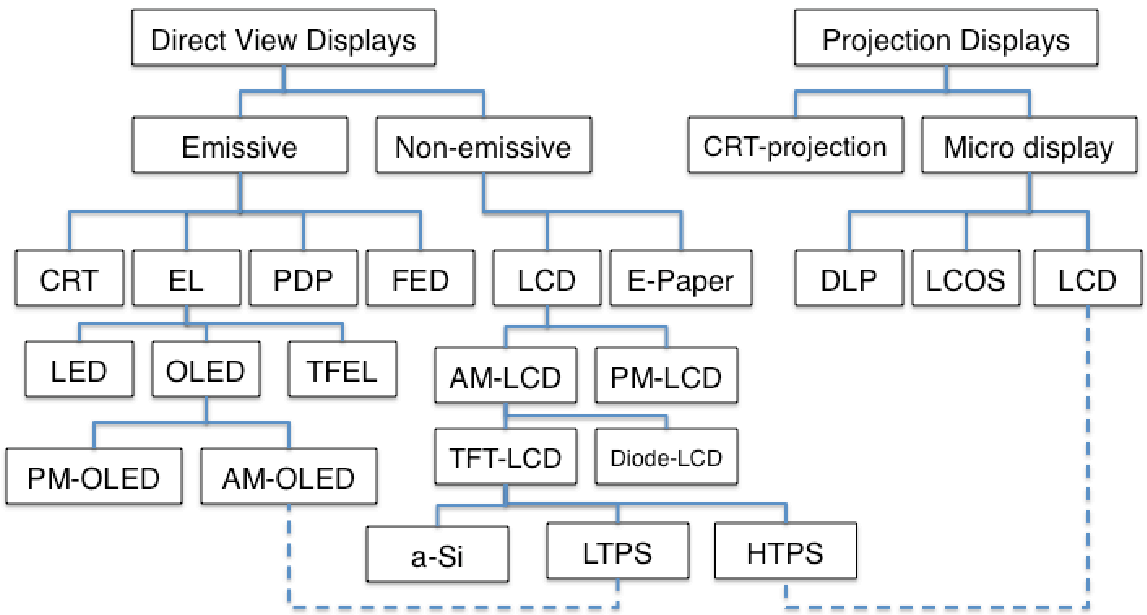
APPENDIX TWO: TYPOLOGY OF DISPLAY TECHNOLOGIES

This appendix presents a typology of display technologies in order to establish the importance of those included in this research and to provide further background for the curious reader. The typology presented below in Figure A-1 is modified from one appearing in Den Boer (2005). Technologies not described in the main text (see Chapter 4) are briefly described below in the course of explaining the typology.

Den Boer (2005) divides display technologies first into projection and direct view types. Projection displays can be rear or front projection. Rear projectors are large boxes with a screen on the front to which images are projected from the back. Front projectors require a separate screen and are generally smaller boxes. Rear projection has been used in consumer television sets for many years, but front projection is much less commonly used for television.

Projection displays can be can be based upon a number of technologies, namely: cathode ray tube, Texas Instruments Digital Light Processing (DLP) technology, Liquid Crystal on Silicon (LCOS), or LCD. Each of these technologies has been used in rear projection television systems. CRT projectors use tubes that are technologically similar to those used in conventional CRT based televisions. CRT projectors have three cathode ray tubes, one each for red, green, and blue. Light is projected through lenses at the end of each tube and onto the screen. DLP technology uses an array of very small mirrors mounted on a silicon chip that adjusts the angle of each mirror continuously. Light is bounced off of these mirrors and through a rotating color filter wheel and onto the display screen. LCOS and LCD both use small, liquid crystal based devices through or off of which light is projected. As a group, rear projection systems have been lower cost than other technologies that also provided large screen, however earlier models were bulky and suffered from dark pictures.

Figure A-1: Typology of Display Technology



Source: adapted from Den Boer, W. 2005. Active Matrix Liquid Crystal Displays: Fundamentals and Applications. Burlington, MA: Newness. p. 198.

Direct view displays are categorized into emissive and non-emissive types. Emissive displays light up on their own, whereas non-emissive require a separate light source. This difference is an important one for some of the firms in the television industry. Informants interviewed had different opinions on whether emissive or non-emissive is more suitable for TV applications, however. One informant commented a reason his firm had invested in PDP because it was emissive and therefore caused less eyestrain for users. Another informant discussed the benefit of LCD, saying it was easier on users' eyes because it was non-emissive.

Non-emissive display types include LCD and e-paper (also called e-ink). E-Paper refers to a group of display technologies that are reflective and appear to be paper-like to the viewer. The technology is not currently relevant to televisions as its ability to display moving images is limited. LCD technologies are discussed in the main text and therefore are not described again here.

There major categories of emissive display technologies include: cathode ray tube (CRT), electroluminescence (EL), Organic Light Emitting Diode (OLED), and Plasma Display Panel (PDP). CRT refers to the large tube technology used until recently in the vast majority of television sets. CRTs have an electron gun that shoots electrons through a vacuum and to a phosphor dot (or pixel) inside the tube, causing it to light up. The phosphor is red, green, or blue. The technology has been developed highly over many years and provides a very good image quality. However, it has drawbacks including weight, size, and high power consumption. These limitations made it impractical to produce CRT TVs with very large diagonal dimensions screen size (NHK, 2004).

EL technology includes several sub-categories. Although each has gone through significant amounts of R&D over the years, OLED is the only one to have received a serious following as a potential display for television applications. OLED is described in detail in the main text (see Chapter 5).

The remaining technologies are also described in the main text. PDP and FED are emissive display technologies that have competed for use in TV sets. PALC is a hybrid technology using Plasma and LCD technologies. Den Boer (2005) did not include it in his typology; perhaps because development ceased a number of years before he wrote the book.

This appendix has presented a typology of display technologies. Some display technologies were not discussed in the main text as they did not have a discernable impact or position relating to the flat panel TV industry. The inclusion of the typology here is meant to provide evidence of the thoroughness of investigation of display technologies performed in this study.

APPENDIX THREE: FIRM LEVEL HISTORICAL TIMELINES

LIST OF FIRM TIMELINES

Year	LCD	PDP	OLED	Other	Event
1966		**X**			Fujitsu, IBM buy rights to Illinois University's PDP patents (Nikkei BP, 1990).
1967		**X**			Monochrome AC-PDP research begins in Fujitsu research lab in Akashi, Hyogo (Kawamura, 2005).
1970	**X**				Fujitsu begins research on FLCD (Sangyo Times, 1992).
1970		**X**			Fujitsu develops Magnesium Oxide protection film for AC-PDP, enhancing product life (Weber et al., 2008).
1972		**X**			Fujitsu begins selling AC memory type plasma display (Nikkei BP, 1990).
1972		**X**			NHK Broadcasting Technology Research Lab and Fujitsu begin to work together on development of monochrome PDP (Kawamura, 2005).
1980	**X**				Fujitsu changes focus to large LCD displays (Sangyo Times, 1992).
1980		**X**			Fujitsu announces color PDP (Nikkei BP, 1990).
1981		**X**			Fujitsu has second place market share for PDP in 1981, with 31%. Fujitsu uses PDPs in computers and in IT applications for financial services companies (Yano Keizai, 1982).
1982		**X**			PDP makers as of 1982: Okatani Electric, Oki Electric, NEC, Fujitsu, Matsushita Denshi Kogyo, Sanya Electronics, Burroughs (Yano Keizai, 1982).
1982				**X**	Fujitsu had a small CRT tube production capability as of 1982 (Yano Keizai, 1982).
1983	**X**				Fujitsu begins TFT LCD R&D (Sangyo Times, 1993).
1986	**X**				Fujitsu begins making B&W STN-LCD displays for use in monitors for its computer line-up (Sangyo Times, 1993).
1988		**X**			Fujitsu develops 3 color PDP for stock price display (Sangyo Times, 1997).
1989	**X**				Fujitsu begins shipping samples of 9.8" multicolor STN-LCD panels (Nikkei BP, 1990).
1989	**X**				Fujitsu develops 640X400 16 gradations DTSN panel (Sangyo Times, 1990).
1989		**X**			Fujitsu beings mass producing 3 color AC-PDP (Kawamura, 2005).
1990	**X**				Fujitsu opens LCD Development Department (Sangyo Times, 1993).
1990	**X**				Fujitsu exhibits laptop computer with 640X400 16 gradation DSTN panel at Business Show (Sangyo Times, 1990).
1990		**X**			Fujitsu develops ADS (Address and Display Separation) method for controlling light gradations of AC-PDP (Kawamura, 2005).
1990		**X**			Fujitsu develops 16 gradation 640X480 pixel AC PDP (FPF8060HRUS) (Sangyo Times, 1990).

1991	**X**				Fujitsu emphasizes video applications for FLCD (Sangyo Times, 1992).
1991	**X**				Fujitsu is producing FLCD samples, but has no mass production facility for FLCD production (Sangyo Times, 1992).
1991		**X**			Fujitsu makes 31" PDP prototype, it was taken to Electronics Show. Fujitsu also shows prototype at Ceatec. Problems occur with the displays including black lines and discoloration (NHK, 2003).
1991		**X**			Fujitsu sells NYSE full color 21" PDPs (Sangyo Times, 1997).
1992	**X**				Fujitsu begins pilot production of TFT-LCDs (Sangyo Times, 1994).
1992		**X**			Fujitsu publishes paper on PDP stripe architecture (Nikkei BP, 1998).
1992		**X**			Fujitsu returns to Ceatec with the new PDP panels resolving earlier problems, and display it as a TV. This was world's first plasma TV (NHK, 2003).
1992		**X**			Fujitsu General begins selling 21" VGA PDP monitor with 260K colors (Kawamura, 2005; Nikkei BP, 1998).
1992		**X**			Fujitsu General begins selling Plasmavision-T21 TV with VGA resolution. Price is 1.25 million yen (Nikkei BP, 1993).
1993	**X**				Fujitsu announced it will build an LCD mass production facility at Yonago (Sangyo Times, 1993).
1993		**X**			Fujitsu begins mass production of 21" VGA AC-PDP (Weber et al., 2008).
1994	**X**				Fujitsu continues FLCD R&D (Sangyo Times, 1993).
1994	**X**				Fujitsu finishes building LCD development and production facility in Yonago (Sangyo Times, 1994).
1994		**X**			Fujitsu develops 40" PDP prototype (Nikkei BP, 2002 (Jitsumu Hen)).
1994		**X**			Fujitsu develops world's first 42" wide color PDP (Sangyo Times, 1995).
1995	**X**				Fujitsu licenses TFT-LCD technology to Samsung Electronics (Deutsche Bank, August, 2004).
1995	**X**				Fujitsu begins production at Yonago facility number one LCD line with 7500 300X400 sheets per month capacity (Sangyo Times, 1997).
1995	**X**				Fujitsu constructs number two line at Yonago (Sangyo Times, 1999).
1995		**X**			Fujitsu develops 42" AC-PDP with 852X480 resolution for TV applications (Nikkei BP, 1995).
1995		**X**			Fujitsu invests 20 billion yen in PDP production facility at Kyushu Electronics Miyazaki plant (Sangyo Times, 1994, 1997).
1995				**X**	Fujitsu introduces color TFT projector (FM-LCP2) capable of 200" image (Sangyo Times, 1995).
1996	**X**				Fujitsu develops 15" XGA TFT LCD for monitor applications (Nikkei BP, 1996).

1996	**X**				Fujitsu begins production at number two LCD plant with a 30 billion yen investment. The line uses 400X500 substrate and has 26K sheets per month capacity (Sangyo Times, 1997).
1996	**X**				Fujitsu develops 3.2" SXGA (1280X1024) resolution high density TFT using LTPS (Sangyo Times, 1997).
1996	**X**				Fujitsu develops Vertical Alignment (VA) LCD display technology (Sangyo Times, 1998).
1996	**X**				Fujitsu develops new liquid crystal material together with Japan Merck. The new material is used in Fujitsu's VA technology allowing for wider viewing angle (Sangyo Times, 1997).
1996	**X**				Fujitsu ends production on its first generation line at Yonago because it cannot efficiently make panels sizes Fujitsu wants (Sangyo Times, 1997, 2002).
1996	**X**				Fujitsu beings producing color filters at its Yonago location (Sangyo Times, 2002).
1996		**X**			Fujitsu begins production at world's first PDP mass production facility in Miyazaki. Production capacity is 10k panels/ mo. 42" WVGA is first product (Kawamura, 2005).
1996		**X**			Fujitsu General announces it will begin selling 42" 852X480 pixel PDP TV. Price is 1.2 million yen (Nikkei BP, 1996).
1996				**X**	As of 1996, Fujitsu does not plan to develop displays for TV or Audio, but will focus on computer, office automation, communication, and factory automation application use displays (Sangyo Times, 1996).
1997	**X**				Fujitsu develops MVA mode TFTs for monitors (Nikkei BP, 1997).
1997	**X**				Fujitsu installs prototype LTPS line at its Yonago plant, integrates LTPS research from central labs and Yonago (Nikkei BP, 1997).
1997	**X**				Fujitsu develops Multi-Domain Vertical Alignment (MVA) LCD display technology, an improvement on VA technology. Viewing angle is over 160 degrees from left, right, top, bottom (Sangyo Times, 1998).
1997	**X**				Fujitsu begins producing 15" MVA mode monitor (Sangyo Times, 1999).
1997		**X**			Philips is receiving PDP supply from Fujitsu as of 1997 (Nikkei BP, 1997).
1997		**X**			Fujitsu develops 25" PDP TV panel with 1280X1024 resolution (Nikkei BP, 1997).
1997		**X**			Fujitsu develops 42" PDP TV panel with 1024X1024 resolution (Nikkei BP, 1997).
1997		**X**			Fujitsu develops 50" full color AC-PDP for full resolution high vision (Kawamura, 2005).
1997		**X**			Fujitsu develops 21" full color PDP (Sangyo Times, 2008).

1998	**X**				Fujitsu develops 12.1" TFT LCD with 800X600 resolution for NBPC applications (Nikkei BP, 1998).
1998		**X**			Fujitsu develop ALIS (Alternative Lighting of Surface) technology for PDP (Nikkei BP, 1998).
1998		**X**			Fujitsu and Philips agreed to cooperate on technologies used in developing PDP for television applications. Improving Fujitsu's 42" PDP for market entry is a focus of the cooperation (Fuji Chimera, 1999).
1998		**X**			Fujitsu and Hitachi announce they will establish a JV called Fujitsu-Hitachi Plasma Display with 50%-50% equity, covering PDP development, manufacturing, and sales, and moved both companys' large PDP businesses into the new company (Fuji Chimera, 1999; Sangyo Times, 2000).
1998				**X**	Fujitsu is researching FED at the Fujitsu Research Lab (Fuji Chimera, 1999).
1999	**X**				Chi Mei Optronics and Fujitsu enter into contract manufacturing agreement for TFT-LCDs (Deutsche Bank, June 2004).
1999	**X**				Fujitsu develops 23.1" New MVA mode TFT panel with UXGA resolution (Nikkei BP, 1999).
1999	**X**				Chi Mei Optronics (CMO) of Taiwan receives technology transfer of MVA from Fujitsu (Sangyo Times, 2005).
1999		**X**			Fujitsu agrees to transfer its monochrome PDP business of Okaya denki. Okaya has produced DC monochrome PDPs, but with the addition of Fujitsu's business, it will add AC PDPs (Sangyo Times, 2000). Fujitsu never reached profitability in the business (Weber et al., 2008).
1999		**X**			Fujitsu begins selling 42" VGA PDP (FP-4200) and 25" SXGA PDP (FP-2500) for computer applications (Sangyo Times, 2000).
2000	**X**				CMO and Fujitsu enter additional contract manufacturing agreement (Deutsche Bank, August, 2004).
2000	**X**				Fujitsu's LCD production is 70-80% 15" panels in 2000 (Nikkei BP, 2000).
2000	**X**				Fujitsu does not have plans to enter LTPS yet (Sangyo Times, 2001).
2001	**X**				Fujitsu exhibits 23.1" MVA mode TFT panel with UXGA resolution (Nikkei BP, 2001 (Jitsumu Hen)).
2001	**X**				Fujitsu continues to develop FLCD technology (Fuji Chimera, 2001).
2001	**X**				Fujitsu has outsourced production of 15" and 17.4" MVA mode LCD panels to CMO. Fujitsu has plans to focus on product development and outsource more volume production (Sangyo Times, 2002).
2001				**X**	Fujitsu General develops full digital video processor for PDP TV (Fuji Keizai, 2005).
2002	**X**				Fujitsu exhibits 20.1" UXGA with MVA model panel at EDEX (Nikkei BP, 2002 (Jitsumu Hen)).

2002	**X**				Fujitsu's LCD revenues are 60-70% from internal customers as of 2002 (Sangyo Times, 2002).
2002	**X**				Fujitsu merged its LCD operations and Yonago Fujitsu into a new entity called Fujitsu Display Technologies Corporation (Sangyo Times, 2003).
2002	**X**				AUO of Taiwan takes a stake in Fujitsu Display Technologies. Fujitsu headquarters holds 80% stake and AUO 20%. AUO will benefit from Fujitsu's advanced display technology, and Fujitsu from AUO's production capability (Sangyo Times, 2003).
2002		**X**			Fujitsu reduces investment in PDP production equipment and states that demand will not grow so quickly (Nikkei BP, 2002 (Jitsumu Hen)).
2002		**X**			Fujitsu General begins selling 61" PDP monitor (Nikkei BP, 2002 (Jitsumu Hen)).
2002			**X**		Fujitsu begins selling cell phone with PM OLED panel (Nikkei BP, 2007 (OLED Hen)). Panel sourced from outside.
2003	**X**				AUO enters into cooperative agreement with Fujitsu Display Technologies. Fujitsu provide technological support on MVA panel development and production, and also receive production from AUO (Fuji Chimera, 2004)
2003	**X**				Fujitsu exhibits 4" field sequential TFT LCD panel (Nikkei BP, 2003 (Jitsumu Hen)).
2003	**X**				Fujitsu begins selling 17"and 19" MVA panels for TV and monitor applications. Panels are produced by CMO (Sangyo Times, 2005).
2004	**X**				Fujitsu Display Technologies exhibits 20.1" TFT panel with LED backlight and 100% NTSC gamut (Nikkei BP, 2004 (Jitsumu Hen)).
2004	**X**				Fujitsu exhibits semi transparent MVA panels at FPD 2004 (Nikkei BP, 2004 (Jitsumu Hen)).
2004	**X**				Fujitsu announces the next generation of MVA, MVA-Superior, at FPD international (Sangyo Times, 2005).
2004		**X**			Fujitsu sues Samsung SDI over PDP patent infringement (Nikkei BP, 2004 (Jitsumu Hen)).
2004		**X**			Fujitsu General releases 55" HD PDP TV (Nikkei BP, 2004 (Jitsumu Hen)).
2005	**X**				As of 2005, 80% of Fujitsu's LCD unit sales are external - the weight of internal sales has dropped dramatically (Sangyo Times, 2005).

2005	**X**					Sharp acquired Fujitsu Display Technology and Fujitsu Research Lab's LCD business - effectively all of Fujitsu's LCD related business. Fujitsu Display Technologies became a wholly owned Sharp subsidiary called Sharp Yonago, possessing a 405 X 515 mm substrate LCD line. According to Sangyo Times (2006), Sharp purchased it in order to gain additional LCD technicians and obtain Fujitsu's MVA technology. Sharp also plans to develop closer ties to Fujitsu as a supplier. The plant has been losing money recently (Fuji Chimera, 2005).
2005		**X**				Fujitsu sold 30% ownership (retaining 20%) in FHP to Hitachi and handed Hitachi the Patents as well. Fujitsu is effectively exiting PDP (Fuji Chimera, 2005).
2005		**X**				Fujitsu General sources plasma display panels from Pioneer, Panasonic (Fuji Chimera, 2005).
2005				**X**		Fujitsu sells its display fabrication equipment business to Ulvac (Nikkei BP, 2005 (Jitsumu Hen)).
2007		**X**				Fujitsu General begins selling Aviamo series of Full HD PDP TVs and TV monitors for US and EU (Nikkei BP, 2007 (Market Hen)).
2008				**X**		Fujitsu General exits consumer Audio Visual business (http://www.fujitsu-general.com/jp/history/2000/index.html)

Year	LCD	PDP	OLED	Other	Event
1990	X				Hitachi introduces 10" color TFT to the market (Sangyo Times, 1992).
1993		X			Hitachi is rumored to have halted PDP technology development temporarily (Economist, 1996).
1994					Hitachi begins producing TFTs on new production line V1. Substrate is 470X370mm (Sangyo Times, 1999).
1995	X				Hitachi develops 10.4" color TFT LCD with SVGA resolution, 12.1" color TFT LCD with XGA resolution (Nikkei BP, 1995).
1995	X				Hitachi develops "Super TFT" technology using In-Plane Switching (IPS) allowing for wider viewing angles than existing TFT technology (Sangyo Times, 1995).
1995	X				Hitachi develops 13.3" XGA TFT LCD panel for computer monitor and TV applications (http://www.hitachi.co.jp/New/cnews/9512/1226.html)
1995	X				Hitachi reaches full 100K units / month production level at new Mobara V1 TFT production line (Sangyo Times, 1997).
1996	X				Hitachi announces its first IPS mode panel (Nikkei BP, 2005(Jitsumu Hen)). Production begins (Nikkei PB, 2007 (TV Hen)).
1996		X			Hitachi establishes New Display Business Promotion Center in its home and information Media Division, begins concentrated effort on developing large color AC-PDPs (Sangyo Times, 1997)
1996		X			Hitachi builds prototype line for PDPs at its facility in Yokohama, invests 3 billion yen (Sangyo Times, 1997).
1996		X			Hitachi exhibits Japan's first 25" color XGA resolution AC-PDP at Electronics Show 1996. It is intended for computer monitor applications (Nikkei BP, 1996; Sangyo Times, 1997).
1997	X				Hitachi begins TFT production on line V2 (Sangyo Times, 1999).
1997		X			Hitachi begins shipping samples of XGA 25" PDP (Sangyo Times, 1999).
1997		X			Hitachi develops 41" XGA PDP panel (Nikkei BP, 1997).
1998	X				Hitachi develops 18" XGA color TFT with wide viewing angle and using IPS mode (Nikkei BP, 1998).
1998	X				Hitachi is operating experimental LTPS line, but has no formal plans yet for mass production line (Sangyo Times, 1999).
1998		X			Hitachi begins selling 25" XGA PDP monitor (Nikkei BP, 1998).
1998		X			Fujitsu and Hitachi agree to establish Fujitsu Hitachi Plasma Displays. The large PDP businesses of both firms are to be integrated into FHP (Business Wire, 1998; Sangyo Times, 2000).

1999	X				Hitachi begins construction of V3 line at Mobara. It will handle 730X920mm substrate (Sangyo Times, 2003).
1999	X				Hitachi begins LCOS development (Sangyo Times, 2003).
1999	X				Hitachi moves LTPS sample / prototype line from its research lab to the Mobara production facility (Nikkei BP, 1999).
1999	X				Hitachi begins selling RPTV with 800X600 resolution using 1.6" LTPS microdisplay (Nikkei BP, 1999).
1999		X			Hitachi begins selling 25" SXGA display, 41" XGA display, and 42" high vision plasma display panels (Sangyo Times, 2000).
2000	X				Hitachi develops 19" TFT panel with 1600X1200 resolution (Nikkei BP, 2000).
2000	X				Hitachi's main customer base for 2000 was Taiwanese notebook assemblers (Fuji Chimera, 2000).
2000	X				In FY 2000, Hitachi's display group has loss of 10. billion yen (Sangyo Times, 2002).
2000		X			FHP develops new driving circuitry TERES which will be lower cost and require less energy (Sangyo Times, 2000).
2000		X			FHP exhibits 32" PDP with XGA resolution and 37" PDP with 1024X1024 resolution at Ceatec (Nikkei BP, 2000).
2000		X			Sony takes an equity stake in Fujitsu Hitachi Plasma Display. Fujitsu 42.5%, Hitachi 42.5%, Sony 15% is the new stake percentages (Sangyo Times, 2001).
2000		X			Hitachi begins selling 37" XGA monitor for commercial applications (http://www.hitachi.co.jp/New/cnews/0003/0330b.html)
2000		X			Hitachi begins selling 42" PDP TV with ALIS technology and BS digital capability in November 2000 (Nikkei BP, 2000). The price is 1.35 million yen (http://www.hitachi.co.jp/New/cnews/0009/0928a.html).
2001	X				Hitachi builds pilot line for LTPS in Mobara (Sangyo Times, 2001).
2001	X				Hitachi exhibits 15" IPS mode impulse type TFT LCD (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				Hitachi exhibits 15" LCD TV with XGA resolution and IPS mode panel (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				Hitachi's V3 TFT line (650X830mm substrate) in Mobara begins production (Sangyo Times, 2001).
2001	X				Hitachi begins selling multimedia PC with TV function called Prius Deck (Sangyo Times, 2002). It later offers the same display with a built in tuner as a stand alone TV (http://www.hitachi.co.jp/New/cnews/2001/1114/index.html)
2001	X				In FY 2001, Hitachi's display group lost 47 billion yen (Sangyo Times, 2003).
2001		X			FHP exhibits 32" PDP using Alis and Teres technologies (Nikkei BP, 2001 (Jitsumu Hen)).

2001		X			FHP begins PDP production aimed at consumer TV applications at its Kyushu No. 2 plant (Sangyo Times, 2003). Total investment is 45 billion yen (Sangyo Times, 2001). Capacity is 30 thousand panels per month (Kawamura, 2005).
2001		X			Hitachi releases 42" PDP TV with 852 x 1024 resolution and ALIS panel (Nikkei BP, 2001 (Jitsumu Hen)). This is a "Hi Vision" (analog high definition) television meant for Japanese household consumption (Kawamura, 2005).
2001		X			Hitachi launches Woo line of PDP-TVs with models in 42" and 37" sizes (http://www.hitachi.co.jp/New/cnews/2001/0830/index.html).
2001		X			FHP enters into JV with Formosa Plastics and AUO in Taiwan. The JV purchases the production equipment from Kyushu FHP's number 1 plant and creates a new production plant. Stakes in the JV are: Formosa plastics 55%, AUO 22.5%, FHP 22.5%. (Sangyo Times, 2002).
2001				X	Hitachi launches Woo brand of flat panel TVs (http://www.hitachi.co.jp/New/cnews/2001/0830/index.html).
2002	X				Hitachi displays announces it wants to support the spread of IPS mode as the de facto technology for LCD TV, and is encouraging licensing activities for this reason (Nikkei BP, 2002 (Senryaku Hen)).
2002	X				Hitachi agreed to license technology and provide technological assistance relating to AS-IPS technology and TFT Color Filter Technology to HannStar of Taiwan (Fuji Chimera, 2003).
2002	X				Hitachi begins prototype LTPS production at Mobara V3 line (Sangyo Times, 2002).
2002	X				Hitachi invests an additional 23 billion yen in V3 line to increase production capacity from 20K sheets/mo to 40K sheets/mo. Volume increase expected in 2004. Target is TV market (Sangyo Times, 2004; Nikkei BP, 2002 (Jitsumu hen)).
2002	X				Hitachi develops 20" LCD TV with super impulse drive to reduce blurring, exhibits at Ceatec 2002 (Nikkei BP, 2002 (Jitsumu Hen); Sangyo Times, 2003). Goes on sale later in the year as first LCD TV in Woo series (http://www.hitachi.co.jp/New/cnews/2002/1017/index.html)
2002	X				HannStar begins producing AS-IPS (Advanced Super In-Plane Switching) 20" wide TV LCD panels with Hitachi technology (Sangyo Times, 2003).
2002	X				Hitachi moves display group to separate subsidiary, Hitachi Displays. Hitachi Displays has two Japanese subsidiaries: Hitachi Display Technologies and Hitachi Display device (Sangyo Times, 2003; Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				In FY 2002, Hitachi Displays lost 15 billion yen (Sangyo Times, 2004).

2002		X			Hitachi releases 32" PDP TV with 852X1024 resolution (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			FHP exhibits 42" 1024X1024 pixel PDP with ALIS (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			FHP brings online additional production capacity to reach 70k panels / month (Kawamura, 2005).
2002		X			Hitachi begins selling 10 PDP TV models using high brightness ALIS panels (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X		Hitachi agrees to do joint R&D on OLED with Rohm, Kyoto University, Pioneer, Hitachi, Mitsubishi Chemicals, NTT (Sangyo Times, 2003).
2002			X		As of 2002, Hitachi is reported to be making good progress on full color OLED development (Fuji Chimera, 2002).
2002			X		Hitachi central research lab announced it had developed driver circuitry that dramatically improved visual quality of OLED displays (Fuji Chimera, 2003).
2003	X				Hitachi Displays exhibits 32" IPS mode HD TFT LCD panel (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Hitachi releases 32" LCD TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Hitachi displays develops IPS mode small panels for cell phone applications (Nikkei BP, 2004 (Senryaku Hen)).
2003	X				Hitachi starts LTPS pilot mass production line at V3 building. Substrate is 730X920mm (Sangyo Times, 2004).
2003	X				In FY 2003, Hitachi Displays had a profit of 5.8 billion yen (Sangyo Times, 2005).
2003		X			FHP exhibits progressive scan 55" PDP (Nikkei BP, 2003 (Senryaku Hen)).
2003		X			FHP develops A1 Series PDPs in 32, 37, and 42" sizes (Nikkei BP, 2003 (Senryaku Hen)).
2003		X			Hitachi releases 42" PDP TV with 1024 X 1024 resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003			X		Hitachi Research Lab is working on OLED R&D, has not decided to focus on large or small particle (Sangyo Times, 2003).
2003			X		Hitachi Displays announces 3.5" QVGA AM-OLED display using small molecule materials at SID 2003 (Fuji Chimera, 2003; Nikkei BP, 2003 (Jitsumu Hen)).
2004	X				Hitachi exhibits new AS-IPS2 panels, an improved version of IPS, at trade show IDW '04. The firm has already begun production (Nikkei BP, 2005 (Jitsumu Hen)).
2004	X				Production of IPS-Pro begins. This technology is first used in 32" TV (Nikkei BP, 2007 (TV Hen)).

2004	X				Hitachi displays makes additional 10 billion yen investment in LTPS production capacity (Nikkei BP, 2004 (Jitsumu hen)).
2004	X				Hitachi Displays begins project to develop TFTs for automotive applications (Sangyo Times, 2008).
2004	X				Hitachi displays obtains license on FFS technology from BOE Hydis. This technology increases viewing angle of LCD displays (Fuji Chimera, 2005).
2004	X				LG Philips LCD and Hitachi cross license IPS technology (Techno Associates, 2008).
2004	X				Hitachi, Toshiba, Panasonic sign formal agreement to JV, will name it "IPS Alpha Technology." (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Hitachi Displays expects to lose money in FY 2004 (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X			FHP announced it will invest 75 billion yen in new plant "Sanbankan" to begin mass production in 2005. (Deutsche Bank. March 11, 2004. FHP to build new PDP plant; Nikkei BP, 2004 (Jitsumu hen)).
2004		X			Hitachi begins selling 55" PDP-TV (Nikkei BP, 2004 (Jitsumu hen)).
2004			X		Hitachi exhibits 2.5" AM-OLED at SID 2004 (Nikkei BP, 2004 (Jitsumu Hen)).
2004				X	Hitachi tries to buy FED related patents from Candescent, but Canon beats them (Consumer Electronics Daily, August 31, 2004).
2005	X				Hitachi Displays and Chimei agree to cross license some LCD related technologies. IPS related technologies not included. (Techno Associates, 2008).
2005	X				Hitachi Displays, Panasonic, Toshiba established IPS Alpha Technology as earlier planned. Original ownership is 50% Hitachi Displays, Toshiba 22%, Panasonic 22%, and Nihon Seisaku Toshi Ginko (a bank) and others 6%. Initial investment totals 70 billion yen (Sangyo Times, 2007). It plans to make 23" IPS panels starting in the second quarter of 2006 (Fuji Chimera, 2005). With Hitachi's large LCD production capability moving to IPS Alpha, Hitachi Displays will refocus its strategy upon small-mid size displays (Sangyo Times, 2006).
2005	X				As of 2005, Hitachi displays sells LCD TV panels to Sony, Toshiba, and Panasonic (Fuji Chimera, 2005).
2005	X				As of 2005, HannStar has sold LCD TV displays to Hitachi, TVE, Compal and Benq (Fuji Chimera, 2005).
2005	X				Hitachi releases 37" HD LCD TV with IPS mode and HD recorder built-in (Nikkei BP, 2005 (Jitsumu Hen)).

2005		X			Hitachi acquires additional 30% stake in FHP from Fujitsu (Fujitsu retains 20% stake), makes the firm a consolidated subsidiary. Fujitsu's Plasma patents were also included in the deal. (Fuji Chimera, 2005; Sangyo Times, 2006).
2005		X			Hitachi and Panasonic agree to cross license PDP patents, cooperate on marketing and standardization of PDP materials and production equipment. Hitachi and Panasonic have announced they plan to cooperate on development, production, marketing, and intellectual property management related to plasma displays. They do not plan to integrate operations at this time, however. (Kotani, 2005 (Hitachi to Matsushita ga PDP Jigyou no hokatsukyogo de goi)). Hitachi Plasma Patent Licensing is established with both Hitachi and MEI taking stakes (Nikkei BP, 2007 (Trend hen)).
2005		X			FHP loses money in the first half of 2005 (Nikkei BP, 2005 (Jitsumu Hen)). FHP takes on organizational changes to improve profitability (Nikkei BP, 2005 (Senryaku Hen)).
2005		X			FHP exhibits world first 42" full HD module (Sangyo Times, 2006).
2005		X			Hitachi releases 55" full HD PDP TV (Nikkei BP, 2005 (Jitsumu hen)).
2005			X		Hitachi Displays develops 2.5" QVGA AM-OLED panel using small particle materials (Fuji Chimera, 2005; Nikkei BP, 2005 (Jitsumu Hen)).
2005			X		Hitachi Displays exhibits 7" OLED panel for automotive applications at Tokyo Motorshow (Nikkei BP, 2005 (Jitsumu Hen)).
2006	X				Hitachi displays moves all TV use LCD organization to IPS Alpha, focuses on small LCDs (Sangyo Times, 2009).
2006	X				IPS alpha develops 32" FHD IPS panel (Nikkei BP, 2007 (Market Hen)).
2006	X				IPS Alpha begins producing 37" Full HD IPS panels (Sangyo Times, 2008).
2006	X				IPS Alpha JV gets additional 30 billion yen investment. New stakes are Hitachi Displays 50%, Toshiba 15%, Panasonic 30%, and others 5%. (Sangyo Times, 2007).
2006	X				Panasonic is planning to take a majority stake in IPS Alpha (Sangyo Times, 2008).
2006		X			Hitachi Displays enters markets for cash machines, vending machines, medical applications and other industrial applications with several different sized displays from 9" to 17" all using IPS technology. (Sangyo Times, 2008)
2006		X			FHP's San Ban Kan, 3rd plant, in Miyagi begins production -- initial investment is 75 billion yen (750 oku), with an additional 10 billion (100 oku) planned. Plans were pushed forward due to growing demand (Sangyo Times, 2006).

2006					FHP begins mass production of 60" FHD PDP (Nikkei BP, 2006 (Senryaku Hen)).
2006			X		Hitachi exhibits 7" OLED at CES (Sangyo Times, 2006).
2007	X				Hitachi exhibits 1.9cm deep 32" ultra-thin LCD TV at Ceatec 2007 (Nikkei BP, 2007 (Trend hen)).
2007	X				Canon and Panasonic announce they will each take 24.9% stakes in Hitachi Displays by the end of March, 2008. (announcement date = 12/2007). Canon plans to increase its investment to take a controlling stake in the future. Canon hopes to work on OLED technology with Hitachi.(http://panasonic.co.jp/corp/news/official.data/data.dir/jn071225-1/jn071225-1.html).
2007		X			Panasonic and Hitachi agree to supply each other with PDPs. Hitachi can use MEI's 103" and MEI can get Hitachi's 85" PDP, in addition to other sizes. (Nikkei BP, 2007 (Trend hen)).
2007		X			Hitachi announces it will procure PDP glass panel materials from Panasonic, moving away from its previous philosophy of producing PDP TVs from end to end. However, Hitachi will not completely exit PDP production. (Sangyo Times, 2009)
2007		X			FHP ends production at Nibankan PDP plant, plans to centralize all PDP production at Sanbankan in Miyazaki (Nikkei BP, 2007 (Market hen)).
2007			X		Hitachi displays continues OLED R&D, but no major developments (Sangyo Times, 2008).
2008	X				Panasonic buys Hitachi's stake in IPS Alpha, makes it a consolidating subsidiary (Nikkei BP, 2008 (Kigyou Bunseki Hen)).
2008			X		Hitachi and Canon begin joint work on OLED development (Nikkei BP, 2008 (Sangyo doko hen)).

Year	LCD	PDP	Projection	Other	Event
1955				X	JVC begins TV assembly (Hiramoto, 1994).
1985			X		JVC begins R&D into light valve technology (JVC, 1999).
1992			X		JVC and Hughes Aircraft form joint venture to develop ILA (JVC, 1999).
1995			X		JVC acquires controlling interest in Hughes-JVC (JVC, 1999).
1996	X				JVC begins selling video cameras with LTPS screens (Nikkei BP, 1998).
1997			X		JVC develops SXGA D-ILA element, enters projection market with a projector using this LCD panel. Production volume is low, and JVC limits itself to Japanese domestic market at first (Sangyo Times, 2001).
1998				X	Canon and JVC cooperate on basic research related to SED. Materials suppliers Nippon Sheet Glass and Noritake Company Limited also participate in basic research (Sangyo Times, 1999).
1999			X		JVC begins selling HD rear projection TVs using D-ILA device. D-ILA is a version of LCOS developed by JVC (Nikkei BP, 1999).
2000			X		JVC develops QXGA (2048X1536 pixel) reflective LCD (LCOS) for projector applications. D-ILA (Sangyo Times, 2002).
2000			X		JVC develops 4K X 2K LCOS device - this meets standards Hollywood studios are pushing for in their Digital Cinema Initiative (Sangyo Times, 2005).
2001	X				JVC releases 15" LCD TV with VGA resolution (Nikkei BP, 200 (Jitsumu Hen)).
2002		X			JVC begins selling 35" and 42" PDP TVs (Nikkei BP, 2002 (Jitsumu Hen)).
2003	X				JVC releases 26" LCD TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			JVC releases 42" PDP TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003			X		JVC introduces 3 new D-ILA devices to bring its line up to 6 models. These range from 0."7 to 1.7" in size and cover SXGA to 720p in resolution (Sangyo Times, 2004).
2004	X				JVC releases 32" HD LCD TV (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X			JVC releases 50" HD PDP TV (Nikkei BP, 2004 (Jitsumu Hen)).
2004				X	JVC re-enters the RPTV business, starting with 61" in the US market (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X		JVC releases 70" HD RPTV with LCOS (Nikkei BP, 2004 (Jitsumu Hen)).

2004			X		JVC begins selling full HD front projector (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X		JVC beings selling 52" and 62" RPTVs in the North American Market using D-ILA liquid crystal device they developed in house (Nikkei BP, 2005 (Senryaku Hen)).
2005	X				JVC releases 40" full HD LCD TV with 32-bit processing (Nikkei BP, 2005 (Jitsumu Hen)).
2005		X			As of 2005, JVC was acquiring PDP supply from Pioneer (Fuji Chimera, 2005).
2005			X		JVC develops full HD D-ILA LCD device for projection applications (Nikkei BP, 2005 (Senryaku Hen)).
2005			X		JVC releases 70" D-ILA LCD based RP TV (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X		JVC begins selling 61" and 52" 720p rear projection TVs in Japan (Sangyo Times, 2006).
2005			X		JVC develops full HD rear projection TV product (Nikkei BP, 2005 (Jitsumu Hen)).
2005				X	JVC exhibits "Super high vision theatre" at Aichi Banpaku with NHK (Sangyo Times, 2007).
2007	X				JVC exhibits LCD panel with 180hz drive at Ceatec (Nikkei BP, 2007 (Market Hen)).
2007	X				JVC develops 3.7cm deep 42" LCD TV. (Backlight portion was developed by JVC.) (Nikkei BP, 2007 (Trend Hen)).
2007	X				JVC plans to sell 3.7cm deep 42" LCD TV in Spring 2008 (Nikkei BP, 2007 (Market Hen)).
2007	X				JVC announces it has developed 12 bit color LCD TV (prior technology was 10 bit) (Nikkei BP, 2007 (Trend Hen)).
2007			X		JVC begins selling 110" rear projection TV (Nikkei BP, 2007 (Market Hen)).
2007			X		JVC changes its projector strategy to move away from rear projectors and focus on front projectors, home theatre. Drop in prices of large Plasma and LCD is given as reason. The firm's D-ILA LCOS device is suitable for either (Sangyo Times, 2008, 2009).
2008			X		JVC exits RP TV (Sangyo Times, 2000).
2008				X	Funai Electronics and JVC agree to cooperate. Funai will market LCD TVs produced in Victor's North American plant, and JVC will market LCD TVs produced in Funai's Poland plant (Nikkei BP, 2008 (Kigyo Bunseki Hen)).
2008				X	JVC announces it will exit the Japanese TV business and focus on overseas markets (Nikkei BP, 2008 (Kigyo Bunseki Hen)).

Year	LCD	PDP	OLED	Other	Event
1974				X	LG and Hitachi enter into JV on CRTs (Sangyo Times, 2002).
1987	X				LG Central Labs begin TFT LCD research (Sangyo Times, 2008).
1988	X				LG Group enters LCD business (Sangyo Times, 1994).
1993	X				LG establishes an LCD Business Unit inside of LG Electronics (Sangyo Times, 2008).
1995	X				LG Electronics and Alps Electric (Japan) establish a Joint Venture named "Frontec" and located at Alps' central research lab, to perform R&D on TFT-LCD technology (Deutsche Bank, August, 2004).
1995	X				LG Electronics develops 12.1"color XGA TFT LCD (Nikkei BP, 1995).
1995	X				LG Electronics begins mass production of TFT LCDs on 365 X 465 substrate mm line (Sangyo Times, 1995).
1997	X				LG Electronics develops 12.1" LTPS panel with 800X600 resolution (Nikkei BP, 1997).
1997	X				LG Electronics develops 13.3" XGA TFT panel (Nikkei BP, 1997).
1997		X			LG Electronics installs prototyping line for PDP (Nikkei BP, 1997).
1998	X				LG Electronics develops 14.1" XGA TFT LCD for NBPC applications (Nikkei BP, 1998).
1998	X				LG Electronics develops 18.1" XGA TFT panel with wide viewing angle (Nikkei BP, 1998).
1998	X				LG Groups' LCD perorations are merged into LG LCD from LG Electronics and LG Semiconductor (Fuji Chimera, 1999).
1998	X				LG LCD has IBM as a client (Fuji Chimera, 1999).
1998			X		LG Electronics beings research into OLED technology (Sangyo Times, 2006; Techno Associates, 2008).
1998			X		LG Electronics develops 4" OLED (Sangyo Times, 2003).
1999	X				LG Electronics and Philips Electronics form LG Philips LCD, a 50-50 JV focusing on LCD production. (Nikkei BP, 2006 (Gyokai Bunseki Hen)).
1999	X				LG Philips LCD exhibits 18.1" XGA TFT LCD panel (Nikkei BP, 1999).
1999			X		LG Electronics develops 8" OLED (Sangyo Times, 2003).
2000	X				Alps and LG JV Frontech is not renewed at the end of the contract (Sangyo Times, 2002).
2000	X				LG Philips Displays exhibits 15" TFT LCD panel with 1600X1200 resolution (Nikkei BP, 2000).
2000	X				LG Philips LCD develops first 20.1" LCD TV panel (Nikkei BP, 2006 (Gyokai Bunseki Hen)).

2000	X				LG Philips LCD begins mass producing 20.1" VGA LCD panels for a Japanese TV maker (Nikkei BP, 2000).
2000	X				Philips and Toshiba cross license patents on display cells, circuits, extend this to LG Philips LCD (Techno Associates, 2008).
2000		X			LG Electronics develops 60" PDP TV use panel with HD resolution (Nikkei BP, 2000).
2000			X		LG Electronics develops 1.8" full color moving picture OLED display with 20 research staff and 200 million yen budget. LG Electronics gets 40 patents for this effort (Sangyo Times, 2003).
2000			X		LG Electronics invests 10 billion yen in production equipment for OLED at Kumi (Sangyo Times, 2003).
2001	X				LG Philips LCD exhibits 20.1" TFT with VGA resolution (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				LG Philips LCD develops 30" TFT for digital TV (Sangyo Times, 2003).
2001	X				LG Japan enters the LCD TV market (Nikkei BP, 2002 (Jitsumu Hen)).
2001		X			LG Electronics begins PDP production in March, 2001 (Nikkei BP, 2001 (Senryaku Hen)).
2001		X			LG Electronics begins selling 60" PDP (Nikkei BP, 2001 (Senryaku Hen)).
2001			X		LG Electronics begins OLED production in September 2001 (Nikkei BP, 2001 (Senryaku Hen)).
2002	X				LG Philips Displays exhibits 42" HD TFT LCD panel - (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				LG Philips LCD announces it has developed 52" full HD display for TV applications - this is world's largest (Fuji Chimera, 2003). It was developed by 25 specialists in approximate 10 month development program (Sangyo Times, 2003).
2002	X				LG Philips develops 20.1" QUXGA LTPS display (Sangyo Times, 2002).
2002		X			LG begins shipping 50" HD PDP TV (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			LG Electronics develops 60 HD PDP panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X		LG Electronics produces cell phone with OLED display -- display is from Tohoku Pioneer (Sangyo Times, 2003).
2002				X	LG begins shipping Korea's first 52" LCD projection TV (Nikkei BP, 2002 (Jitsumu Hen)).
2003	X				LG Electronics release 30" LCD TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				LG Philips LCD exhibits 55" IPS mode FHD TFT LCD panel (Nikkei BP, 2003 (Jitsumu Hen)).

2003	X				As of 2003, LG Philips LCD is Sony's lead TV Panel vendor (LG is using IPS technology) (Fuji Chimera, 2003).
2003	X				LG Philips LCD begins mass production on its 1100X1250mm line (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				LG Philips LCD signs agreement with Korean government to develop major LCD producing industrial park in Paju (Sangyo Times, 2004).
2003	X				LG Philips LCD is the largest LCD manufacturer in the world in 2003 (Nikkei BP, 2006 (Gyokai Bunseki Hen)).
2003		X			LG Electronics and Thomson partner on PDP technology development. Agreement is valid until 2005 (Sangyo Times, 2004).
2003		X			LG develops 50" PDP TV with built-in digital tuner (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			LG Electronics releases 60" PDP TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			LG Electronics develops 71" PDP (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			LG Electronics announces world's largest PDP TV - 76"and FHD compatible (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			LG Electronics begins production on Kumi #2 PDP line. Investment is 13.5 billion yen; it can produce 35K 50" PDP panels/month (Sangyo Times, 2004).
2003			X		LG Electronics finishes construction of first line for PM-OLED production (Sangyo Times, 2006).
2003				X	LG Electronics has 258 billion Korean Won profits in second quarter (Nikkei BP, 2003 (Jitsumu Hen)).
2004	X				LG Philips Displays exhibits 32" TFT with backlight control to improve dynamic range (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				LG Philips Displays exhibits 42" TFT panel with impulse drive (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				LG Electronics releases 30" HD LCD TV (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				LG Philips LCD begins construction on world's largest display cluster (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				LG Philips LCD and Hitachi cross license IPS technology (Techno Associates, 2008).
2004	X				Sony stopped sourcing LCD TV panels from LG-Philips and moved business to Samsung LCD (Fuji Chimera, 2004).
2004	X				LG Philips develops 3 mask process for TFT production - this reduces steps, improves yield from existing methods that used more masks (Sangyo Times, 2005).
2004		X			LG Electronics begins shipping 71" PDP TV (Nikkei BP, 2004 (Jitsumu Hen)).

2004		X			Panasonic Electric Industry requests Japanese government prevent PDP imports due to patent infringements by LG Electronics (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X		LG Philips Displays exhibits 20.1" AM-OLED with 1280X800 resolution on LTPS (Nikkei BP, 2004 (Jitsumu Hen); Sangyo Times, 2005). It is developed together with LG Electronics.
2004			X		LG Electronics begins mass producing PM-OLED panels (Sangyo Times, 2005).
2004			X		LG Electronics is selling 200K OLED panels / month, making it a major player (Sangyo Times, 2005).
2004			X		LG Electronics began mass production of PM-OLEDs using 370X470mm substrate for 1.77" displays to be used in GSM phones sold in China (Sangyo Times, 2007).
2004				X	LG Electronics releases 60" FHP RPTV with LCOS (Nikkei BP, 2004 (Jitsumu Hen)).
2004				X	For the year 2004, Sharp is #1, LG #2, and CMO #3 in LCD production volume (Fuji Chimera, 2005).
2005	X				LG Philips / LG Electronics shows 20.1" WXGA small molecule OLED on LTPS (using RGB) (Nikkei BP, 2005 (Gijutsu Hen)).
2005	X				LG Philips LCD achieves 85% yield ratio in first quarter 2005 for P6 sixth generation plant which started production in August of 2004 (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				LG Philips Displays exhibits 42" TFT TV use panel with 12 bit color (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				LG Philips Displays exhibits 47" full HD LCD TV use panel with LED backlight and area control (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				LG Philips LCD exhibits 55" FHD IPS mode LCD TV panel (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				LG Philips LCD is investing 530 billion yen in a Generation 7 line in Paju (Sangyo Times, 2005).
		X			LG begins mass production on A3 PDP line (Nikkei BP, 2005 (Jitsumu Hen)).
		X			LG Electronics' PDP module business becomes profitable - it was loss making from mid 2004 (Sangyo Times, 2006).
			X		LG Electronics begins making AM-OLEDs using LTPS backplane (Sangyo Times, 2008).
2006	X				US DOJ begins joint investigation with Japanese and Korean Fair Trade Commissions on alleged anti-competitive actions from major LCD producers including Sharp, Samsung Electric, LG Philips, and others (Deutsche Bank, December 2006).
2006	X				LG Philips LCD begins mass production of 42" LCD panels for LCD TV applications on P7 line (Nikkei BP, 2006 (Senryaku Hen)).

2006	X				LG Philips LCD develops 100" LCD panel - world's largest (Nikkei BP, 2006 (Senryaku Hen)).
2006	X				LG announces 3D LCD monitor (Nikkei BP, 2007 (Market Hen)).
2006				X	LG Philips LCD loses money in 2006 and Q1 2007 (Nikkei BP, 2007 (Trend Hen)).
2007	X				Samsung Electric and LG Philips LCD have agree to cross purchasing between their equipment makers (buy from each others equipment makers), a practice previously avoided. Now suppliers of one are no longer excluded from being suppliers of the other (Daewoo Securities, October, 2007).
2007	X				Philips sells its stake in LG Philips LCD back to LG (Nikkei BP, 2006 (Gyokai Bunseki Hen)).
2007	X				LG Electronics finishes construction on LG Poland cluster which includes assembly from LCD module to TV (Nikkei BP, 2007 (Market Hen)).
2007	X				LG Philips LCD develops flexible full color LCD panel (Nikkei BP, 2007 (Market Hen)).
2007	X				LG Philips LCD begins shipping 19.8mm thick 42" TV panels (Nikkei BP, 2007 (Market Hen)).
2007	X				LG Philips LCD announces it will invest 2.5 trillion Korean Won in a new Generation 8 production line (Nikkei BP, 2007 (Trend Hen)).
2007		X			LG Electronics begins production on new PDP line that allows 8 displays / sheet (Nikkei BP, 2007 (Market Hen)).
2007		X			LG Electronics reduces 71" plasma TV price by 80% (Nikkei BP, 2007 (Market Hen)).
2007		X			LG Electronics integrates the Plasma Rear Panel operation of LG Micro to integrate PDP operation altogether (LG Micro had been producing PDP backplane) (Sangyo Times, 2008).
2007		X			LG Electronics shuts down production on Kumi A1 PDP line (Sangyo Times, 2009).
2007			X		LG Philips LCD to source OLED materials from UDC (Nikkei BP, 2007 (Market Hen)).
2007			X		LG Philips LCD develops 2.4" and 3" AM-OLED prototypes (Sangyo Times, 2008).
2007				X	LG Philips LCD loses 177 billion Korean Won in the fourth quarter of 2006 (Nikkei BP, 2007 (Market Hen)).
2007				X	LG Electric sues China's largest TV maker, TCL Thomson Electronics (TTE) for patent invasion (Nikkei BP, 2007 (Market Hen)).
2008	X				LG Display is the new name of the LG Philips LCD entity after Philips liquidated its share of the JV (Nikkei BP, 2008 (Kigyo Bunseki Hen)).

2008	X				LG Display Co begins installing generation 8 equipment at P8 plant (Nikkei BP, 2008 (Sangyo Doko Hen)).
2008		X			LG Group merges PDP related businesses into LG Electronics' PDP business unit (Sangyo Times, 2009).
2008		X			LG Electronics changes over Kumi PDP module Line (A1) to solar panel production. It plans to retain 2 PDP lines (Sangyo Times, 2009).
2008			X		LG's OLED business is moved from LG Electronics to LG Philips (Sangyo Times, 2008).

Year	LCD	PDP	OLED	other	Event
1955				X	Mitsubishi Electric begins TV assembly (Hiramoto, 1994).
1970	X				Mitsubishi began LCD research program with longer term goal of television application. The firm had been doing some LCD work in a wall hanging TV development group at the central research lab. This research had also developed EL, PDP, and flat CRT technologies (Numagami, 1999).
1970				X	Mitsubishi Electric exhibits small EL TV prototype at the 1970s Japan World Exposition (Numagami, 1999).
1973		X			Hitachi and Mitsubishi develop grey scale technologies for AC-PDP (Weber et al., 2008).
1974	X				Mitsubishi announces LCD TV 6400 dot LCD TV in academic conference (Nikkei Electronics, 1974).
1975		X			Mitsubishi sells neon orange type PDP on make-to-order basis (Nikkei BP, 1990).
1976	X				Optrex is formed as a JV between Asahi Glass and Mitsubishi Electric to produce LCDs for calculators and clocks (Sangyo Times, 1992). Optrex remains in PM-LCD domain, and does not enter AM-LCD or Television applications.
1989	X				Mitsubishi Electric establishes LCD Device Development Center at its materials research lab in Amagasaki (Sangyo Times, 1990).
1989	X				Mitsubishi Electric successfully develops 5 and 10" color TFT displays (Sangyo Times, 1990).
1989	X				Mitsubishi Electric begins shipping samples of its 5" color TFT to Mitsubishi auto for consideration for in-car TV applications (Sangyo Times, 1990).
1989		X			Mitsubishi Electric develops DC PDP (Sangyo Times, 1999).
1990	X				Mitsubishi Electric begins selling Maxy line of computers with color TFT displays (Sangyo Times, 1990).
1991	X				Mitsubishi and Asahi Glass establish joint venture called Advanced Display to develop TFT LCD. Mitsubishi has 80% share and Asahi 20%. Located in Kumamoto (Sangyo Times, 1992).
1991	X				ADI builds TFT-LCD prototype development line (2 P line) in Mitsubishi Kumamoto plant (Sangyo Times, 1999).
1992	X				Advanced Display starts operation. ADI's initial equipment includes a pilot line for improving yield, reducing cost and fabricating samples. It is not meant for mass production. Focus is completely large TFT-LCDs (Sangyo Times, 1993).
1992	X				Advanced Display begins sample production (Sangyo Times, 1992).

1993	X				ADI demonstrates 9.5 and 12" TFT LCDs at 1993 Electronics Show (Sangyo Times, 1993).
1994	X				ADI builds additional line (4P line) at Kumamoto plant (Sangyo Times, 1999).
1994		X			Mitsubishi Electric stops DC PDP development, focuses only on AC PDP (Sangyo Times, 1999).
1995	X				Mitsubishi Electric (ADI) began mass production of amorphous silicon TFTs in 1995 (Fuji Chimera, 2000).
1995	X				ADI changes from development company to manufacturing company (Sangyo Times, 1999).
1995		X			Mitsubishi Electric successfully developed 20" PDP, began shipping samples (Sangyo Times, 1995).
1996	X				Mitsubishi Electric develops, begins shipping samples of 15.1" XGA TFT LCD for monitor applications (Nikkei BP, 1996; Sangyo Times, 1997).
1996		X			Mitsubishi develops 40" VGA resolution PDP for TV applications (Nikkei BP, 1996).
1996		X			Mitsubishi Electric begins construction of PDP pant in Nagaoka (Sangyo Times, 1999).
1997	X				ADI plans to begin shipping LTPS panels in 1998 (Nikkei BP, 1997).
1997	X				ADI transfers LCD technology to CPT (Taiwan), assists in construction of line at CPT (Nikkei BP, 1998). ADI will provide CPT with LCD production technology relating to 12.1" SVGA, 12.1" XGA, and 15.1" XGA displays. CPT will build a plant using the same technology as existing ADI 410X520 mm plant. Mitsubishi will have right to purchase one third of CPT's production (Sangyo Times, 1998).
1997	X				Mitsubishi Electric exhibits 12.1" TFT panel with 800X600 resolution (Nikkei BP, 1997).
1997		X			Mitsubishi Electric begins mass production of PDPs at its Nagaoka plant (Fuji Chimera, 2000).
1997		X			Mitsubishi begins shipping 40" VGA PDP (Sangyo Times, 1999).
1997		X			Mitsubishi Electric begins selling 46" PDP monitor with 852X480 resolution (Nikkei BP, 1997).
1998	X				ADI develops 15" XGA color TFT for monitor applications (Nikkei BP, 1998).
1998		X			Mitsubishi Electric decides to stop PDP production and freeze further investment into PDP. Unclear what the firm will do with the business (Sangyo Times, 1999).
1999	X				Mitsubishi Electric discusses how it has increased its production capacity through its relationship with CPT. It also says it will focus on non-commodity types of displays for large customers (Nikkei BP, 1999).

1999	X				Mitsubishi Electric exhibits 15" 1280X960 resolution (Quad VGA) LCD panel (Nikkei BP, 1999).
1999	X				Mitsubishi Electric bought out ADI JV partner Asahi Glass to make ADI a wholly owned subsidiary (Fuji Chimera, 2000).
1999		X			Mitsubishi Electric agrees to jointly develop PDP with Taiwan's CPT. Mitsubishi plans to buy PDPs from CPT once production can begin (Fuji Chimera, 2000).
1999		X			Mitsubishi ceases production of PDPs, and continues with R&D only. Smaller than expected market size and inability to break even are given as reasons (Fuji Chimera, 2000).
2000	X				CPT begins producing LCDs using Mitsubishi Electric's technology. Mitsubishi is contracting production - main focus is 14.1" (Sangyo Times, 2001).
2001	X				Mitsubishi Electric exhibits 2.15" LTPS display with DRAM on board (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				Mitsubishi Electric exhibits 15" XGA LCD TV panel with overdrive (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				Mitsubishi Electric begins LTPS production at Shizui plant (Sangyo Times, 2002).
2001	X				Mitsubishi Electric develops memory embedded LCD using LTPS (Sangyo Times, 2002).
2001	X				Mitsubishi Electric plans to produce LTPS for cell phone applications (Sangyo Times, 2002).
2002	X				Mitsubishi Electric exhibits 18.1" XGA TFT LCD panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				Mitsubishi Electric exhibits 22" Overdrive TFT LCD panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				Mitsubishi establishes MELCO Display Technology - this will focus on developing, producing, and selling small and mid-sized TFT-LCDs (Fuji Chimera, 2002; Sangyo Times, 2003).
2002	X				Mitsubishi Electric ceases OEM LCD purchasing from CPT (Fuji Chimera, 2003).
2002				X	Mitsubishi Electric begins selling DLP based rear projector (Sangyo Times, 2003).
2003	X				Mitsubishi Electric exhibits 22" LED backlit TFT LCD panel with 105% NTSC Gamut (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Mitsubishi Electric exhibits XGA resolution OCB LCD prototype with 4ms response speed at FPD International 2003 (Nikkei BP, 2004 (Jitsumu Hen)).
2003	X				Mitsubishi Electric releases 30" LCD TV with HD resolution for US market (Nikkei BP, 2003 (Jitsumu Hen)).

2003	X				Mitsubishi Electric's LCD business returns to the black. The change is driven by refocusing from commodity items such as monitors to niches such as POS, ATM, cameras, auto, industrial, medical, etc. (Sangyo Times, 2004).
2003			X		Mitsubishi Electric is developing small particle OLED at their research lab and an outside partner (Sangyo Times, 2004).
2003				X	Mitsubishi Electric introduces 82" FHD rear projection TV with LCOS (Nikkei BP, 2003 (Jitsumu Hen)).
2004	X				Mitsubishi Electric exhibits 22.2" TFT with adjusted backlight (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Mitsubishi Electric releases 37" FHD LCD TFT TV (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Mitsubishi Electric continues to work on Feed Forward Driving and Natural Color Matrix video processing technologies for driving LCD TVs and other multimedia displays (Sangyo Times, 2004).
2004	X				Mitsubishi Electric announces it does not plan to make large LCD panels, and will transfer OCB technology to other firms when it finishes development (currently expected in 2007) (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X			Mitsubishi Electric confirms it has exited the PDP market (Deutsche Bank, March 11, 2004).
2005	X				Mitsubishi Electric exhibits 23" TFT TV use panel with 6 color backlights (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				Mitsubishi Electric decides to stop developing its LTPS business (Sangyo Times, 2008).
2005		X			Mitsubishi continues to purchase Plasma display panels from Pioneer to use in TV sets (Fuji Chimera, 2005).
2005				X	Mitsubishi Electric releases 62" DLP based RP-TV (Nikkei BP, 2005 (Jitsumu Hen)).
2006	X				Mitsubishi Electric exits LCD monitor panel production (Sangyo Times, 2009).
2006	X	X	X		Mitsubishi exits flat panel display (Fuji Chimera, 2006).
2006				X	Mitsubishi develops xvYCC color laser based projection TV. World's first. (Fuji Keizai, 2007 (Denki Maker R&D Survey)).
2007	X				Mitsubishi Electric sells entire 40% stake in Optrex to fund Nihon Sangyo Partners (Sangyo Times, 2008).

Year	LCD	PDP	OLED	Other	LCD
1969	X				Kahn, a recent PHD from the US begins working on LCD technology at NEC (Numagami, 1999).
1969				X	Samsung and NEC set up joint venture on CRTs; this later becomes Samsung SDI (Sangyo Times, 2002).
1971		X			NEC begins single color PDP production (Fuji Chimera, 2003).
1974		X			NEC begins selling AC-PDPs (Nikkei BP, 1990).
1981		X			NEC has top market share for PDP in 1981 with 35%. It is strong in segment displays and competes with Fujitsu in POS, ECR (Yano Keizai, 1982).
1982		X			PDP makers as of 1982 included Okatani Electric, Oki Electric, NEC, Fujitsu, Matsushita Denshi Kogyo, Sanya Electronics, and Burroughs (Yano Keizai, 1982).
1987	X				NEC establishes Electric Display Development Department, begins R&D on TFT-LCD for office automation applications (Sangyo Times, 1990; 1993).
1988	X				NEC develops prototype 4.3" portable LCD TV panel (Sangyo Times, 1990).
1988	X				NEC develops prototype 9" laptop LCD display (Sangyo Times, 1990).
1988		X			NEC decides that AC-PDP is the most promising large flat panel technology and starts R&D with aim to create wall mounted TV at the NEC central research labs (Kawamura, 2005).
1988		X			NEC begins research on color PDP (Fuji Chimera, 2003).
1989	X				NEC develops 9.3" prototype a-Si TFT LCD (Nikkei BP, 1990).
1989	X				NEC Home Electronics enters LCD TV business (Nikkei BP, 1990).
1989	X				NEC begins mass producing 4.3" a-SI TFT panels (Nikkei BP, 1990).
1989	X				NEC is using a prototype LCD line at Tamagawa for development (Nikkei BP, 1990).
1989		X			NEC develops 26 inch PDP with 576X256 resolution (Nikkei BP, 1990).
1990	X				NEC starts color LCD development promotion office and new development project (Sangyo Times, 1994).
1990	X				NEC decides to build color TFT LCD mass production line in Kagoshima, invests 10 billion yen (Sangyo Times, 1990).
1990	X				NEC exhibits the world's first laptop with color TFT (PC-9801 model F5) at Business Show in Tokyo (Sangyo Times, 1990).
1990	X				TFT-LCD mass production begins at Kagoshima plant (Sangyo Times, 1992).

1990		X			NEC develops 10 inch prototype PDP with 120X160 resolution (Kawamura, 2005).
1991	X				NEC fully enter into LCD business (Sangyo Times, 1992).
1991	X				NEC begins large scale production of 10" color TFT (Sangyo Times, 1993).
1991	X				NEC introduces laptop using 10" color TFT screen - world's first (Sangyo Times, 1993).
1991		X			NEC announces it can make full color AC-PDP at academic conference (Kawamura, 2005).
1992		X			NEC exhibits 19 inch plasma display with 240X320 resolution and 128 gradation levels (Kawamura, 2005).
1992		X			NEC establishes color PDP development center (Sangyo Times, 1995).
1993	X				NEC develops 100" color TFT LCD projector using 4.2" XGA a-Si panel (Nikkei BP, 1993).
1993	X				NEC begins selling TFT projector for engineering work station applications. It is priced at 10 million yen (Nikkei BP, 1993).
1993	X				NEC develops 10.4" XGA TFT LCD panel for portable workstation applications (Nikkei BP, 1993).
1993	X				NEC develops 13" XGA panel for office automation applications (Nikkei BP, 1993).
1993	X				NEC develops 6.5" VGA TFT LCD for sub-notebook applications (Nikkei BP, 1993).
1993	X				NEC is developing polysilicon TFT technology (Sangyo Times, 1993).
1993	X				NEC invests 30 billion yen, begins ramping up production at second line (K2) in Kagoshima (Sangyo Times, 1993, 1997).
1993		X			NEC is considering establishing a PDP business within the next 2 to 3 years (Nikkei BP, 1994).
1993		X			NEC installs PDP production line at its development center (Kawamura, 2005).
1994	X				NEC develops 10.4" VGA TFT LCD panel (Nikkei BP, 1994).
1994	X				NEC develops 9.4" TFT LCD with 800X600 resolution (Nikkei BP, 1994).
1994	X				NEC develops 12.1" XGA TFT LCD panel (Nikkei BP, 1994).
1994	X				NEC begins full production at new line (K2) in Kagoshima (Sangyo Times, 1994).
1994	X				Production begins at new line (A-1) in Akita (Sangyo Times, 1994).
1994	X				NEC Home Electronics introduces 9.5" TFT LCD TV (Sangyo Times, 1994).
1994		X			NEC develops 40" AC-PDP for AV applications (Nikkei BP, 1994).

1994		X			NEC exhibits 40" WVGA panel at Electronics Show. This was the largest AC-PDP ever made at the time. It features 256 gradation levels (Kawamura, 2005).
1995	X				NEC develops 12.1" TFT LCD with 800X600 resolution (Nikkei BP, 1995).
1995	X				NEC develops Super Fine Technology LCDs with IPS mode technology at its core (Sangyo Times, 2004).
1995		X			NEC establishes a special project to promote color PDP business development (Sangyo Times, 1995).
1995		X			NEC develops 33" AC PDP with 840X480 resolution for TV applications (Nikkei BP, 1995).
1995		X			NEC begins construction of PDP production line at Tamagawa facility. PDP line investment is 6 billion yen. Initial production to be one thousand panels per month (Sangyo Times, 1995, 1997).
1996	X				NEC develops 13.3" XGA TFT for NBPC application (Nikkei BP, 1996).
1996	X				NEC develops 14.1" XGA TFT LCD for monitor applications (Nikkei BP, 1996).
1996	X				NEC develops 20.1" 1280X1024 (SXGA) TFT LCD display for monitor applications (Nikkei BP, 1996).
1996	X				NEC begins construction of new 550X650 line (A2) in Akita. Total investment is 24 billion yen (18 equipment, 6 building) (Sangyo Times, 1997).
1996	X				NEC develops Super Fine TFT (SFT) technology that increases viewing angle to 160 degrees vertical and horizontal (Sangyo Times, 1997).
1996		X			Tamagawa office ramps up PDP production (Fuji Chimera, 2003).
1996		X			NEC Home Electronics announces it will begin selling 42" 852X480 pixel PDP TV. Price is below 1.2 million yen (Nikkei BP, 1996).
1996		X			NEC begins shipping sample plasma display panels to Japanese TV manufacturers (Sangyo Times, 1997).
1996		X			NEC begins construction of new plant in Kagoshima to produce color PDPs. It will be world's first to produce two 42" screens per substrate. Investment is 25 billion yen (Sangyo Times, 1999).
1997	X				NEC develops 15" XGA TFT panel (Nikkei BP, 1997).
1997	X				NEC develops 20.3" TFT with 1600X1200 resolution (Nikkei BP, 1997).
1997	X				NEC is working on developing LCDs for projection applications including both a-Si and LTPS (Sangyo Times, 1997).
1997	X				NEC is purchasing 11.3" LCDs from Hoshiden, because Hoshiden's substrate dimensions produces this size more efficiently than NEC's (Sangyo Times, 1997).

1997	X				NEC begins shipping samples of three new ultrathin (6.4mm) ultra light TFT modules for notebook computer applications (Sangyo Times, 1998).
1997	X				NEC beings LCD production at A2 line in Akita (Sangyo Times, 1998).
1997		X			NEC develops 50" PDP TV with HD resolution (Nikkei BP, 1997).
1997		X			NEC begins selling 50" plasma High Vision (Japanese high definition standard) TV (Sangyo Times, 1999).
1997		X			NEC Home Electronics begins selling 42" and 33" plasma TVs (Sangyo Times, 1999).
1997		X			NEC begins producing Plasma TVs at NEC Nagano location (Sangyo Times, 2000).
1998	X				NEC develops 15.4" XGA TFT LCD for monitor applications (Nikkei BP, 1998).
1998	X				NEC develops prototype 11.3" color TFT LCD with 1600X1200 resolution (Nikkei BP, 1998).
1998	X				NEC begins shipping samples of 15.4" full color SXGA (1280X1024) panels (Sangyo Times, 1999).
1998	X				NEC Home Electronics ships 20.1" full color TFT LCD monitor with wide viewing angle technology (Sangyo Times, 1999).
1998		X			NEC begins mass producing PDPs at Kagoshima (Nikkei BP, 1997).
1998		X			NEC and Thompson announced they agreed to cooperate on development of PDP, PDP-TV, and PDP monitors. NEC will also supply Thomson with Plasma panels (Fuji Chimera, 1999).
1998		X			NEC develops high resolution 42" PDP (Nikkei BP, 1998).
1998				X	Takemura et al paper on FED technology is presented at IEDM (Nikkei BP, 2005 (Kihon Gijutsu Hen)).
1998				X	Yoshiki et al paper on FED technology presented at IVMC (Nikkei BP, 2005 (Kihon Gijutsu Hen)).
1999	X				NEC announces it will invest 10 billion yen in a used 370X470 LCD line - this investment is meant to be a stop gap until they make an investment in a major new line (Nikkei BP, 1999).
1999	X				NEC builds additional color TFT volume production line at Kagoshima with used equipment to keep cost down and get the production running quickly (Sangyo Times, 2000).
1999	X				NEC develops 9.4" 1600X1200 LCD resolution panel for photo viewing applications (Nikkei BP, 1999).
1999	X				NEC develops color a-Si TFT display with double the pixel density of prior a-Si TFTs. 9.4" display has 211 pixels/inch (Sangyo Times, 2000).
1999			X		NEC develops 5.7" OLED prototype with 320X240 resolution (Nikkei BP, 1999).
1999				X	NEC closes its CRT business (Nikkei BP, 2000).

2000	X				NEC develops 20.1" LCD TV panel with VGA resolution (Nikkei BP, 2000).
2000	X				NEC develops 20" UXGA LCD panel (Nikkei BP, 2000).
2000	X				As of 2000, NEC has a focus on amorphous silicon TFT for three uses: monitors, notebook PCs, and industrial usage (Fuji Chimera, 2000).
2000	X				NEC develops 20" a-Si TFT display capable of high vision content with 1920X1200 pixel resolution (Sangyo Times, 2001).
2000	X				NEC is investing 3 billion yen at NEC Akita to build a line capable of making reflective LCDs. This will be used in cell phones (Sangyo Times, 2001).
2000		X			NEC develops 42" PDP TV use panel with 853X480 resolution (Nikkei BP, 2000).
2000		X			NEC is first to introduce a 42" plasma TV with a list price below 1 million yen. (Plasma X PX-42VT) (Sangyo Times, 2001).
2000			X		NEC exhibits full color OLED prototype (Nikkei BP, 2000).
2000			X		Samsung SDI and NEC agree to cooperate on OLED (Sangyo Times, 2001).
2000			X		Samsung SDI and NEC jointly develop 2" OLED for cell phone application (Sangyo Times, 2001).
2000				X	NEC says that it is no longer developing FED technology (Nikkei BP, 2000).
2000				X	NEC loses 12 billion yen on display business during 2000. It had profits of 10 billion yen in 1999 (Sangyo Times, 2002).
2000				X	NEC Home Electronics exits TV business (NEC Annual Reports, 1999, 2000).
2001	X				NEC exhibits 2.5" reflective TFT LCD panel (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				NEC exhibits 23" TFT panel with IPS mode and HD resolution (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				NEC exhibits impulse type TN mode TFT panel (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				NEC begins shipping samples of 23" wide XGA for multimedia monitor (Fuji Chimera, 2002).
2001	X				NEC and CMO of Taiwan enter into alliance. They will cooperate on developing TFT-LCDs for notebooks and monitors. NEC will outsource 14.1" LCD manufacturing to CMO (Nikkei BP, 2001 (Senryaku Hen)).
2001	X				NEC exits market for LCDs used in notebooks and common computer monitors after obtaining supply agreement from CMO (Sangyo Times, 2004).
2001		X			NEC exhibits 61" PDP TV with HD resolution (Nikkei BP, 2001 (Jitsumu Hen)).

2001		X			NEC decides to build a new PDP line at Kagoshima. It will invest 27 billion yen in the project (Sangyo Times, 2002).
2001		X			NEC introduces the world's largest commercial PDP - 61" (Sangyo Times, 2002).
2001		X			NEC and Thomson Multimedia agree to establish a 50-50 JV to develop, produce, and sell PDP globally (Sangyo Times, 2002). This never materializes.
2001			X		NEC begins selling cell phone with PM OLED panel (Nikkei BP, 2007 (OLED Hen)).
2001			X		Samsung and NEC establish Samsung NEC Mobile Displays in Korea to develop and produce OLED displays (SDI 51%, NEC 49%) (Sangyo Times, 2001). Note: As of 2001, NEC owns 4.4% of Samsung SDI (Sangyo Times, 2001).
2002	X				NEC and SVA (China) agree to form color TFT producing JV in Shanghai. SVA will take 75% and NEC 25% stake. Total planned investment is 50 billion yen (Sangyo Times, 2003).
2002	X				NEC and SVA (China) enter into contract manufacturing agreement. SVA is to manufacture LCDs for NEC beginning in 2004, in its 5G plant (Deutsche Bank, August, 2004).
2002	X				NEC develops 5.24 megapixel 20.1" TFT LCD with super wide viewing angle (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				NEC has decided to establish a new company, NEC LCD Technologies, to focus on LCD market and develop NECs strategic shift from computer-related displays to high end niches (e.g., FA, Medical, CAD). LCD capability will be transferred to the new firm (Sangyo Times, 2003).
2002		X			NEC announces it will divide the TFT business group and PDP operations (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			NEC announces it will spin off PDP operations into new subsidiary called NEC Plasma Display (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			Sony is negotiation with NEC on cooperation in PDP (no details given) (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			NEC Plasma Display ramps up second generation PDP line (Nikkei BP, 2002 (Senryaku Hen)).
2002			X		NEC announces 1.9" AM-OLED with 6 bit color (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X		NEC successfully puts OLED driver on display glass making first system on glass OLED (Sangyo Times, 2004).
2002			X		NEC and Samsung SDI jointly invested in LTPS pilot line for OLED applications (Nikkei BP, 2002 (Senryaku Hen)).
2003	X				NEC establishes separate company for LCD, called "NEC LCD Technology" as previously announced (Nikkei BP, 2003 (Jitsumu Hen)).

2003	X				NEC LCD develops 21.2" super high resolution QXGA TFT panel (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				NEC has stopped OEM purchasing from CMO because of LCD prices have fallen and it is no longer attractive (Fuji Chimera, 2003).
2003		X			NEC Plasma develops 61" PDP with 45mm depth, digital processing circuitry built in the module (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			NEC Plasma reaches full production at its second generation PDP lines (Nikkei BP, 2003 (Senryaku Hen)).
2003		X			NEC Plasma says it is only firm to be able to reliably ship 61" VGA PDP panels (Nikkei BP, 2003 (Senryaku Hen)).
2003		X			NEC receives 5 billion yen capital from Sony to pay for part of investment in new TV PDP production line (Fuji Chimera, 2003).
2003		X			As of 2003, NEC was selling PDPs to Sony, TCL (CHINA), and Daewoo (Fuji Chimera, 2004).
2004	X				NEC and SVA's JV is building a 5th generation (1100X1300 mm) plant in Shanghai (Sangyo Times, 2004).
2004	X				NEC-SVA JV begins production using 5th generation substrate at location in Shanghai. This is the first plant in China to include the front end LCD processing (Sangyo Times, 2005).
2004	X				NEC LCD Technologies exhibits energy efficient LTPS panels at FPD 2004 (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				NEC LCD Technologies exhibits 21.3" TFT with LED backlight and 104% NTSC gamut (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				NEC develops special use medical LCDs with high resolution, LCD backlights, SA-SFT, and 3070 gradations (Sangyo Times, 2005)
2004		X			Pioneer acquires NEC's PDP operations - Pioneer's existing organization is called Pioneer Display Products, and the formerly NEC organization is renamed Pioneer Plasma Display. Pioneer pays 40 billion yen. Pioneer gains NEC's color filter technology and ability to manufacture multiple PDPs per substrate, also PDP patents (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X		NEC sells its stake in Samsung NEC mobile display to Samsung SDI along with NEC's OLED patents, exits OLED (Nikkei BP, 2004 (Jitsumu Hen); Sangyo Times, 2005).
2005	X				NEC LCD Technologies exhibits 21.3" TFT with LED backlight for TV use (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				NEC to invest 5 billion yen in NEC Akita plant to begin LTPS TFT-LCD production in 2006 (Sangyo Times, 2006).
2005	X				NEC begins producing color filters at its Kagoshima plant (Sangyo Times, 2006).
2005	X				NEC begins selling 5.5" and 12.1" Super-Transmissive Natural Light TFTs (Sangyo Times, 2006). They can be veiwed eve in bright places.

2005	X				NEC begins selling 2.7" QVGA with touch panel for PDA and smart phone applications (Sangyo Times, 2006).
2005	X				NEC has developed 19" monochrome LCD for CT Scans, MRI, and other medical applications. The 19" display has SXGA resolution, high contrast and wide viewing angle (Sangyo Times, 2006).
2005	X				NEC has developed worlds fastest A-Si TFTs, both 10.4" - one is VGA and one XGA (Sangyo Times, 2006).
2006	X				NEC develops 3.5" SOG LCD (LTPS) with 100% coverage of NTSC colors and QHD resolution (960X540 dots). This is over 300 PPI. Plans to be used in professional video cameras and other broadcasting applications (Sangyo Times, 2007).
2006	X				NEC LCD installs LTPS-TFT manufacturing equipment at its Akita Plant, using an existing 370X470 mm line (Sangyo Times, 2007).
2007	X				NEC LCD Technology ships samples of displays with Horizontally Double-Density Pixels - which allow mixed 2D and 3D images(Nikkei PB, 2007 (Trend Hen)).
2007	X				NEC has developed technology that allows the visible angle of a screen to be controlled or modified using signals. It has to do with modifying backlight, and is used in applications where privacy is needed, for instance, in ATM machines (Sangyo Times, 2008).
2007	X				NEC LCD has integrated DRAM memory directly on the glass substrate of an LCD module - this is a world's first (Sangyo Times, 2008).
2007	X				NEC LCD integrates subsidiaries NEC Akita and NEC Kagoshima into a single entity (Sangyo Times, 2008).
2008	X				NEC LCD Technologies develops 12.1" SVGA LCD display with 3D that can be see without special glasses (Sangyo Times, 2009).

Year	LCD	PDP	OLED	FED	Other	Event
1952					X	Panasonic develops 17" monochrome TV set (http://panasonic.net/history/corporate/products/inp1952.html)
1952					X	Panasonic Electric Industry and Philips establish joint venture called Panasonic Denshi (Weber et al., 2008).
1955					X	Panasonic begins TV assembly at Kadoma plant (Hiramoto, 1994).
1960					X	Panasonic develops its first color TV set. The 21" set had a CRT designed by Panasonic (http://panasonic.net/history/corporate/products/inp1960.html)
1960					X	Panasonic Electric Industry began research on LCD technology, initially focusing on TN-LCD for calculator applications (Sangyo Times, 1993).
1972		X				Panasonic Denshi begins selling DC-PDPs (Nikkei BP, 1990).
1972					X	Panasonic exhibits prototype DC EL TV (Television Kyokai, 1974).
1977		X				Panasonic Denshi announces research in color PDP (Nikkei BP, 1990).
1980	X					Panasonic Electric Industry began research on color TFT at the central research lab (Sangyo Times, 1993).
1981		X				Panasonic Denshi announces 3-cathode PDP research (Nikkei BP, 1990).
1981		X				Panasonic Denshi enters the PDP business, kicks off with exhibit at electronics show 1981.(Yano Keizai, 1982)
1984		X				Panasonic Denshi begins selling 600X400 orange monochrome PDP (Weber et al., 2008).
1985	X					Panasonic Electric Industry begins selling a 3" portable LCD TV (Sangyo Times, 1993).
1985	X					Panasonic Electric Industry establishes the Ishikawa LCD plant (Sangyo Times, 1992).
1985		X				Panasonic Denshi begins selling high resolution PDPs for laptop applications (Nikkei BP, 1990). Group company Panasonic communications recieves order for PCs with PDP displays from Ericsson (Weber et al., 2008).
1985		X				Panasonic Denshi agrees to supply Toshiba with PDPs for Toshiba portable computers. This continues to the early 1990s (Weber et al., 2008).

1985		X				Panasonic Denshi supplies PDPs to a number of computer manufacturers, including Compaq, and becomes the leader of monochrome PDP production, passing Fujitsu (Weber et al., 2008).
1986	X					Panasonic Electric Industry builds an a-Si TFT LCD TV (Nikkei BP, 2000).
1986		X				Panasonic Denshi exhibits green PDP (Nikkei BP, 1990).
1986		X				Panasonic Denshi begins selling high contrast 3-cathode PDPs (Nikkei BP, 1990).
1986					X	Panasonic develops prototype 40" EL LCD TV (Nikkei BP, 1990).
1989	X					As of 1989, Panasonic Electric Industry considers Flat CRT and LCD to be potential next generation technologies for AV applications (Nikkei BP, 1990).
1989	X					Panasonic Denshi is reported to be considering entering into polysilicon TFT (Nikkei BP, 1990).
1989		X				Panasonic Denshi exhibits 17" multicolor DC-PDPs (Nikkei BP, 1990).
1989		X				Panasonic Denshi plans to begin shipping samples of 17" multicolor PDP with VGA resolution (Nikkei BP, 1990).
1989		X				Panasonic Denshi's single color PDP business reaches 20 billion yen in annual revenue (Weber et al., 2008).
1989					X	Panasonic Denshi announces sample shipments of 6" flat screen CRTs (Nikkei BP, 1990).
1990	X					Panasonic Electric Industry establishes a LCD Strategic Business Unit to develop large LCDs (Sangyo Times, 1993).
1990	X					Panasonic Electric Industry producing 1-3" AM-LCDs for video cameras, small TVs, and passive matrix panels up to 10" (Sangyo Times, 1992).
1991	X					Panasonic Electric Industry develops 15" high resolution full color LCD for workstation applications (full color was a world's first) (Sangyo Times, 1993).
1991		X				Panasonic Denshi begins DC-PDP development with Japanese National Broadcaster, NHK (Kawamura, 2005).
1993	X					Panasonic Electric Industry develops 10.4" VGA TFT LCD for office automation applications (Nikkei BP, 1993).
1993	X					Panasonic begins production of 0.7" polysilicon TFT color viewfinder (Sangyo Times, 1993).
1993		X				Panasonic Denshi develops a 26" PDP with 896X512 resolution (Nikkei BP, 1993).
1993					X	Panasonic Electric Industry begins selling 14" flat CRT based "Color Flat Vision" TV. Price is 288,000 yen (Nikkei BP, 1993).

1993					X	Panasonic Electric Industry acquires Philips Electronics' share in the Panasonic Denshi JV (Lineback, 1993).
1994	X					Panasonic Electric Industry develops 10.4" TFT LCD with SVGA resolution (Nikkei BP, 1994).
1994	X					Panasonic Electric Industry plans to develop and produce FLCD (Sangyo Times, 1993).
1995	X					Panasonic Electric Industry releases LCD Digicam video camera with 4" TFT LCD screen (Nikkei BP, 1995).
1995		X				Panasonic develops 26" DC-PDP with 896X512 resolution for TV applications (Nikkei BP, 1995).
1995		X				Panasonic begins shipping 26" color PDP samples (Sangyo Times, 1995).
1995		X				Panasonic Electric Industry and Plasmaco agree to joint development (Weber et al., 2008).
1995		X				NHK and Panasonic show jointly developed 40" high vision PDP (Weber et al., 2008).
1996	X					Panasonic develops 14" XGA TFT LCD for monitor applications (Nikkei BP, 1996).
1996	X					Panasonic invests additional 5.3 billion yen in B1 Line to enable LTPS-TFT production (Sangyo Times, 1999).
1996	X					Panasonic starts production on new 370X470mm B2 LCD line in Ishikawa (Sangyo Times, 1997).
1996		X				Panasonic successfully develops 42" wide AC-PDP with combined efforts from Plasma Co, Panasonic Denshi and Panasonic Electric Industry (Sangyo Times, 1997).
1996		X				Panasonic acquires Plasmaco for around 2 billion yen, gets AC-PDP technology from the deal (Sangyo Times, 1997).
1996		X				Panasonic begins selling 26" "Plasma View" TV (Sangyo Times, 1997; Weber et al., 2008).
1997	X					Panasonic plans to create LTPS display products in the 3-5" range (Sangyo Times, 1998).
1997	X					Panasonic exhibits 15" XGA TFT panel (Nikkei BP, 1997).
1997	X					Panasonic builds new B3 line 550X670mm at Ozu plant (Sangyo Times, 1998).
1997		X				Panasonic introduces 42" PDP TV with 853X480 resolution (Fuji Chimera, 2000; Nikkei BP, 1997).
1997		X				Panasonic installs PDP line at Takazuki location (Sangyo Times, 2000).
1997					X	Panasonic Denko announces good emission quality using silicon FEDs (Nikkei BP, 2007 (Market Hen)).
1998	X					Panasonic Electric Industry develops 2.5"LTPS for digital camera applications (Nikkei BP, 1998).

1998	X					Panasonic Electric Industry develops 19" XGA TFT for monitor applications (Nikkei BP, 1998).
1998	X					Panasonic achieves 35% share in 15" monitor market, giving it leading share status. Panasonic considers the monitor business to be an important step towards a new LCD TV market (Sangyo Times, 1999).
1998	X					Panasonic signed contract to provide technology (license) and technological assistance relating to large TFT LCD display production to UMC Group's Unipac (Taiwan) (Fuji Chimera, 2000; Sangyo Times, 1999).
1998		X				Panasonic Electric Industry is the first to successfully develop 42" FHD PDP for TV applications (Nikkei BP, 1998).
1998		X				Panasonic begins selling 42" Plasma Tau TV (Sangyo Times, 1999).
1998		X				Panasonic establishes Plasma Display Panel Business Unit reporting directly to President Morishita (Sangyo Times, 1999).
1998					X	Panasonic Electric Industry begins selling 56" RPTV with HD capabilities based upon CRT projection (Nikkei BP, 1998).
1998					X	Panasonic Electric Industry begins selling 36" HD capable CRT based TV (Nikkei BP, 1998).
1999	X					Panasonic announces it will sell 15.2" LCD TV (Nikkei BP, 1999).
1999	X					Panasonic invests 32 billion yen in new TFT facility (C1) at Ishikawa using 550X670mm substrate to produce panels for monitors and TVs (Sangyo Times, 2001).
1999	X					Panasonic developed a prototype 22"TFT for TV application with fast response speed color gamut greater than that from CRT (Fuji Chimera, 2000).
1999	X					Panasonic develops prototype 23" wide LCD UGA display with wide viewing angle (Sangyo Times, 2000).
1999	X					Panasonic develops Advanced IPS technology for wider viewing angle, increased brightness compared to IPS (Sangyo Times, 2000).
1999	X					Unipac plans to begin production at new TFT line with Panasonic assistance (Sangyo Times, 1999).
1999	X					Unipac (Taiwan) became a supplier of LCD panels to Panasonic in 1999 (Fuji Chimera, 2000).
1999		X				Panasonic introduces 37" PDP TV adding to Plasma Tau lineup (Nikkei BP, 1999; Sangyo Times, 2000).
1999		X				Panasonic reduces price of 37" PDP TV from 1.2 million yen to 1.1 million, and price of 42" PDP TV from 1.5 million to 1.3 million yen (Nikkei BP, 1999).

1999		X				Panasonic introduces 60" HD PDP for TV application (Nikkei BP, 1999).
1999				X		Panasonic develops 2.6" prototype FED using silicon emitter (Nikkei BP, 2007 (Market Hen)).
1999				X		Panasonic Denko is working with Tokyo Noko University on BSD, a form of FED (Sangyo Times, 2000).
2000	X					Panasonic begins selling 22" TFT LCD TV with 854X480 resolution for 480,000 yen in July 2000 (Nikkei BP, 2000).
2000	X					Panasonic begins construction of C1, C2 buildings, and foundation for C3 all at Ishikawa location. The additional production capacity is planned for increasing monitor and TV applications (Sangyo Times, 2000).
2000		X				Panasonic exhibits 50" PDP TV use panel with HD resolution (Nikkei BP, 2000).
2000		X				Panasonic begins selling improved 42" W PDP TV with real black drive in July 2000 for 1.1 million yen (Nikkei BP, 2000).
2000		X				Panasonic and Toray establish production JV, Panasonic Plasma Display (Weber et al., 2008).
2000		X				Panasonic established a with Shanghai SVA JV to produce and sell PDPs as well as related products and parts (Sangyo Times, 2001).
2000				X		Panasonic Denko announced the development of Ballistic electron Surface-emitting Display (BSD - a form of FED) together with professor from Tokyo Noka University. It is presented as the net generation flat panel low energy display. Panasonic Denko made a 2.6" prototype of the display but has no display manufacturing expertise (Sangyo Times, 2001).
2000					X	Panasonic and TI agree to work together on developing HDTV using rear projection with DLPs (Sangyo Times, 2001).
2000					X	Nakamura Kunio becomes president of Panasonic (Osada, 2006).
2001	X					Panasonic exhibits 11" OCB mode impulse type TFT TV LCD panel (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X					Panasonic releases 15.2" and 11" LCD TVs with 854x480 resolution (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X					Matsushita began producing 22" and 15" high speed LCD panels for TV use (Fuji Chimera, 2001).
2001	X					Unipac is supplying Panasonic with 14.1 and 13.3" displays for notebook computers (Sangyo Times, 2002).
2001		X				Panasonic begins PDP production at Ibaragi and Takazuki plants (Nikkei BP, 2001 (Senryaku Hen)).
2001		X				Panasonic begins PDP production at Shanghai plant (Nikkei BP, 2001 (Senryaku Hen)).

2001		X				Panasonic begins selling 42" PDP TV with BS Digital tuner in Japan for 800,000 yen (Nikkei BP, 2001 (Senryaku Hen)).
2001		X				Panasonic Plasma Display invests 35 billion yen in first PDP line. Plant will produce TV panels and finished TV sets (Sangyo Times, 2001).
2001				X		Panasonic develops process to make BSD on silicon wafer, announces full color panel prototype (Nikkei BP, 2007 (Market Hen)).
2001				X		Panasonic Denko has over 100 patents relating to BSD in EU, US, Japan (Sangyo Times, 2002).
2001					X	Panasonic Electric Industry absorbs Panasonic Denshi (Osada, 2006).
2002	X					Toshiba and Panasonic establish Toshiba Matsushita Display Technology JV, integrating LCD operations from bother firms. 60% Toshiba, 40% owned by Panasonic. From Development to Sales - all are integrated in the new JV. OLED development will also be included in the new firm (Fuji Chimera, 2002).
2002	X					TMDT develops 14" VGA LTPS-TFT panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Panasonic exhibits 17" LCD TV using LTPS panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					TMDT exhibits 229ppi LTPS panel at Ceatec (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Toshiba Matsushita Display Technology announces that it plans to enter TV with LTPS, and will continue work on developing OCB technology (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Toshiba and Panasonic's JV "Advanced Flat Panel Display" plant in Singapore begins mass production - it is the largest LTPS plant in world (Sangyo Times, 2001).
2002		X				Panasonic introduces 42" HD PDP TV (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X				Panasonic Plasma Displays announced its decision to build a new PDP plant with 60 billion yen investment (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X			TMDT exhibits 2.2" 176X220 128pp large particle OLED panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X			TMDT announces world's largest OLED panel prototype at EDEX 2002. The 17" XGA wide full color OLED prototype was made using inkjet printing on a LTPS backplane. Development work was done at Fukaya ((Nikkei BP, 2005 (Oyo Gijutsu Hen); Sangyo Times, 2003; http://techon.nikkeibp.co.jp/members/01db/200204/1003265/)

2002			X			TMDT has an OLED pilot line at its Fukaya plant (Fuji Chimera, 2003).
2002			X			As of 2002, Toshiba-Matsushita Display Technology is planning to supply OLEDs for TV applications in the 2005-6 time frame (Fuji Chimera, 2002).
2002			X			As of 2002, Toshiba Matsushita Display Technology is following both large and small OLED types, expecting one of the two to emerge as a prevalent type, but unsure of which at this point (Fuji Chimera, 2002).
2002				X		Panasonic Group successfully develops BSD prototype on glass (2.6", 168X126 resolution) (Nikkei BP, 2002 (Jitsumu Hen)).
2002				X		Panasonic develops full color panel prototype BSD (Nikkei BP, 2007 (Market Hen)).
2002				X		Panasonic Denko finishes basic research on BSD, but is still working on manufacturing process, size, and lifespan issues (Sangyo Times, 2003).
2002					X	Panasonic takes controlling stake in new CRT JV with Toshiba (Nikkei BP, 2002 (Jitsumu Hen)).
2002					X	TMDT has loss for year (Sangyo Times, 2005).
2003	X					Panasonic Electric Industry releases 32" LCD TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X					TMDT says plans to develop OCB, OLED, SOG panels in 2004 have a high priority (Nikkei BP, 2003 (Senryaku Hen)).
2003	X					TMDT exhibits LCD Panel that can also function as scanner (Nikkei BP, 2004 (Jitsumu Hen)).
2003	X					TMDT begins selling lead free industrial use TFT panels (Sangyo Times, 2004).
2003	X					TMDT says it hopes to achieve profitability at its Singapore plant in 2004 (Nikkei BP, 2003 (Senryaku Hen)).
2003		X				Panasonic Electric Industry has been selling about 10% of its PDP to other firms, but plans to increase this to 30% after it gets the second plant running (Nikkei BP, 2003 (Senryaku Hen)).
2003		X				Panasonic 's Shanghai JV Plant begins shipping PDPs (Sangyo Times, 2003).
2003			X			TMDT's Ishikawa plant has a prototyping line for large and small particle OLED, but production plans have yet to be made (Sangyo Times, 2004).
2003			X			TMDT exhibited 2 small particle AM-OLEDs at EDEX 2003. One is a 2" QCIF+ (176X220) and 3.5" QVGA (Sangyo Times, 2004).
2003				X		Panasonic develops 7" full color prototype BSD on glass (Nikkei BP, 2007 (Market Hen)).

2003					X	Panasonic Electric Industry launches new flat panel TV brand "Viera" (Weber et al., 2008).
2003					X	Panasonic begins shipping TVs with new image processing system called PEAKS (Sangyo Times, 2004).
2004	X					Hitachi, Toshiba, Panasonic sign formal agreement to JV, will name it IPS alpha technology (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					As of 2004, Panasonic is sourcing some LCD TV panels from Samsung (Fuji Chimera, 2004).
2004	X					TMDT begins mass production of OCB TFT panels for TV applications (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					TMDT exhibits 23" and 32" OCB LCD panels. 32" is HD (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					TMDT wins advanced display of the year award for 0.3mm thick polysilicon display at Flat Panel Production Technology show in Tokyo (Sangyo Times, 2005).
2004	X					TMDT develops 32" wide LTPS panel (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					TMDT develops LTPS prototype TV panel with LTPS for TV applications (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					TMDT develops LCD panel which has variable (controllable) viewing angle for ATMs and other applications where privacy is an issue (Sangyo Times, 2005).
2004		X				Panasonic begins selling a 65" PDP TV model - it is the world's largest (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X				Panasonic will invest 95 billion yen to build a new PDP plant with 250K sheets / month capacity and will begin production in late 2005 (Nikkei BP, 2004 (Jitsumu Hen); Sangyo Times, 2005).
2004			X			TMDT exhibits 3.5" AM-OLED using small particle materials at Ceatec Japan 2004; plans to begin mass producing it in 2005 for portable AV applications (Nikkei BP, 2004 (Jitsumu Hen); Sangyo Times, 2005).
2004			X			TMDT plans to begin mass production of AM-OLEDs using small particle materials in 2005 (Sangyo Times, 2005).
2005	X					Hitachi Displays, Panasonic Electric Industry, Toshiba established IPS Alpha Technology. It is planned to make 23" IPS panels starting in q2, 2006 (Fuji Chimera, 2005).
2005	X					TMDT develops LCD panel with driver circuitry on the glass (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X					TMDT increases LTPS production at Ishikawa plant, increasing its focus on LTPS and decreasing a-Si focus (Nikkei BP, 2005 (Senryaku Hen)).

2005	X					TMDT begins construction of 3rd line at Ishikawa plant. New line is 730X920mm substrate; LTPS (Sangyo Times, 2007).
2005		X				Panasonic Plasma's 3rd plant begins production in Amagasaki, two months earlier than planned. Substrate sizes are 1664X1961 and 1329X2332 mm. Together line 1 and 2 at Plant number 3 represent 95 billion yen investment ((Nikkei BP, 2005 (Senryaku Hen); Sangyo Times, 2006).
2005		X				As of 2005, Panasonic sells PDPs to Sanyo, Toshiba, JVC, Fujitsu general, TCL, B&O, Philips, etc. (Fuji Chimera, 2005).
2005		X				Hitachi and Panasonic agree to cooperate on PDP TV (Nikkei BP, 2007 (Trend Hen)).
2005		X				Hitachi Plasma Patent Licensing is established with both Hitachi and Panasonic taking stakes (Nikkei BP, 2007 (Trend Hen)).
2005			X			TMDT exhibited prototype 20.8" OLED with large particle materials from CDT on LTPS (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X			TMDT beings producing small volumes of 3.5" small molecule OLEDs for personal music players. Production is at Ishikawa plant, where OLED development also is. Backplane is produced at Fukaya (Sangyo Times, 2006).
2005			X			TMDT states it plans to mass produce OLEDs in 2008 (Nikkei BP, 2005 (Senryaku Hen)).
2005					X	Panasonic introduces its final 2 CRT TV models for the Japanese market (Fuji Chimera, 2000 (Digital AV Market)).
2005					X	Panasonic launches a new line of Viera FP TV models in overnight display changes through retail stores in Japan. Company ships 22 thousand sets in 3 days. The strategy is called ichiya-jo, meaning to build a fortress overnight, following a historical event in Japan (Osada, 2006).
2006	X					TMDT announces it will invest 30 billion yen to build an additional LTPS line at Ishikawa - it is planned to enter production in late 2007 (Sangyo Times, 2007).
2006	X					TMDT develops 0.99mm thick LTPS LCD for cell phone application - world's thinnest. Samples are planned to ship in 4/2007 (Sangyo Times, 2007).
2006		X				Panasonic develops a 103" FHD plasm display (Nikkei BP, 2006 (Senryaku Hen)).
2006		X				Panasonic Plasma announces it will begin construction on a 4th Plasma plant near the Amagasaki #3 plant (Sangyo Times, 2006).
2006				X		Panasonic Denko begins working on BSD for applications in lighting and displays (Sangyo Times, 2008).
2007	X					Panasonic releases 37" LCD TV, reversing its statement that 37" and larger will all be PDP (Nikkei BP, 2007 (Market Hen)).

2007	X					Matsushita, Hitachi, and Canon agree to work together on LCD panels (Nikkei BP, 2008 (Sangyo Doko Hen)).
2007	X					Canon and Panasonic announce they will each take 24.9% stakes in Hitachi Displays by the end of march, 2008. (announcement date = 12/2007). Canon plans to increase its investment to take a controlling stake in the future. Canon hopes to work on OLED technology with Hitachi (Sangyo Times, 2008).
2007	X					Panasonic is planning to take a majority stake in IPS Alpha (Sangyo Times, 2008).
2007		X				Panasonic begins selling new 42" Plasma Full HD TV. Prior 42" were 768p and not 1080p (Nikkei BP, 2007 (Market Hen)).
2007		X				Panasonic Plasma decides to begin production at Number 4 PDP plant one month earlier than planned, increases its annual production target (Nikkei BP, 2007 (Market Hen)).
2007		X				Panasonic is worldwide share leader in PDP TV for 2007 according to DisplaySearch (Nikkei BP, 2008 (Kigyo Bunseki Hen)).
2007		X				Panasonic and Hitachi agree to supply each other with PDPs. Hitachi can use Panasonic 's 103" and Panasonic can get Hitachi's 85" PDP, in addition to other sizes (Nikkei BP, 2007 (Trend Hen)).
2007		X				Panasonic Plasma announces it will its fifth PDP plant - this one also will be in Amagasaki. Total investment is planned to be 280 billion yen. Substrate will be similar size to Gen 10 LCD (Sangyo Times, 2007).
2007			X			TMDT develops 21" prototype large particle AM-OLED, shows it at Display 2007 in Tokyo. The display uses inkjet printing on LTPS, with OLED materials from CDT. Resolution is WXGA. This display was part of project funded through NEDO ((Nikkei BP, 2007 (Market Hen); Sangyo Times, 2008).
2008	X					Panasonic buys Hitachi's stake in IPS Alpha, makes it a consolidated subsidiary (Nikkei BP, 2008 (Kigyo Bunseki Hen)).
2008	X					Panasonic and IPS Alpha begin construction of an LCD panel in Hyogo, but reduce investment from initially planned 300 billion yen to 235 billion yen (Sangyo Times, 2009).
2008		X				Panasonic agrees to joint PDP design, production, and supply with Pioneer (Nikkei BP, 2008 (Kigyo Bunseki Hen)).
2008		X				Panasonic announces NEO PDP line at 2008 International CES (Nikkei BP, 2008 (Sangyo Doko Hen)).
2008		X				Panasonic exhibits 150" PDP at 2008 International CES (Nikkei BP, 2008 (Sangyo Doko Hen)).

2008		X				Pioneer decides to obtain PDP supply from Panasonic and end in house production (Sangyo Times, 2009).
2008		X				Pioneer's PDP technical staff who produced Kuro Panels are moved to Panasonic (Sangyo Times, 2009).
2008		X				Hitachi announces it will procure PDP glass panel materials from Panasonic, moving away from its previous philosophy of producing PDP TVs completely in house starting with the panels (Sangyo Times, 2009).
2008			X			TMDT announces it will make a 16 billion yen investment in its Ishikawa line to mass produce OLED using part of the existing LTPS line (Nikkei BP, 2008 (Sangyo Doko Hen)).
2008			X			TMDT announces it plans to begin shipping small partial OLED displays in October, 2009. Production will be done at a new line at the Ishikawa plant (Sangyo Times, 2009).

Year	LCD	PDP	OLED	Other	Event
1968		X			Philips announces DC-PDP concept design (Nikkei BP, 1990).
1989	X				Philips performs trial sales of LCD TVs (Nikkei BP, 1990).
1991			X		Philips commences R&D on OLED technology (Sangyo Times, 2005).
1996	X				Hoshiden and Philips agree to form JV on TFTs, with Hoshiden's TFT capacity inside the new firm (Sangyo Times, 1997, Jiji Press, 1996).
1996		X			Philips announces it will begin selling a 42" 852X480 pixel PDP TV model. The price is 22,000 gilder or approximately 1.4 million yen (Nikkei BP, 1996).
1997	X				Hoshiden and Philips establish TFT producing JV as agreed in prior year; Hoshiden puts TFT capacity into this JV. Both partners take equal equity stakes (Sangyo Times, 1999).
1997	X				Hoshiden Yonago and Hoshiden Kobe R&D subsidiary become wholly owned subsidiaries of JV between Hoshiden and Phillips. Kobe center is Hoshiden-Phillips Display (HAPD) head office (Sangyo Times, 1998).
1997	X				Hoshiden-Philips develops 22.9" TFT with 1600X1200 resolution (Nikkei BP, 1997).
1997		X			Philips is receiving PDP supply from Fujitsu as of 1997 (Nikkei BP, 1996).
1997				X	Philips joins existing cooperative R&D arrangement between Sony and Sharp to develop PALC and production technology related to PALC. The joint project is planned to last until September of 1999. Focus is on 40" class screen (Fuji Chimera, 1999, 2001; Sangyo Times, 1997, 1999).
1997				X	Sony, Sharp, and Philips successfully develop prototype 42" PALC with wide view area -- ASM (Axiallly Symmetric aligned Micro Cell mode) (Sangyo Times, 1999, 2007).
1998	X				Philips increases stake in Hoshiden Philips from 50% to 80%, also takes all of the firm's panel production output (Nikkei BP, 1998).
1998	X				Hoshiden Philips focuses on 15" XGA TFT for Philips monitors (Nikkei BP, 1999).
1998		X			Pioneer agrees to joint development of PDP with Philips (Sangyo Times, 1999).
1998		X			Fujitsu and Philips agreed to cooperate on technologies used in developing PDP for television applications. Improving Fujitsu's 42" PDP for market entry is a focus of the cooperation (Fuji Chimera, 1999).

1998				X	Sony, Sharp, and Philips successfully develop prototype 42" PALC HDTV display and 42" VGA PALC display (Sangyo Times, 1999, 2001).
1999	X				Hoshiden Philips achieves single month profitability (Nikkei BP, 1999).
1999	X				Hoshiden-Philips develops 3.8" reflective TFT with 320X240 resolution and COG (Nikkei BP, 1999).
1999	X				LG Electronics and Philips Electronics form LG Philips LCD, a 50-50 JV focusing on LCD production. It is the largest LCD manufacturer in the world in 2003 (Nikkei BP, 2006 (Gyokai Bunseki Hen)).
1999	X				LG Philips Displays exhibits 18.1" XGA TFT LCD panel (Nikkei BP, 1999).
1999		X			Philips begins selling 42" PDP TV (Nikkei BP, 1999).
1999				X	Philips is developing micro display technologies based upon liquid crystal (Nikkei BP, 1999).
1999				X	Contract to cooperate on PALC ends, Philips does not renew (Sangyo Times, 2000).
2000	X				Philips Mobile Display Systems (PMDS) Kobe, formerly Hoshiden-Philips Display, is taken over by Philips with Hoshiden selling its entire stake, and exiting TFT (Sangyo Times, 2001).
2000	X				PMDS focuses on 10" and smaller LCDs and functions as a globally TFT development center for Philips (Sangyo Times, 2002).
2000	X				Philips and Toshiba cross license patents on display cells, circuits, extend this to LG-Philips LCD (Techno Associates, 2008).
2000	X				LG Philips LCD begins mass producing 20.1" VGA LCD panels for a Japanese TV maker (Nikkei BP, 2000).
2000	X				LG Philips LCD exhibits 15" TFT LCD panel with 1600X1200 resolution (Nikkei BP, 2000).
2000		X			Philips ended its PDP relationship with Pioneer in 1999, and has not decided to mass produce PDPs as of 2000 (Nikkei BP, 2000).
2000			X		Philips exhibits 1.4" yellow-green OLED display at Ceatec. It was produced in research lab in Heerlen Netherlands. Appears to use large molecule materials (Sangyo Times, 2001).
2000				X	Philips is reported as not undertaking FED development (Nikkei BP, 2000).
2001	X				PMDS Kobe exhibits 3.1" translucent LCD panel (Nikkei BP, 2001 (Jitusmu Hen)).
2001	X				Philips mobile and ADI (Mitsubishi) sign a supply contract and agree to jointly design LTPS (and for ADI to be a contract manufacturer for this) (Sangyo Times, 2002).
2001	X				LG Philips LCD develops 30" TFT for digital TV (Sangyo Times, 2003).

2001			X		Philips working on developing large molecule OLED panels at its headquarters in Holland using organic materials from Covion Organic Semiconductor (Fuji Chimera, 2002; Sangyo Times, 2002).
2001			X		Philips components exhibits prototype area color OLED made with inkjet printing process and large particle materials (Nikkei BP, 2001 (Jitusmu Hen)).
2002	X				LG Philips LCD develops 20.1" QUXGA LTPS display (Sangyo Times, 2002).
2002	X				LG Philips LCD develops 42" full HD LCD TV panel - world's largest (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				LG Philips develops 52" full HD TFT LCD for TV applications - World's largest. It was developed by 25 specialists in approximate 10 month development program (Sangyo Times, 2003).
2002			X		Philips announces it is world's first large particle OLED supplier (Nikkei BP, 2002 (Jitusmu Hen)).
2002			X		Philips exhibits 1 micrometer thickness large particle OLED display (Nikkei BP, 2002 (Jitusmu Hen)).
2002				X	Philips exhibits 1.18" LCOS projector panel (Nikkei BP, 2002 (Jitusmu Hen)).
2002				X	Philips begins selling 44" RPTV using LCOS panel (Nikkei BP, 2002 (Jitusmu Hen)).
2003	X				LG Philips LCD exhibits 2.2" field sequential QVGA TFT LCD (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				LG Philips LCD exhibits 55" IPS mode FHD TFT LCD panel (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				LG Philips LCD begins mass production on its 1100X1250mm line (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				As of 2003, LG Philips LCD is Sony's lead TV Panel vendor (Fuji Chimera, 2003).
2003	X				LG Philips signs agreement with Korean government to develop major LCD producing industrial park in Paju (Sangyo Times, 2004).
2003		X			Philips develops PDP with improved brightness (Nikkei BP, 2003 (Jitusmu Hen)).
2003			X		Philips obtains a license from CDT on large molecule OLED technology (Fuji Chimera, 2003).
2003			X		Philips develops 2.6" full color AM-OLED (Sangyo Times, 2004).
2003			X		Philips is mass producing OLED displays, using inkjet printing, for use in shavers (Sangyo Times, 2004).
2003				X	Philips releases 55" FHD rear projection TV with LCOS (Nikkei BP, 2003 (Jitusmu Hen)).
2004	X				LG Philips LCD develops 3 mask process for TFT production - this reduces steps, improves yield from existing methods that used more masks (Sangyo Times, 2005).

2004	X				LG Philips LCD exhibits 32" TFT with backlight control to improve dynamic range (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				LG Philips LCD exhibits 42" TFT panel with impulse drive (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Sony stopped sourcing LCD TV panels from LG-Philips and moved business to Samsung LCD (Fuji Chimera, 2004).
2004	X				LG Philips LCD and Hitachi cross-license IPS technology (Techno Associates, 2008).
2004	X				LG Philips LCD begins construction on world's largest display production cluster (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X			Philips Electronics releases a 42" FHD PDP TV model (Nikkei BP, 2004 (Jitusmu Hen)).
2004			X		Philips research developed a 10" 576X324 pixel large molecule OLED prototype panel (Fuji Chimera, 2005).
2004			X		Philips develops 13" large particle AM-OLED panel, emphasizes target is TV application (Nikkei BP, 2004 (Jitusmu Hen)).
2004			X		LG Philips Displays exhibits 20.1" AM-OLED with 1280X800 resolution (Nikkei BP, 2004 (Jitsumu Hen)).
2005	X				Philips Mobile increases production capability for semi transparent LCDs for cell phone applications (Sangyo Times, 2005).
2005	X				LG Philips Displays exhibits 42" TFT LCD TV use panel with 12 bit color (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				LG Philips Displays exhibits 47" full HD LCD TV use panel with LED backlight and area control (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				LG Philips LCD exhibits 55" FHD IPS mode LCD TV panel (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				LG Philips LCD achieves 85% yield ratio in first quarter 2005 for P6 sixth generation plant which started production in August of 2004 (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				LG Philips is investing 530 billion yen in a generation 7 line in Paju (Sangyo Times, 2005).
2005		X			As of 2005, Matsushita sells PDPs to Philips amongst others (Fuji Chimera, 2005).
2006	X				LG Philips LCD begins mass production of 42" LCD panels for LCD TV applications on P7 line (Nikkei BP, 2006 (Senryaku Hen)).
2006	X				LG Philips LCD develops 100" LCD panel - world's largest (Nikkei BP, 2006 (Senryaku Hen)).
2006	X				LG Philips LCD loses 177 billion won in the fourth quarter of 2006 (Nikkei BP, 2007 (Market Hen)).
2006			X		Philips and Novaled jointly develop longer life OLED (Sangyo Times, 2007).
2007	X				LG Philips LCD continues to lose money in first quarter of 2007 (Nikkei BP, 2007 (Trend Hen)).

2007	X				LG Philips LCD develops flexible full color LCD panel (Nikkei BP, 2007 (Market Hen)).
2007	X				LG Philips LCD begins shipping 19.8mm thick 42" TV panels (Nikkei BP, 2007 (Market Hen)).
2007	X				LG Philips announces it will invest 2.5 trillion Korean Won in a new Generation 8 production line (Nikkei BP, 2007 (Trend Hen)).
2007	X				Philips sells its stake in LG Philips LCD to LG (Nikkei BP, 2006 (Gyokai Bunseki Hen)).
2007			X		LG Philips LCD to source OLED materials from UDC (Nikkei BP, 2007 (Market Hen)).
2007			X		LG Philips develops 2.4" and 3" AM-OLED prototypes (Sangyo Times, 2008).
2007				X	Philips and Epson announce they have jointly developed a fanless small projector technology (Nikkei BP, 2007 (Trend Hen)).
2008				X	Funai acquires Philips' North American TV unit (Nikkei BP, 2008 (Kigyo Bunseki Hen)).

Year	LCD	PDP	OLED	Other	Event
1980s				x	Pioneer enters TV business with CRT based and rear projection models (Kawamura, 2005).
1988			x		Pioneer begins research on OLED at its Main R&D lab in Saitama (Sangyo Times, 2000).
			x		Tohoku Pioneer begins research on OLED technology (Sangyo Times, 2002).
1990		x			Pioneer decides to focus on color AC-PDP as next generation display technology (Kawamura, 2005).
1991		x			Pioneer establishes display research lab and begins work on PDP technology (Nikkei BP, 1995).
1991				x	Pioneer establishes display committee with members from projection TV plant, Pioneer video, and Pioneer precision (Kawamura, 2005).
1993		x			Pioneer develops 8" AC PDP which clears the brightness problem Pioneer had identified with PDPs (Nikkei BP, 1995).
1994			x		Pioneer discovers first green OLED material (Sangyo Times, 2000).
1995		x			Pioneer exhibits 40" VGA AC-PDP for TV applications at Electronics Show 1995 (Nikkei BP, 1995).
1995			x		Pioneer successfully develops OLED display using Kodak technology (Sangyo Times, 1995).
1995			x		Tohoku Pioneer obtains license from Kodak (Fuji Chimera, 2003; Wall Street Journal, October, 1995).
1995			x		Pioneer transfers OLED to Tohoku Pioneer from HQ. This is for manufacturing purpose, it is said (Sangyo Times, 2000).
1995			x		Tohoku Pioneer exhibits green OLED at EL Show (Sangyo Times, 2002).
1996		x			Pioneer increases the importance of Plasma in the firm by turning its Display Research Center into a Plasma Display Division (Sangyo Times, 1997).
1996		x			Pioneer invests 5 billion yen in PDP production capability at facility in Kofu. Plant can produce 10K panels/month when it achieves full production (Sangyo Times, 1997).
1996			x		Pioneer develops 3.5" single color OLED display for automotive applications (Nikkei BP, 1996).
1996			x		Pioneer has begun making white OLED for backlighting applications to be used in combination with LCDs (Sangyo Times, 1997).
1997		x			Pioneer begins production of first generation PDPs (Nikkei BP, 2008 (TV Hen)).

1997		x			Pioneer begins shipping 40" VGA PDP samples (Nikkei BP, 1997).
1997		x			Pioneer develops HD compatible 50" PDP TV (Nikkei BP, 1997).
1997		x			Pioneer begins selling 50" HD PDP TV (Nikkei BP, 1998).
1997		x			Pioneer is first in world to use T character independent cathode design (Nikkei BP, 2008 (TV Hen)).
1997			x		Pioneer exhibits OLED panel for automotive applications with 256X64 resolution - no size given (Nikkei BP, 1997).
1997			x		PM OLED manufactured by Tohoku Pioneer is used in world's firs commercial OLED application, a Pioneer car radio (Nikkei BP, 2008 (OLED Hen); Sangyo Times, 1999).
1997				x	Pioneer announces MIS type FED emitter (Komoda, 2005; Nikkei BP, 2007 (Market Hen)).
1998		x			Pioneer begins selling 50" XGA plasma display (PDP-501MX) (Sangyo Times, 1999).
		x			Pioneer begins selling a 40" PDP for commercial applications (Sangyo Times, 1998).
		x			Pioneer agrees to joint development of PDP with Philips (Sangyo Times, 1999).
			x		Tohoku Pioneer begins mass production of OLEDs; it is first in the world to do so (Sangyo Times, 1999, 2001).
			x		Tohoku Pioneer announces it has made 5.2" 320X240 pixel PM-OLED prototype display capable of displaying 260 colors using 3 color sub-pixels per pixel (Sangyo Times, 2000, 2002).
1999		x			Pioneer begins production of second generation PDPs 502 (Nikkei BP, 2008 (TV Hen)).
1999		x			Pioneer is first in world to use waffle structure to replace rib structure in PDP (Kawamura, 2005; Nikkei BP, 2008 (TV Hen)).
1999		x			Pioneer exhibits 50" HD PDP for TV application (Nikkei BP, 1999).
1999		x			Pioneer begins selling a new 50" HD plasma display. The price is 1.7yen, a reduction from the 2.5 million yen price of the prior model (Sangyo Times, 2000).
1999		x			Philips ended its PDP relationship with Pioneer in 1999 (Nikkei BP, 2000).
1999			x		Tohoku Pioneer ships first OLEDs from mass production facility (Sangyo Times, 2001).
2000		x			Sharp begins receiving PDPs from Pioneer, and selling them in TVs in North America (Sangyo Times, 2001).
2000		x			Pioneer begins construction of a new PDP production line in Shizuoka. Investment is 15 billion yen. The facility will produce both panels and fully assembled TV sets (Sangyo Times, 2002).
			x		Tohoku Pioneer exhibits 1.6" full color OLED panel for cell phone applications (Nikkei BP, 2000).

			x		Tohoku Pioneer increases size of clean room for OLED production (Sangyo Times, 2001).
			x		Motorola begins selling cell phones using OLED displays produced by Tohoku Pioneer (Sangyo Times, 2001).
			x		Tohoku Pioneer purchases automated integrated OLED production equipment from Tokki (Sangyo Times, 2001).
			x		Tohoku Pioneer develops prototype 3" AM-OLED jointly with Semiconductor Energy Lab, using small particle materials (Nikkei BP, 2001 (Jitsumu Hen); Sangyo Times, 2002).
2001		x			Pioneer begins production of third generation PDPs (Nikkei BP, 2008 (TV Hen)).
2001		x			Pioneer is first in world to use high Xenon gas in PDP (Nikkei BP, 2008 (TV Hen)).
2001			x		Tohoku Pioneer, SEL and Sharp form JV "ELDis" to produce CG Silicon TFTs for use in AM-OLED displays. Capital is 10 billion yen; Stakes are 45% each for Tohoku Pioneer, SEL, and 10% for Sharp (Sangyo Times, 2002).
2001			x		Tohoku Pioneer builds full color OLED production facility (Nikkei BP, 2001 (Jitsumu Hen)).
2002	x				Pioneer begins selling 30" LCD TV using Sharp ASV panel (Nikkei BP, 2002(Jitsumu Hen)).
2002	x				Pioneer delays sales of 30" LCD TV (Nikkei BP, 2002 (Jitsumu Hen)).
2002		x			Pioneer begins construction of third PDP production line earlier than planned, will increase annual capacity to 150K units. Total new investment will amount to 16 billion yen (Nikkei BP, 2002 (Jitsumu Hen); Sangyo Times, 2003).
2002		x			Pioneer says it will focus on 43" and 50" PDPs and not follow the industry movement into 37" panels (Nikkei BP, 2002 (Senryaku Hen)).
2002		x			Pioneer begins selling 60" PDP TVs in US on a trial basis (Nikkei BP, 2002 (Senryaku Hen)).
2002		x			Pioneer announced it will build a fourth PDP line - investing 26-7 billion yen, with plans to begin construction in 2003 and begin production in 2005 (Sangyo Times, 2003).
2002			x		Rohm, Kyoto University, Pioneer, Hitachi, Mitsubishi Chemicals, NTT agree to do joint R&D on the next generation of OLED electronics devices (Sangyo Times, 2003).
2002			x		Tohoku Pioneer begins shipping OLED displays for use in car stereos and cell phones to Fujitsu, Kenwood, and LG (Sangyo Times, 2003).
2003		x			Pioneer begins production of fourth generation PDPs (Nikkei BP, 2008 (TV Hen)).

2003		x			Pioneer releases 50" PDP TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003			x		As of 2003, Tohoku Pioneer has invested a total of between 50-60 billion yen in OLED, including R&D, production facilities, etc. (Sangyo Times, 2003).
2003			x		Tohoku Pioneer exhibits 2.1" OLED prototype with one side top emission and another side bottom emission at FPD International 2003 (Nikkei BP, 2003 (Jitsumu Hen)).
2003			x		Tohoku Pioneer exhibits 2.4" color OLED panel with 170 PPI (Nikkei BP, 2003 (Jitsumu Hen)).
2003			x		Tohoku Pioneer exhibits 4.3" VGA OLED prototype using top emission at FPD International 2003 (Nikkei BP, 2003 (Jitsumu Hen)).
2003			x		Pioneer developed three dimensional OLED panel (Fuji Keizai, 2005).
2003			x		Tohoku Pioneer begins selling full color PM-OLED products (Sangyo Times, 2003).
2003			x		Tohoku Pioneer has 2 PM-OLED and 1 AM-OLED lines (Sangyo Times, 2003).
2004					Pioneer begins production of fifth generation PDPs (Nikkei BP, 2008 (TV Hen)).
2004		x			Pioneer releases 61" HD PDP TV (Nikkei BP, 2004 (Jitsumu Hen)).
2004		x			Pioneer acquires NEC's PDP operations - Pioneer's existing organization is Pioneer Display Products, and the formerly NEC organization is renamed Pioneer Plasma Display. Pioneer pays 40 billion yen. Pioneer gains NEC's color filter technology and ability to manufacture multiple PDPs per substrate. NEC's patents are also included in the deal (Kawamura, 2005; Nikkei BP, 2004 (Jitsumu Hen)).
2004		x			Pioneer is first in world to use direct color filter in PDP (Nikkei BP, 2008 (TV Hen)).
2004		x			Pioneer makes 2.6 billion yen in operating income in FY 2004, including 10.2 billion yen of revenue from patent licensing activities (Sangyo Times, 2006).
2004			x		Pioneer exhibits an OLED panel prototype using an organic TFT at SID 2004 (Nikkei BP, 2004 (Jitsumu Hen)).
2004			x		Tohoku Pioneer will begin mass producing AM-OLEDs staring with 2.4" cell phone display in 2005 (Nikkei BP, 2004 (Jitsumu Hen)).
2004			x		Tohoku Pioneer is in the process of adding another AM OLED line (Sangyo Times, 2005).
2005		x			Pioneer exhibits 50" FHD PDP at Ceatec 2005 (Nikkei BP, 2005 (Jitsumu Hen)).

2005		x			Pioneer begins production of sixth generation PDPs (Nikkei BP, 2008 (TV Hen)).
2005		x			Pioneer shuts down two PDP lines after revising down expected PDP sales (Nikkei BP, 2005 (Jitsumu Hen)).
2005		x			As of 2005, Pioneer (after acquiring NEC's plasma business) was shipping panels to Hitachi, Sony, JVC, Conrac, View sonic, Thomson, NEC, Fujitsu General, Mitsubishi, TCL Marantz and Daewoo (Fuji Chimera, 2005).
2005		x			As a part of restructuring, Pioneer is reducing its contract production of PDP TVs for other companies (Sangyo Times, 2006).
2005			x		Tohoku Pioneer decides to exit AM-OLED production (Sangyo Times, 2007).
2006		x			Pioneer begins production of seventh generation PDPs (Nikkei BP, 2008 (TV Hen)).
2006		x			Pioneer reorganizes its PDP business, reducing related headcount by 700 (Fuji Chimera, 2006).
2006		x			Pioneer's financial performance rebounds, increasing sales and profitability in Q1, 2006 (Nikkei BP, 2006 (Senryaku Hen)).
2007	x				Pioneer is cooperating with Sharp, and planning to use LCD in 40" and smaller TV lineup. They each purchase equity stakes in each other, but Pioneer's stake in Sharp is less than 1%, and Sharp's stake in Pioneer is 14% (Sangyo Times, 2009).
2007		x			Pioneer begins production of eight generation PDPs. This includes the Kuro panels (Nikkei BP, 2008 (TV Hen)).
2007		x			Pioneer states that it will not pursue market share with PDP TVs, but will seek high end market segments (Nikkei BP, 2007 (Market Hen)).
2007		x			Pioneer introduces new KURO line of PDP TVs with high contrast and high quality images (Sangyo Times, 2008).
2007		x			Pioneer has frozen its plans to build a new PDP facility in the southern Japanese Alps due to decrease in demand, and sales (Sangyo Times, 2008).
2007		x			Pioneer decideds to stop some PDP production after disappointing results in TV business (Nikkei BP, 2007 (Market Hen)).
2007			x		Tohoku Pioneer develops touch panel PM-OLED for Factory Automation applications (Sangyo Times, 2008).
2008		x			Pioneer signs joint PDP design, production, and supply arrangement with Panasonic. Pioneer will obtain PDP supply from Panasonic and end in house production. Pioneer will close its Kofu plant in 2008 and its Kagoshima plant in 2009 after production from Panasonic begins (Nikkei BP, 2008 (Kigyo Bunseki Hen); Sangyo Times, 2009).

2008		x			Pioneer's PDP technical staff who produced Kuro Panels are moved to Panasonic (Sangyo Times, 2009).

Year	LCD	PDP	OLED	Other	Event
1969				X	Samsung and NEC set up joint venture on CRTs. It is called Samsung SDI (Sangyo Times, 2002).
1970				X	Samsung Electronics begins selling TV sets (Nikkei BP, 2006 (Gyokai Bunseki Hen)).
1984	X				Samsung begins LCD development (Castellano, 2005).
1991	X				Samsung Electronics builds pilot production line for TFT-LCD (Sangyo Times, 1994).
1991	X				Samsung moves TFT LCD business to Samsung Electronics (Sangyo Times, 1994).
1992	X				Samsung Electronics develops 1.4" color LCD panel (Nikkei BP, 2006 (Gyokai Bunseki Hen)).
1993	X				Samsung Electronics begins construction of first mass production LCD line (Sangyo Times, 1994).
1994	X				Samsung Electronics develops 10.4" VGA TFT LCD panel (Nikkei BP, 1994).
1994	X				Samsung Electronics exhibits 4 TFT panels in the 7-10" range, and one workstation-sized 14" TFT panel at LCD International in Makuhari, Japan (Sangyo Times, 1994).
1994	X				Samsung Electronics begins TFT mass production on 300X400mm line (Sangyo Times, 1997).
1995	X				Fujitsu licenses TFT-LCD technology to Samsung Electronics (Deutsche Bank, August, 2004).
1995	X				Samsung Electronics develops 22" color XGA TFT panel for monitor applications (Nikkei BP, 1995).
1995	X				Samsung Electronics enters into a strategic partnership with the Liquid Crystal Institute at Kent State University to jointly develop display technologies (Sangyo Times, 2005).
1995	X				Samsung and Corning establish Samsung Corning Precision Glass JV to produce LCD substrate glass. The two firms previously cooperated on CRT glass (Techno Associates, 2008).
1995		X			Samsung SDI begins PDP R&D in mid-1990s (Jiang, Lim & Oh, 2002).
1996	X				Samsung develops 15.1" XGA TFT LCD for monitor applications (Nikkei BP, 1996).
1996	X				Samsung begins LCD production at Line 2 (Giheung) (Samsung Electronics, 2008).
1996	X				Samsung Electronics exhibits 22" TFT LCD monitor prototype (Sangyo Times, 1997).

1997	X				Samsung Electronics develops 30" TFT with 1600X1200 resolution (Nikkei BP, 1997).
1998	X				Samsung Electronics obtains top share in large LCD panel market (Nikkei BP, 2002 (Senryaku Hen)).
1998	X				Samsung LCD begins production at line 3 (Cheonan) (Samsung Electronics, 2008).
1999	X				Samsung Electronics develops 24" 1920X1200 resolution TFT LCD (Nikkei BP, 1999).
1999	X				Samsung Electronics continues to hold top share in large LCD panel market (Nikkei BP, 2002 (Senryaku Hen)).
1999	X				Samsung receives $100 million investment from Apple (Fuji Chimera, 2000).
1999	X				Samsung receives $200 million investment from Dell with 5 year TFT panel supply agreement (Fuji Chimera, 2000).
1999	X				Samsung begins selling 15" LCD TV. It is priced at 108,000 yen in Japan (Fuji Chimera, 2000).
2000	X				Samsung Electronics develops 15" TFT LCD panel with 1400X1050 resolution (Nikkei BP, 2000).
2000	X				Samsung Electronics develops 15, 17, and 24" LCD TV panels (Nikkei BP, 2001 (Senryaku Hen)).
2000	X				Samsung Electronics continues to hold top share in large LCD panel market (Nikkei BP, 2002 (Senryaku Hen)).
2000	X				Samsung LCD begins production at line 4 (Cheonan) (Samsung Electronics, 2008).
2000			X		Samsung SDI begins research into AM-OLEDs (Nikkei BP, 2004 (Gijutsu Hen)).
2000			X		Samsung SDI and NEC begin joint development of full color OLED (Sangyo Times, 2001).
2000			X		Samsung SDI and NEC jointly develop 2" OLED for cell phone application (Sangyo Times, 2001).
2000				X	Samsung SDI starts research on FED (Nikkei BP, 2000).
2001	X				Hitachi exhibits 40" PVA mode HD LCD TV panel (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X				Samsung Electronics begins production on new 730X920 mm LCD line (Nikkei BP, 2001 (Senryaku Hen)).
2001	X				Samsung Electronics continues to hold top share in large LCD panel market (Nikkei BP, 2002 (Senryaku Hen)).
2001	X				Samsung begins producing panels for 40"TV it developed using PVA (Patterned Vertical Alignment) (Fuji Chimera, 2002).
2001		X			Samsung SDI begins PDP production at its first plant in July 2001; it is the world's largest PDP plant at the time (Nikkei BP, 2001 (Senryaku Hen)).
2001		X			Samsung SDI enters PDP market (Sangyo Times, 2008).

2001			X		Samsung SDI develops 3.6" QVGA AM-OLED prototype (Nikkei BP, 2004 (Gijutsu Hen)).
2001			X		Samsung SDI exhibits 8.4" color OLED with SVGA resolution using small particle materials (Nikkei BP, 2001 (Jitsumu Hen)).
2001			X		Samsung SDI develops the world's largest full color AM-OLED (15.1"). Resolution is XGA class (Sangyo Times, 2002).
2001			X		Samsung and NEC establish Samsung NEC Mobile Displays in Korea to develop and produce OLED displays (SDI 51%, NEC 49%) (Sangyo Times, 2001).
2001				X	Samsung SDI exhibits 4.9" color FED using carbon nanotubes. Samsung plans to develop 32 and 38" models by 2004, and produce at $20US/inch (Nikkei BP, 2001 (Senryaku Hen); Nikkei BP, 2001 (Jitsumu Hen)).
2001				X	Samsung SDI is developing FED, LCOS, 3D displays as of end of 2001 (Nikkei BP, 2001 (Senryaku Hen)).
2001				X	Samsung begins selling lightweight and thin LCD projection TV (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				Samsung exhibits 40" LCD TV at LCD/PDP International 2001 (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				Japan Samsung releases 40" LCD display; it is priced at 990,000 yen (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				Samsung releases photographs of its newly developed 46" PVA mode LCD panel - world's largest (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				Samsung Japan releases 40" HD LCD TV (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X				Samsung Electronics continues to hold top share in large LCD panel market (Nikkei BP, 2002 (Senryaku Hen)).
2002	X				Samsung Electronics announces goal to produces 40" panel module at $1000 USD at FPD International 2002 (Nikkei BP, 2004 (Senryaku Hen)).
2002	X				Samsung LCD begins production at line 5 (Cheonan) (Samsung Electronics, 2008).
2002		X			Samsung SDI announced its PDP production volume grew from 4K units in 2001 to 60K in 2002 (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			Samsung SDI develops 63" HD PDP panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			Samsung SDI increases PDP production capacity at Tenan plant (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X			Samsung SDI and Fujitsu begin negotiating PDP patent licensing (Nikkei BP, 2004 (Jitsumu Hen)).
2002			X		Samsung SDI announces large polymer AM-OLED panel development (Nikkei BP, 2002 (Jitsumu Hen)).

2002			X		Samsung SDI begins mass producing 256 color OLED panels (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X		Samsung SDI develops AM-OLED for IMT-2000 (cell phone) application (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X		Samsung SDI exhibits 2.2" color OLED using thermal transfer production technique (prototype) (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X		NEC and Samsung SDI jointly invested in LTPS pilot line for OLED applications (Nikkei BP, 2002 (Senryaku Hen)).
2002			X		Samsung NEC mobile display obtains a production license from Kodak (Fuji Chimera, 2003).
2002			X		Samsung NEC began production of 1" OLED for cell phone sub panels, to be sold to Samsung Electronics (Sangyo Times, 2003).
2002				X	Samsung begins selling DLP based projection TV (Nikkei BP, 2002 (Jitsumu Hen)).
2002				X	Samsung SDI exhibits 5.2" color CNT FED with 240X320 resolution (Nikkei BP, 2002 (Jitsumu Hen)).
2002				X	Samsung SDI announced it developed a 32" 480X720 FED prototype (Nikkei BP, 2002 (Jitsumu Hen)). It is exhibited at IMID 2002 (Komoda, 2005).
2002				X	Samsung SDI completes construction of new cutting edge research central lab - it will conduct OLED and FED research amongst other things (Nikkei BP, 2002 (Jitsumu Hen)). Investment is 15 billion yen (Sangyo Times, 2005).
2003	X				Samsung Electronics announced its plans to build a 7G TFT LCD line (Daewoo Securities, May, 2003).
2003	X				Samsung Electronics exhibits 32" IPS mode HD TFT LCD panel with EEFL (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Samsung (Japan) release 32" HD resolution LCD TV (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Samsung develops first 46" FHD TFT LCD panel (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Samsung announces it has developed 54" TFT LCD panel - world's largest (Nikkei BP, 2003 (Jitsumu Hen)), exhibits it at 2003 International CES (Fuji Chimera, 2003).
2003	X				Samsung develops 3.83" VGA LTPS panel (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Samsung Electronics exhibits 17" LCD panel with different arrangement of color filters, higher brightness (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Samsung Electronics exhibits 21.3" TFT with SLS (resolution - 1600X1200) (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X				Samsung Electronics develops 57" HD TV panel with S-PVA LCD (Sangyo Times, 2005).

2003	X				Samsung Electronics successfully ramps up production on 5th generation line (Nikkei BP, 2003 (Senryaku Hen)).
2003	X				Samsung developed PVA mode on a patterned ITO; This improved image contrast (Nikkei BP, 2008 (TV Hen)).
2003	X				Sony And Samsung agree to form JV S-LCD to produce a-Si TFTs for TV applications. The JV will build a generation 7 plant in Korea (Fuji Chimera, 2005).
2003	X				Samsung LCD begins production on line 6 (Cheonan) (Samsung Electronics, 2008).
2003	X				Samsung SDI exhibits 2.3" field sequential LCD with 205 PPI (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			Samsung becomes the share leader for PDP TVs in the US market (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			Samsung Electronics releases 63" PDP TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			Samsung SDI becomes world leader in PDP production in October (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			Samsung SDI develops 70" PDP - world's largest (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			Samsung SDI reaches monthly breakeven level on PDP production (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X			Samsung SDI invests 583 billion Won on PDP capacity increase (Nikkei BP, 2004 (Jitsumu Hen)).
2003		X			Samsung SDI develops 37"Full HD PDP (Sangyo Times, 2004).
2003		X			Samsung SDI is first maker to have all HD PDP line up (Nikkei BP, 2003 (Jitsumu Hen)).
2003			X		Samsung SDI develops 15.5" OLED using small particle materials on LTPS (Nikkei BP, 2003 (Jitsumu Hen)).
2003			X		Samsung SDI develops transparent OLED (Nikkei BP, 2003 (Jitsumu Hen)).
2003			X		Samsung SDI is working together with Vitex Systems (US) on mobile OLED displays using Vitx's thin film coating technology (Fuji Chimera, 2003).
2003			X		Samsung NEC invested 10 billion yen in new production equipment for OLED (Sangyo Times, 2004).
2003			X		Samsung SDI achieves 32% share of the world wide market for PM-OLEDs in 2003 (Sangyo Times, 2005).
2003				X	Samsung Electronics introduces 61" HD rear projection TV with DLP (Nikkei BP, 2003 (Jitsumu Hen)).
2003				X	Samsung SDI announces it has developed a 38" FED capable of HD TV applications (Nikkei BP, 2003 (Jitsumu Hen)).
2004	X				Samsung Electronics develops S-PVA mode LCD. This improves viewing angle (Nikkei BP, 2008 (TV Hen)).

2004	X				Samsung develops 2.6" VGA a-Si TFT panel; this is high resolution for a-Si (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Samsung Electronics proclaims a-Si can be used in applications with up to 350 PPI resolution (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Samsung continues to have largest share of large size LCD panel market (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Samsung Electronics exhibits 32" TFT panel with S-PVA mode, LED backlight and 102% of the NTSC gamut specification (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Samsung Japan releases 46" FHD LCD TV (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X				Samsung Electronics plans to begin production on LCD line specifically making panels for TV applications (Nikkei BP, 2004 (Senryaku Hen)).
2004	X				Samsung and Sony establish JV S-LCD (Techno Associates, 2008).
2004	X				Samsung Electronics and Sony agree to sign cross licensing agreement covering over 10,000 patents (Nikkei BP, 2005 (Jitsumu Hen)).
2004	X				Construction of S-LCD plant at Tajeon is finished; test production begins (Sangyo Times, 2005).
2004	X				Sony stopped sourcing LCD TV panels from LG-Philips and moved business to Samsung LCD (Fuji Chimera, 2004).
2004	X				Samsung Electronics produced over 2 million LCD TVs in 2004 (Sangyo Times, 2004).
2004	X				As of 2004, Panasonic is sourcing some LCD TV panels from Samsung (Fuji Chimera, 2004).
2004		X			Samsung exhibits 80" PDP TV at CES - world's largest (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X			Samsung SDI achieves number one market share (shipment based) in PDPs in the first quarter of 2004. FHP is second, LG Electronics is third, and Matsushita is 4th in share (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X			Samsung SDI announces it has developed 102" PDP (Nikkei BP, 2005 (Jitsumu Hen)).
2004			X		Samsung SDI develops 1.8" 256K color OLED for main cell phone display use (Sangyo Times, 2005).
2004			X		Samsung SDI exhibits 2.0" AM-OLED prototype with 520X220 resolution at IDW 2004 (Nikkei BP, 2004 (Gijutsu Hen)).
2004			X		Samsung SDI exhibits 2.2" QVGA AM-OLED panel prototype with top emission at SID 2004 (Nikkei BP, 2004 (Gijutsu Hen)).
2004			X		Samsung SDI exhibits 2.5" AM-OLED prototype with system on panel at SID 2004 (Nikkei BP, 2004 (Gijutsu Hen)).

2004			X		Samsung Electronics exhibits 14.1" and 7" a-Si OLEDs at Asia Display/IMID 2004 (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X		Samsung SDI exhibits 17" UXGA AM-OLED prototype panel made using Laser Induced Thermal Imaging (LITI) at SID 2004 (Nikkei BP, 2004 (Gijutsu Hen)).
2004			X		NEC sells its stake in Samsung NEC mobile display to Samsung SDI along with NEC's OLED patents. Samsung SDI also gets Korean plant in deal (Nikkei BP, 2004 (Jitsumu Hen); Sangyo Times, 2005).
2004			X		Samsung NEC is renamed "Samsung OLED" proclaims goal to be global no. 1 in OLED (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X		Samsung OLED begins production with 2.5M units/month capacity (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X		Samsung SDI develops vacuum deposition system for AM-OLED fabrication (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X		Samsung SDI exhibits 2 kinds of differently driven OLED panels at IDW '04 (Nikkei BP, 2005 (Jitsumu Hen)).
2004			X		Samsung SDI's subsidiary Samsung OLED begins mass production of OLEDs for main displays in cell phone applications (Fuji Chimera, 2005).
2004			X		Share of OLED market in 2004: Samsung SDI: 38%; RiT: 23% (Sangyo Times, 2006).
2004				X	Samsung begins selling 50" and 56" DLP based slim RPTVs (Nikkei BP, 2004 (Jitsumu Hen)).
2004				X	Samsung makes 6 base color LCD and 5 base color DLP products (Nikkei BP, 2004 (Jitsumu Hen)).
2004				X	Samsung SDI enlarges patent management function (originally started in 1999), applies for approximately 1400 PDP patents in Korea and other countries in 6th month period (Nikkei BP, 2004 (Jitsumu Hen)).
2005	X				Samsung Electronics exhibits 46" LCD TV with 120hz frame rate at IMID 2005 (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				Samsung Electronics exhibits 32" TFT with field sequential LED backlight control (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				Samsung Electronics exhibits 57" FHD VA mode LCD TV panel (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				Samsung Electronics exhibits 82" FHD LCD TV panel - World's largest (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				Samsung Electronics exhibits 5" LCD panel of flexible plastic - world's largest of this type (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				Samsung finishes pilot test runs on its new 7th generation 7-2 line (Nikkei BP, 2005 (Jitsumu Hen)).

2005	X				Samsung introduces LED backlight LCD TV (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				Samsung develops 32" LCD Panel that does not have color filter (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X				Samsung Electronics is first to start shipping a-Si TFT with the driver circuitry on glass (Nikkei BP, 2005 (Senryaku Hen)).
2005	X				S-LCD begin production on world's first G7 line (Fuji Chimera, 2005).
2005	X				As of 2005, Samsung SDI is the largest producer by volume of displays for cell phones (Fuji Chimera, 2005).
2005	X				Samsung and Sony agree to joint development of LCD panels using Samsung's mass production knowledge and Sony's video technologies (Techno Associates, 2008).
2005	X				Samsung reports LCD business performance improving, and companywide increase in revenues and profitability in the third quarter compared with the previous quarter (Nikkei BP, 2005 (Jitsumu Hen)).
2005		X			Samsung SDI exhibits 102" PDP for TV use at CES (Nikkei BP, 2005 (Jitsumu Hen)).
2005		X			Samsung SDI exhibits 50" full HD PDP TV use panel (Nikkei BP, 2005 (Jitsumu Hen)).
2005		X			Samsung SDI's PDP business achieves number 1 share position, is on chart to be profitable (Nikkei BP, 2005 (Senryaku Hen)).
2005			X		Samsung SDI exhibits 2.65" OLED panel with VGA resolution (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X		Samsung SDI exhibits 14.1" OLED using large particle materials (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X		Samsung SDI exhibits 17" OLED TV use panel prototype 1600X1200 resolution (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X		Samsung SDI develops 17" UXGA AM-OLED using super grain silicon (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X		Samsung Electronics exhibits 21" WXGA small molecule OLED on a-SI (using RGB) for TV applications (Nikkei BP, 2004 (Gijutsu Hen); (Nikkei BP, 2005 (Jitsumu Hen)).).
2005			X		Samsung Electronics exhibits 40" OLED prototype - world's largest. It was exhibited at SID 2004 and made using small molecule materials (Fuji Chimera, 2005; Nikkei BP, 2005 (Jitsumu Hen)).
2005			X		Samsung SDI develops flexible OLED display on stainless (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X		Samsung SDI exhibits world's highest density OLED panel - 302ppi (Nikkei BP, 2005 (Jitsumu Hen)).

2005			X		Samsung SDI begins construction of LTPS AM-OLED line using generation 4 substrate. Investment total 57 billion yen (Sangyo Times, 2006).
2005				X	Samsung SDI announces record revenue and profitability (Nikkei BP, 2005 (Jitsumu Hen)).
2006	X				US DOJ begins joint investigation with Japanese and Korean Fair Trade Commissions on alleged anti-competitive actions from major LCD producers including Sharp, Samsung Electronics, LG Philips, and others (Deutsche Bank, December, 2006).
2006	X				Samsung Electronics continues to have top LCD panel market share (Nikkei BP, 2006 (Senryaku Hen)).
2006	X				Samsung Electronics makes 1.98" VGA screen - first to achieve 400ppi on a-Si (others did this using LTPS) (Nikkei BP, 2008 (TV Hen)).
2006	X				Samsung Electronics announces it developed a 40" LCD TV using LED backlights (Fuji Chimera, 2006).
2006	X				Samsung LCD begins production at line 7-2 (Tangjeong) (Samsung Electronics, 2008).
2006	X				Samsung makes additional 28 billion yen investment in generation 7 line to increase production capacity form 75K sheets/month to 90K sheets/month (Sangyo Times, 2007).
2006	X				Sony and Samsung agree for S-LCD to set up new 8G production (Techno Associates, 2008).
2006	X				Samsung and AUO cross license LCD-TV technology (Techno Associates, 2008).
2006		X			Samsung SDI ships the equivalent of 4.3 million PDPs (converted to 42" size) (Nikkei BP, 2006 (Senryaku Hen)).
2006		X			Samsung SDI ends production of 32-37" PDPs in face of strong 30" class competition from LCD panels (Fuji Chimera, 2006).
2006		X			Samsung SDI opens new PDP plant which uses much larger substrate (2400X2200 mm) (Sangyo Times, 2005).
2006			X		Samsung SDI announces 5.6" flexible OLED panel on metal foil at SID 2006 (Nikkei BP, 2008 (OLED Hen)).
2007	X				Samsung Electronics and LG Philips LCD have agree to cross purchasing between their equipment makers (buy from each others equipment makers) (Daewoo Securities, October, 2007).
2007	X				Samsung develops 1cm deep 40" LCD panel (Nikkei BP, 2007 (Market Hen)).
2007	X				Samsung begins selling 52" full HD LED backlit LCD TV (Nikkei BP, 2007 (Market Hen)).
2007	X				Samsung Electronics develops 0.82mm thick 2.2" LCD panel (Nikkei BP, 2007 (Trend Hen)).

2007	X				Samsung electronics develops 70" full HD TV with local dimming LED technology (Nikkei BP, 2007 (Trend Hen)).
2007	X				S-LCD adds capacity to generation 7 line for a second time. New capacity is 15K sheets/mo. Additional investment is 28 billion yen (Sangyo Times, 2008).
2007	X				S-LCD begins production on generation 8 line. Investment is 1.9 billion USD (Nikkei BP, 2007 (Trend Hen); Sangyo Times, 2008).
2007		X			Samsung SDI begins mass production at Pusan #4 PDP line for 50" production (Nikkei BP, 2008 (TV Hen)).
2007		X			Samsung SDI develops 50" full HD single scan PDP (Nikkei BP, 2007 (Market Hen)).
2007		X			Samsung begins shipping 50" full HD PDP TV "PAVV Cannes" (Nikkei BP, 2007 (Market Hen)).
2007			X		Samsung SDI develops 0.25mm thick OLED 4" panel prototype using top emission, small particle materials, and LTPS (Nikkei BP, 2007 (Market Hen)).
2007			X		Kodak and Samsung SDI exhibit 14.1" WXGA white + color filter OLED display prototype (Nikkei BP, 2008 (OLED Hen)).
2007			X		KDDI begins selling cell phone with AM-OLED panel. Panel is produced by Samsung SDI (Nikkei BP, 2008 (OLED Hen)).
2007			X		Samsung SDI begins producing 2" AM-OLED panels at Chonan plant (Nikkei BP, 2007 (Trend Hen)).
2007			X		Samsung SDI develops 0.52mm thick 2.2" AM-OLED (Sangyo Times, 2008).
2007				X	Samsung SDI has profits of 130.5 billion Korean won during 2006 (Nikkei BP, 2007 (Market Hen)).
2008	X				Samsung Electronics announces it plans to build Generation 11 plant with 3320X3000mm substrate to begin production ins 2010-2011 (Nikkei BP, 2008 (Kigyou Bunseki Hen)).
2008	X				Samsung Electronics loses money in Q4 2008 (Nikkei BP, 2008 (Kigyou Bunseki Hen)).
2008	X				S-LCD announces it will build 8th generation line 8-2 (Nikkei BP, 2008 (Kigyou Bunseki Hen)).
2008	X				Samsung Electronics exhibits 82" Ultra Definition (4X2K) LCD TV at SID 2007 (Nikkei BP, 2009 (Kigyou Bunseki Hen)).
2008	X				Samsung Electronics exhibits ultra-thin 52" LCD TV at SID 2008 (Nikkei BP, 20098(Kigyou Bunseki Hen)).
2008	X				Samsung LCD begins production at line 8-1, phase II (Samsung Electronics, 2008).
2008	X				Samsung LCD begins construction of line 8-2 (Tangjeong) (Samsung Electronics, 2008).
2008		X			Samsung Electronics exhibits 3D plasma TV (Nikkei BP, 2008 (Kigyou Bunseki Hen)).

2008			X		Samsung Electronics exhibits 14.1" HD OLED TV at SID 2008 (SDI made panel) (Nikkei BP, 2008 (Kigyou Bunseki Hen)).
2008			X		Samsung Electronics exhibits FHD 31" OLED TV at CES 2008. It uses a SDI made panel (Nikkei BP, 2008 (Kigyou Bunseki Hen); Sangyo Times, 2008).
2008			X		Samsung SDI announces 12.1 WXGA OLED panel (Nikkei BP, 2008 (Kigyou Bunseki Hen)).
2008			X		Samsung SDI exhibits WVGA 3" OLED panel (Nikkei BP, 2008 (Kigyou Bunseki Hen)).
2008			X		Samsung SDI exhibits 40" OLED panel at FPD International 2008 (Nikkei BP, 2008 (Senryaku Hen)).
2008			X		Samsung Electronics and Samsung SDI set up JV to develop small and mid size AM-OLED business (Nikkei BP, 2008 (Kigyou Bunseki Hen)).

Year	LCD	OLED	Other	Event
1955			X	Sanyo begins TV assembly (Hiramoto, 1994).
1970	X			Sanyo begins basic research on LCD technology (Sangyo Times, 1993).
	X			Sanyo's Tokyo location developed LCDs for clock applications (Sangyo Times, 1990).
1974	X			Sanyo began production of TN LCD for watches and calculators (Sangyo Times, 1994).
	X			Sanyo Electric developed TN-LCDs at central research lab (Sangyo Times, 1992).
1982	X			Tottori Sanyo begins selling (STN) LCD modules (Sangyo Times, 1993).
	X			Sanyo develops world's first black and white a-Si TFT-LCD TV (Sangyo Times, 1994).
1983	X			Sanyo was first to successfully develop a-Si color TFT-LCD (Sangyo Times, 1993).
1988	X			Sanyo LCD Engineering was established to produce TFTs for portable TVs and VTRs (Sangyo Times, 1990).
1989	X			Sanyo Electric started a new TFT LCD R&D center (Nikkei BP, 1990).
1989	X			Tottori Sanyo begins producing 9.2" color STN panels for laptop applications. NEC will use this display in new laptop model (Nikkei BP, 1990).
1989	X			Sanyo plans to develop 12" a-Si TFT, and is focusing on mass production technologies to realize this (Nikkei BP, 1990).
1989			X	Sanyo states that they ceased research on flat CRT displays (Nikkei BP, 1990).
1990			X	Sanyo begins making LCD projectors (Sangyo Times, 1990).
1991			X	Sanyo successfully commercializes high vision LCD projector using TFT technology (Sangyo Times, 1993).
1993	X			Sanyo Electric develops 10.4" VGA TFT LCD for office automation applications (Nikkei BP, 1993).
1993	X			Tottori Sanyo builds plant to produce color filters for LCD (Sangyo Times, 1993).
1993	X			Sanyo Electric is developing polysilicon TFTs (Sangyo Times, 1993).
1993	X			Sanyo builds small/mid size TFT production line GIII Building at Gifu location (Sangyo Times, 1998).
1994	X			Sanyo Electric develops 3" TFT LCD with 324X234 resolution (Nikkei BP, 1994).

1994	X			Sanyo is reported to be working on FLCD technology (Sangyo Times, 1993).
1995	X			Sanyo Electric announces it is first to develop a low temperature process for fabricating poly-silicon (LTPS) TFT LCDs in volume (Sangyo Times, 2000).
1995	X			Sanyo develops 5" color TFT with 320X234 resolution (Nikkei BP, 1995).
1995	X			Sanyo Electric develops 2.4" LTPS display with drivers on board and 320X240 resolution (Nikkei BP, 1995).
1995	X			Sanyo's strategy is to focus on 6" and smaller TFTs and increase its outside sales (Sangyo Times, 1995).
1995	X			Sanyo begins building LTPS line at Gifu plant (Sangyo Times, 1999).
1995	X			Sony and Sanyo announce they have agreed to jointly develop LTPS (Sangyo Times, 2001).
1996	X			Sanyo Electric develops 2" LTPS display for personal applications (Nikkei BP, 1996).
1996	X			Sanyo Electric begins shipping samples of 2" 110K pixel LTPS LCDs for digital cameras (Nikkei BP, 1996).
1996	X			Sanyo Electric plans to enter large panel TFTs at its Tottori Sanyo Electric group company. The company plans to begin constructing a plant in 1997 to begin production later that year. Production of a-Si modules is planned using 550X650 mm substrates (Sangyo Times, 1997).
1996	X			Tottori Sanyo adds a second line to Shimane Sanyo color filter plant (Sangyo Times, 1997).
1996	X			Sanyo (Gifu plant) begins mass production on LTPS, begins shipping sample displays (Sangyo Times, 1999).
1996	X			Sony and Sanyo begin producing low temperature polysilicon displays in a joint business. Sony designs the displays, and Sanyo performs contract manufacturing (Sangyo Times, 2001).
1997	X			Sanyo Electric develops 4" LTPS with 320X240 resolution (Nikkei BP, 1997).
1997	X			Tottori Sanyo installs 47 billion yen TFT-LCD line, begins production. Substrate is 550X670mm (Nikkei BP, 1997).
1998	X			Sanyo Electric develops LTPS for digital still camera applications (Nikkei BP, 1998).
1998	X			Sanyo begins TFT production at new line in Gifu GIII plant (Sangyo Times, 1998).
1998	X			Tottori Sanyo's TFT production dramatically reduces its focus on STNs (Sangyo Times, 2000).
1999	X			Tottori Sanyo develops 15" XGA TFT panel (Nikkei BP, 1999).

1999	X			Sanyo announces it will begin selling 15" LCD TV (Nikkei BP, 1999).
1999	X			Tottori Sanyo begins producing 15" TFTs for monitors. It already produced 12.1" TFTs (Sangyo Times, 1999).
1999	X			Tottori Sanyo TFT production is 90% 12.1" size - Sanyo is late entrant into market (Sangyo Times, 2001).
1999	X			Tottori Sanyo's main STN and TFT customers are Taiwanese notebook assemblers (Fuji Chimera, 2000).
1999		X		Sanyo and Kodak sign agreement to jointly develop OLED from production to sales. Sanyo will bring low temp polysilicon driver circuit for AM-OLED (Sangyo Times, 2000).
1999		X		Sanyo and Kodak announce they have successfully jointly developed full color OLED as well as PM area color OLED (Sangyo Times, 2000).
1999		X		Kodak and Sanyo announced they have jointly developed world's first 2.4" AM-OLED panel (Nikkei BP, 2002 (Jitsumu Hen)). It will be used for digital still camera application (Nikkei BP, 1999).
2000	X			Sanyo develops 0.55" LTPS panel for viewfinders (Nikkei BP, 2000).
2000		X		Kodak and Sanyo announced they have jointly developed 5.5" full color AM-OLED panel (Nikkei BP, 2002 (Jitsumu Hen)).
2001	X			Sanyo releases 15" LCD TV with XGA resolution and IPS mode panel (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X			Sanyo concentrates all LCD activities at Tottori Sanyo. All OLED is concentrated at Sanyo Electric (Fuji Chimera, 2001).
2001	X			Toppoly (Taiwan) received LTPS technology transfer from Sanyo around 2001-2 (Fuji Chimera, 2003).
2001	X			Tottori Sanyo begins production at second plant (680X880 mm substrate; a-Si) (Sangyo Times, 2001).
2001	X			Tottori Sanyo exhibits 29" TFT panel with HD resolution (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X			Sanyo announces it will integrate TFT businesses from Tottori Sanyo and Sanyo (Sangyo Times, 2002).
2001		X		Sanyo announces it will build an OLED business (Sangyo Times, 2002).
2001		X		Kodak and Sanyo Electric establish "SK"" JV to develop and produce AM-OLEDs. The JV will be owned 66% Sanyo, 33 Kodak, and will invest up to 50 billion yen (33 billion Sanyo, 17 billion from Kodak) in production capability by 2005 (Nikkei BP, 2002 (Jitsumu Hen)).
2001		X		SK JV plans to produce large screen AM-OLED TV in 2004 (Nikkei BP, 2002 (Jitsumu Hen)).

2001		X		Tottori Sanyo's number one plant will be bought by SK Display. SK will invest and additional 42 to 47 billion yen on evaporation equipment and other OLED related production equipment (Sangyo Times, 2002).
2001		X		Sanyo and Kodak build small volume line at Gifu (Sangyo Times, 2001).
2001			X	Sanyo releases 32" PDP TV with 852X1024 resolution and ALIS panel (Nikkei BP, 2001 (Jitsumu Hen)).
2002	X			Sanyo intends to produce LCD TV panels at No. 2 Tottori Sanyo plant beginning in 2003. These are to be assembled at 4 Sanyo TV plants world-wide (Sangyo Times, 2003).
2002	X			Sanyo Electric exhibits 39.6" LCD TV panel at Edex (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X			Tottori Sanyo begins producing 29" and 40" TFT panels at its number 2 plant (Nikkei BP, 2002 (Senryaku Hen)).
2002		X		Sanyo exhibits 2 color-filter-on-white OLED panels, 14.7" at Ceatec Japan 2002 (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X		Sanyo Electric develops 14.7" color AM-OLED HD panel. (CF on White OLED) (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X	Sanyo releases 42" PDP TV with 1024X1024 pixel resolution (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X	Sanyo releases 59" HD RPTV using DLP (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X	Sanyo and iFire agree to partner on TV application TDEL development (Sangyo Times, 2004).
2003	X			Sanyo Electric begins LTPS production at Tottori plant (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X			Sanyo Electric releases 30" LCD TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X			As of 2003, Sanyo has sold panels for TV usage to other firms, including Samsung - but they don't seem to have used these panels for their own TVs (Fuji Chimera, 2003).
2003	X			Sanyo begins production on second line in number two Tottori Sanyo plant. Substrate is 680X880mm (Sangyo Times, 2004).
2003	X			Sanyo exhibits 1.9" semi transparent LCD at Ceatec 2003 (Sangyo Times, 2004).
2003	X			Sanyo shifts TFT production from large panels to mid and small panels (Sangyo Times, 2004).
2003	X			Tottori Sanyo and Twinhead of Taiwan enter into long term partnership contract on LCD (Deutsche Bank, August, 2004).
2003	X			As of June 2003, Tottori Sanyo is using MVA mode (Deutsche Bank, June, 2003).

2003		X		Sanyo Electric exhibits 2.5" OLED using color filters on white OLED (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X		SK Display begins volume shipment of AM-OLEDs (Sangyo Times, 2003).
2004	X			Sanyo to procure panels for TVs from outside, not interested in making additional investment for consumer TV panel development or production (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X			Sanyo releases 23" HD LCD TV (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X			Sanyo and Epson agree to integrate their LCD businesses into a single entity, Sanyo Epson Imaging Device. Epson to hold 55%, Sanyo 45%. New company to develop, manufacture, and sell STN, MD-TFD LCD, Amorphous TFT LCD, LTPS-TFT LCD. Note: high temp polysilicon not included (Fuji Chimera, 2004; Sangyo Times, 2005). OLED isn't part of the deal, but most of the equipment used to produce OLED moves to the new company (Sangyo Times, 2005). Prior to establishing Sanyo Epson Imaging Device, Sanyo bought HTPS from Epson, both had OEM relationships relating to semiconductors (Sangyo Times, 2005).
2004		X		Sanyo electric exhibits 2.5" AM-OLED panel (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X		Kodak and Sanyo exhibit 2.16" OLED with lower energy requirements at IDW '04 -using white + color filter (Nikkei BP, 2005 (Jitsumu Hen)).
2004			X	Sanyo announces new FPTV product line with 7 models having built in digital tuners ranging from 17" LCD to large PDP models (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X	Sanyo releases 55" HD RP TV with HTPS panel (Nikkei BP, 2004 (Jitsumu Hen)).
2005	X			Sanyo releases 37" Full HD LCD TV (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X			Sanyo Electric begins selling LCD TV with VA mode panels produced by CMO. They had been using IPS mode panels (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X	Sanyo releases 42" PDP TV using 5th generation ALIS panels (Nikkei BP, 2004 (Jitsumu Hen)), supplied by Panasonic (Fuji Chimera, 2005).
2006	X			Sanyo exits small and middle size LCD panels, sells its stake in Sanyo Epson to Epson (Nikkei BP, 2008 (Jitsumu Hen)). The organization's new name is Epson Imaging Device (Sangyo Times, 2007).

2006		X		SK Display, the JV between Sanyo and Kodak that developed and produced OLED panels, is dissolved as part of Sanyo's reorganization (Sangyo Times, 2007).Tohoku Device purchases production line from SK Display when SK exits OLED production (Sangyo Times, 2007).
2008			X	Sanyo and Panasonic agree for Panasonic to acquire Sanyo (Sanyo, 2008).

Year	LCD	OLED	PALC	EL	Other	Event
1969	X					Wada, the person initially behind LCD development at Sharp, first hears of LCDs through an NHK TV program "Sekai no Kigyo." He had been interested in transparent films, EL, and displays in general (Numagami, 1999).
1970	X					Sharp licenses LCD technology from RCA (Murtha et al., 2001), begins LCD development (Sangyo Times, 1992).
1973	X					Sharp begins selling world's first LCD segment display calculator, LC Mate EL805. The LCD used was a segment DSM type (Nikkei BP, 2000; Sangyo Times, 1993).
1973	X					Sharp is first to mass produce segment LCD displays (Nikkei BP, 2004 (Jitsumu Hen)).
1974	X					Orient begins selling TN-LCD watches with LCD supplied by Sharp (Numagami, 1999).
1974				X		Sharp publishes paper on 2 layer agriculture EL (Nikkei BP, 1998).
1978	X					Sharp develops PDA with FEM-LCD. This is first LCD display that can be used for more than just characters (Sangyo Times, 1997).
1978				X		Sharp demonstrates working video-capable EL panel at CES (Johnstone, 1999).
1980	X					Sharp begins research on high information LCDs for applications such as OA and TV (Numagami, 1999).
1980	X					Sharp develops TSTN, FSTN LCD technologies (Sangyo Times, 1999).
1983				X		Sharp develops 6" single color EL monitor product (Nikkei BP, 1998).
1984	X					Sharp begins mass production of B&W STN LCD displays (Sangyo Times, 1993).
1985	X					Sharp begins developing mass production technology for TFT-LCD (Fuji Chimera, 2002).
1986	X					Sharp begins producing PC with a color STN display (Nikkei BP, 2004 (Jitsumu Hen)).
1986	X					Sharp creates LCD department inside of its electronic parts business unit. Until this point, LCD research had been conducted in the display department. of the electronics parts business unit together with EL and LED technologies (Miyamoto, 2007).
1986	X					Sharp exhibits 3" color TFT TV at Electronics Show (Sangyo Times, 1993).

1986	X					Sharp's "Shoin" Japanese word processor with STN display becomes a "hit product" (Sangyo Times, 2001).
1987	x					Sharp begins mass production of 3" color TFT LCD TV (Sangyo Times, 1993). Yield on TFTs for the set is 2% (Nikkei BP, 2004 (Jitsumu Hen)).
1987	x					Sharp develops 14" TFT LCD display (Sangyo Times, 1990).
1989	X					Sharp begins shipping samples of 14" and 11" high resolution B&W STN LCD panels (Nikkei BP, 1990).
1989	X					Sharp begins shipping samples of 5.7" full color TFT LCD (Nikkei BP, 1990).
1989	X					Sharp begins using DSTN-LCD for color displays in laptop computer applications (Sangyo Times, 1992).
1989	X					Sharp develops a 14" full color a-Si LCD (Nikkei BP, 1990).
1989	X					Sharp president Asada predicts Hi Vision Japanese (Analog High Definition) LCD TV can be developed in two years (Nikkei BP, 1990).
1989	X					Sharp releases video camera with LCD viewfinder (Nikkei BP, 1990).
1989	X					Sharp shows 10.4" TFT multicolor LCD panel with VGA resolution (Nikkei BP, 1990).
1989	X					Sharp uses LCD in car navigation application (Nikkei BP, 2006 (TV Gijutsu Hen)).
1989				X		Sharp announces it has developed a 9.4" EL display with 16 gradation levels, VGA resolution (Nikkei BP, 1990).
1989				X		Sharp announces it plans to ship samples of 9" EL with VGA resolution (Nikkei BP, 1990).
1989					X	Sharp develops 100" TFT projector (Sangyo Times, 1993).
1990	X					Sharp begins producing 10" and 14" TFT LCDs (Nikkei BP, 1990).
1991	X					Sharp begins selling the world's first wall-hanging LCD TV. 8.6" display; the price is 500,000 yen (Sangyo Times, 1992).
1991	X					Sharp exhibits an 8.4" color TFT which is energy efficient and aimed at laptop computer applications (Sangyo Times, 1992).
1991	X					Sharp started producing 10.4" TFT VGA panels (Nikkei BP, 2006 (TV Gijutsu Hen)).
1992	X					As of 1992, Hitachi is in the same realm as Sharp as far as LCD patenting is concerned (Sangyo Times, 1992).
1992	X					Sharp begins mass production of color 8.4" TFT displays for laptops (Sangyo Times, 1992).
1992	X					Sharp begins selling LCD View Cam video recorder with 3" TFT-LCD display. This becomes major hit (Sangyo Times, 1993).

1992	X					Sharp establishes center for developing applications for LCD displays at Tenri (Sangyo Times, 1993).
1992	X					Sharp is first in the world to develop a 16.5" color TFT display (Sangyo Times, 1992).
1992	X					Sharp plans to invest 30 billion yen in LCD production facilities for 1992 (Sangyo Times, 1992).
1993	X					As of 1993, 88% of Sharp's production is color (Sharp TFTs are 100% color) (Sangyo Times, 1993).
1993	X					Sharp develops 17" XGA TFT panel with wide viewing angle (Nikkei BP, 1993).
1993	X					Sharp develops 5" color TFT with 320X234 resolution for small AV applications (Nikkei BP, 1993).
1993	X					Sharp develops 6.4" VGA TFT LCD with low power usage for subnotebook applications (Nikkei BP, 1993).
1993	X					Sharp has 40% share in the LCD driver IC market (Sangyo Times, 1993).
1993	X					Sharp introduces Zaurus LCD based PDA (Sangyo Times, 1998).
1993				X		Sharp develops 8.9" VGA EL display for factory automation and measurement applications (Nikkei BP, 1993).
1993					X	Sharp begins selling HDTV LCD projector with three polysilicon Si TFT panels (Nikkei BP, 1993).
1993					X	Sharp develops 200" color LCD projector using a 2" XGA resolution a-Si panel (Nikkei BP, 1993).
1994	X					Sharp begins construction of large TFT LCD plant in Mie prefecture. This is the world's largest scale LCD plant at the time. Initial investment is 53 Billion yen (Sangyo Times, 1994).
1994	X					Sharp begins producing mass producing plastic LCDs (Sangyo Times, 1994).
1994	X					Sharp develops prototype 21" VGA TFT LCD panel with wide viewing angle (Nikkei BP, 1994).
1994	X					Sharp develops reflective color LCD (Sangyo Times, 2000).
1994				X		Sharp is selling EL displays in 1994 (Nikkei BP, 19954).
1995	X					Sharp begins production at Mie plant (Sangyo Times, 1994).
1995	X					Sharp develops 11.3" TFT LCD with 800X600 resolution (Nikkei BP, 1995).
1995	X					Sharp is first to commercialize SVGA 11.3" color TFT (Sangyo Times, 1995).
1995	X					Sharp develops 12.1" color XGA TFT (Nikkei BP, 1995).
1995	X					Sharp develops 13.8" color XGA panel for monitor applications (Nikkei BP, 1995).

1995	X					Sharp develops 28" color VGA TFT panel for TV applications (Nikkei BP, 1995).
1995	X					Sharp develops 4" LTPS display with drivers on board and 380X354 resolution (Nikkei BP, 1995).
1995	X					Sharp develops DMGH reflective color LCD technology (Sangyo Times, 1998).
1995	X					Sharp develops Super HA LCD technology (Sangyo Times, 1998).
1995	X					Sharp introduces 8.4" color VGA TFT based television for automotive applications (Nikkei BP, 1995).
1995	X					Sharp introduces "Window" LCD TV in 10.4" and 8.4" sizes. Sharp sells out of initial production of 28K units in less than 3 months (Sangyo Times, 1996). 10.4" model is 150,000 yen. (Nikkei BP, 1995).
1995	X					Sharp introduces Mebius line of laptop computers using Sharp LCDs (Sangyo Times, 1998).
1995				X		Sharp is selling EL displays in 1995 (Nikkei BP, 1995).
1995					X	Sharp develops 5.8" reflective TFD display with 480X320 resolution for automotive applications (Nikkei BP, 1995).
1995					X	Sharp introduces Gaia (XV-R43) 43" rear projection TV using a-Si LCD display (Sangyo Times, 1995).
1995					X	Sharp's Urayama et al present paper on FED technology at IEDM conference (Nikkei BP, 2004 (Kihon Gijutsu Hen)).
1996	X					Sharp begins full production at world's largest LCD Plant in Mie with 110 billion yen investment (Sangyo Times, 1998).
1996	X					Sharp develops 13.3"and 15" XGA TFT LCDs for monitor applications (Nikkei BP, 1996).
1996	X					Sharp develops 40" color TFT with 800X600 resolution for TV applications - it is world's largest (Nikkei BP, 1996, 1998).
1996	X					Sharp develops Super-V technology which gives TFT LCDs much wider viewing angle (Sangyo Times, 1999).
1996	X					Sharp releases new model of 10.4" VGA TFT color TV "Window. " It has two tuners allowing two different channels to be watched simultaneously. Price is 170,000 yen (Nikkei BP, 1996).
1996	X					Sharp increases "Window" LCD TV lineup to include 13" model, sets goal of 200K units sales in 1996 (Sangyo Times, 1995).
1996			X			Sharp enters licensing agreement with Techtronix on PALC (Fuji Chimera, 2001).

1996			X			Sharp and Sony begin cooperating on PALC. Philips joins in 1997 (Fuji Chimera, 2001). The joint project is planned to last until September of 1999. Focus is on 40" class screen (Fuji Chimera, 1999).
1996					X	Sharp develops 6"FLCD (Fuji Chimera, 2001).
1997	X					Sharp develops 20.1" XGA TFT panel (Nikkei BP, 1997).
1997	X					Sharp develops 6.5" reflective TFT for portable use (640X240 pixels) (Nikkei BP, 1997).
1997	X					Sharp successfully develops prototype 4.5"VGA LTPS. Plans to enter production (Sangyo Times, 1998).
1997			X			Sony, Sharp, and Philips successfully develop prototype 42" PALC with wide view area (Sangyo Times, 1999, 2001).
1997					X	Sharp had not clarified its LCD focus (over other display technologies) at the time the NHK PDP development group was formed in 1994. It declared this focus in 1997 and dropped out of the group (Weber et al., 2008)
1997					X	Sharp Develops 17" full color FLCD (Fuji Chimera, 2001).
1998	X					Sharp declares it will replace its entire TV lineup with LCD TVs by 2005 (Miyamoto, 2007; Weber et al., 2008).
1998	X					Sharp and Quanta Computer plan to establish JV Quanta Display to manufacture TFT LCD modules. This is seen as a way for Sharp to increase market share in computer applications while also reducing risk (Sangyo Times, 2001).
1998	X					Sharp and Semiconductor Energy Lab announced that they have cooperated on developing Continuous Grain Silicon. This is much faster than amorphous or low temperature polysilicon It is seen as being suitable for rear projection TVs (Fuji Chimera, 2000).
1998	X					Sharp announces worlds first full lineup of flat panel TVs (Murtha et al., 2001).
1998	X					Sharp begins production of 20.1" SXGA Super-V LCD with high contrast and wide viewing angle (Sangyo Times, 1998).
1998	X					Sharp develops 11.3" reflective color TFT with 800X600 resolution for NBPC applications (Nikkei BP, 1998).
1998	X					Sharp develops 18.1" ASV color TFT with wide viewing angle (Nikkei BP, 1998).
1998	X					Sharp develops 20" VGA LCD based TV to be sold in Japan and overseas in 1999 (Nikkei BP, 1998).
1998			X			Sony, Sharp, and Philips successfully develop prototype 42" PALC HDTV display and 42" VGA PALC display (Sangyo Times, 2000).
1998					X	Sharp develops 2.6" continuous grain crystal Si XGA TFT for projection applications (Nikkei BP, 1998).

1998					X	Sharp develops 60" RPTV using 2.6" CGS-LCD panels, with HD resolution (Nikkei BP, 1998).
1999	X					Sharp and Quanta computer jointly invest in TFT LCD production JV called Quanta Display. Sharp will provide LCD drivers to Quanta, and Quanta will perform contract production, including notebook computers, for Sharp (Sangyo Times, 2000).
1999	X					Sharp begins production of ASV wide angle viewing 20+" TVs (Sangyo Times, 2000).
1999	X					Sharp begins selling 20" "Window" LCD TV (Sangyo Times, 2000). The prices is 440,000 yen (Nikkei BP, 2000).
1999	X					Sharp develops 3D color LCD TV (Sangyo Times, 2000).
1999	X					Sharp exhibits 28" HD LCD TV (Nikkei BP, 1998).
1999	X					Sharp introduces 10" LCD TV with depth of under 50mm, for home and auto use (Sangyo Times, 2000).
1999	X					Sharp introduces 18.1" LCD computer monitor (Sangyo Times, 2000).
1999	X					Sharp introduces notebook computer with 15" TFT and TV tuner included (Sangyo Times, 2000).
1999	X					Sharp is first to develop color reflective STN plastic display (Sangyo Times, 2000).
1999	X					Sharp ships ten thousandth 20" LCD TV (Nikkei BP, 1999).
1999			X			Contract to cooperate on PALC ends, Philips does not renew. Sony and Sharp continue cooperating on PALC development (Sangyo Times, 2000).
1999					X	Sharp announces prototype 65" PDP TV, entering PDP TV size arena (Nikkei BP, 2004 (Senryaku Hen)).
2000	X					Sharp and Hitachi agree on LCD patent cross-licensing deal (Techno Associates, 2008).
2000	X					Sharp begins production of large TFTs at Mie Number 2 Plant (Sangyo Times, 2001).
2000	X					Sharp buys Nippon Paint's STN LCD plant, and jointly develops color filter technology (Nikkei BP, 2008 (Kigyo Bunseki Hen)).
2000	X					Sharp develops 28" TFT panel prototype with QSXGA (2560X2048) resolution (Nikkei BP, 2000).
2000	X					Sharp develops UHA LCD technology for ultra large apertures, providing brighter displays with wider viewing angles (Sangyo Times, 2001).
2000	X					Sharp introduces AQUOS brand LCD TV line with 13, 15, and 20" panels, design by Japanese designer in Italy (Sangyo Times, 2001).

2000					X	Sharp begins receiving PDPs from Pioneer, and using them in TVs in North America (Sangyo Times, 2001).
2001	X					Sharp changes focus of Mie Number 1 plant to smaller screen production for cell phones, game boy advance, Zaurus, and car navigation (Sangyo Times, 2001).
2001	X					Sharp begins production on its second line at Mie #2 plant. This is be used for increasing supply of Aquos. Investment was 70 billion yen (Sangyo Times, 2002).
2001	X					Sharp begins shipping samples of plastic LCD for cell phone applications. It is lighter, thinner, and stronger than LCDs using glass substrate (Sangyo Times, 2001).
2001	X					Sharp develops Double Metal Twisted Nematic display for cell phone applications (Sangyo Times, 2001).
2001	X					Sharp develops ULC HR-TFT, an energy efficient reflective TFT that can be used in mobile devices (Sangyo Times, 2002).
2001	X					Sharp exhibits 3.7" CGS TFT with multi-resolution capability (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X					Sharp exhibits 7" CGS TFT LCD with duty driver built in (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X					Sharp introduces B-1 series of Aquos, in the same sizes as 2000 (Sangyo Times, 2002).
2001	X					Sharp introduces C-1 series of Aquos TVs, including 30" and 22" LCD models. 30" model has HD resolution, 22" model has VGA resolution (Nikkei BP, 2001 (Jitsumu Hen)). It has been only 7 months since the B series was introduced (Sangyo Times, 2002).
2001	X					Tohoku Pioneer, SEL and Sharp form JV ELDis to produce CG Silicon TFTs for use in AM-OLED displays. Capital is 10 billion yen, Stakes are 45% each for Tohoku Pioneer, SEL, and 10% for Sharp. JV plant for producing CG silicon TFT backplanes for AM-OLED applications. JV is to manufacture and sell these products (Sangyo Times, 2002).
2001			X			Sharp decides not to produce PALC displays because they were not convinced of the superiority of the display and there were difficulties encountered regarding developing mass production capability for PALC (Sangyo Times, 2002).
2001					X	Sharp releases 50" PDP TV with HD Resolution (Nikkei BP, 2001 (Jitsumu Hen)).
2002	X					As of 2002, Sharp is selling 30" LCD panels for TV application to Pioneer (Fuji Chimera, 2002).
2002	X					Sharp agrees to provide LCD technology to CPT, withdraws patent infringement lawsuit (Sangyo Times, 2003).

2002	X					Sharp and 13 other firms including Microsoft and Sony announce they have created a consortium to support the development of 3D software contents and 3D display business (Sangyo Times, 2003).
2002	X					Sharp and SEL successfully fabricated an 8 bit CPU on LCD glass substrate used in CGS LCDs (Sangyo Times, 2003).
2002	X					Sharp announces two 37" LCD TV models (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Sharp announces it has developed an LCD display that can be switched between 2d and 3d modes (Sangyo Times, 2003).
2002	X					Sharp begins selling 28" wide TFT LCD TV with HD resolution for 1,100,000 yen in February 2002 (Nikkei BP, 2000).
2002	X					Sharp announces it will build integrated LCD panel, module, and TV assembly Plant in Kameyama, Mie. Total investment will be 100 billion yen including land and production equipment. The plant is 7th generation and will use 1500X1800 mm substrate (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Sharp begins construction of the Kameyama and Mie No. 3 plants (Nikkei BP, 2002 (Senryaku Hen)).
2002	X					Sharp begins to mass production of Low temperature CGS LCD at the NF-1 line of Tenri plant (Sangyo Times, 2002).
2002	X					Sharp develops 3 chip LED backlit 15" LCD panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Sharp develops 37" VA mode HD TFT LCD panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Sharp exhibits 4" class plastic LCD prototype at LCD-PDP International Show (Sangyo Times, 2003).
2002	X					Sharp had 55% market share in LCD panels for TVs in 2002 (Sangyo Times, 2004).
2002	X					Sharp is only Japanese LCD manufacturer to be profitable in the 2002 fiscal year (Fuji Chimera, 2003).
2002					X	Sharp begins selling PDP TVs with built-in satelite recievers using Pioneer-made panels (Sangyo Times, 2002).
2003	X					Sharp is shifting small/mid size LCD strategy to focus on system LCDs - these have built in CMOS chips and are more than just stand alone displays (Sangyo Times, 2003).
2003	X					Sharp and SEL usefully fabricated an audio circuit (including digital to analogy converter, etc) on a LCD glass substrate for CGS (Sangyo Times, 2004).
2003	X					Sharp begins production at Mie #3 plant, which specializes in system LCDs using CGS technology (Sangyo Times, 2004).
2003	X					Sharp develops ASV (a version of VA) for mobile phone applications (Nikkei BP, 2003 (Senryaku Hen)).

2003	X						Sharp exhibits 37" VA mode HD TFT LCD panel (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X						Sharp opens new LCD R&D center at Mie plant for mobile LCDs. Previously, all LCD development had been at Tenri location - this location will also continue R&D. Kameyama will have TV related R&D (Sangyo Times, 2003).
2003	X						Sharp president claims the LCD TVs are the global trend at Ceatec Japan 2003 trade conference (Nikkei BP, 2003 (Jitsumu Hen)).
2003	X						Sharp releases 37" LCD TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003						X	Sharp exits PDP-TV market (Fuji Chimera, 2003).
2004	X						Sharp develops a LCD panel that acts as a speaker through cooperative R&D with Hoshiden (Sangyo Times, 2004).
2004	X						As of 2004, profitability at Sharp is more driven by smaller, custom applications (digital cameras, etc.) rather than the large, more commodity like production (Sangyo Times, 2004).
2004	X						Sharp exhibits 45" TFT panel with VA mode and Full HD (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X						Sharp to begin selling (world's largest) 45" FHD LCD TV with built in tuner in August (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X						Sharp announces development of world's largest LCD TV - 65". Sharp exhibits it at Ceatec Japan 2004, but does not plan to sell it immediately (Nikkei BP, 2004 (Senryaku Hen); Sangyo Times, 2005).
2004	X						Sharp is to begin production of world's first Generation 7 (1500x1800mm) line at Kameyama plant (Sangyo Times, 2003). This is world's first LCD line dedicated to TV production (Nikkei BP, 2003 (Senryaku Hen)).
2004	X						Sharp holds ceremony to celebrate completion of Kameyama plant, announces roughly 80% production yield (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X						Sharp establishes Kameyama TV sub brand (Nikkei BP, 2004 (Senryaku Hen)).
2004	X						Sharp requests Japanese government block imports of Taiwanese made LCD TVs citing patent infringements on LCD panel (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X						Sharp and Sony share lead in WW LCD TV shipments at 11.9% each. Sharp is a leader in numerous specific size ranges (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X						Sharp's LCD business is profitable for FY2004. The small and mid size LCD segment represents 60% of revenues and 70% of profits (Fuji Chimera, 2005).

2004	X					Sharp's LCD revenues continue strong growth 38% up year on year (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					For the year 2004, the three top LCD makers are: Sharp, #1, LG, #2, and CMO, #3 (Fuji Chimera, 2005).
2005	X					Sharp exhibits 37 "FHD VA mode LCD TV panel (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X					Sharp adds 57" full HD LCD TV with wide color range to its Aquos line (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X					Sharp adds 65" full HD LCD TV with three color backlight to its Aquos line (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X					Sharp releases its final 3 CRT TV models for the Japanese market (Fuji Chimera, 2006 (Digital AV Market))
2005	X					Sharp releases 32" LCD TV with wireless network capability (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X					Sharp acquired Fujitsu Display Technology and Fujitsu Research Lab's LCD business; this is effectively all of Fujitsu's LCD related business. Fujitsu Display Technologies became a wholly owned Sharp subsidiary called Sharp Yonago. According to Sangyo Times (2006), Sharp purchased it in order to gain additional LCD technicians and obtain Fujitsu's MVA technology. Sharp also plans to develop closer ties to Fujitsu as a supplier. The plant had been losing money recently (Fuji Chimera, 2005).
2005	X					Sharp and AUO (Taiwan) cross-license TFT LCD patents relating to PC applications after court battle (Techno Associates, 2008).
2005	X					Sharp begins construction of Kameyama Number 2 plant which will have generation 8 line using 2160X2400 mm substrate. Sharp is first to build this generation. Plant to come on line in October, 2006; total investment is 150 Billion yen (Fuji Chimera, 2005; Nikkei BP, 2005 (Jitsumu Hen); Sangyo times, 2006).
2005	X					Sharp and Tokyo University establish Todai Sharp Lab, agree to 5 year cooperative research. A number of topics may be included; the lab is not dedicated exclusively to display related research (Sangyo Times, 2006).
2005	X					Sharp develops ASV Premium Mega-contrast LCD. This technology to be used in master monitor for video production (Sangyo Times, 2006).

2005	X					Sharp developed TFT display with ability to control viewing angles. The Veil View LCD can be limit view to narrow range or open it back up. The Dual View LCD can show different images depending on angle of the viewer (Sangyo Times, 2006).
2005	X					Sharp develops mega contrast LCD with 1 million to 1 contrast in dark locations (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X					As of 2005, mid/ small LCDs become more competitive, and Sharp lo longer has as much profitability in this area as a result (Sangyo Times, 2006).
2005					X	Sharp begins rear projection TV production using TI's DLP. Sharp enters target markets are North America and China with 56" and 65" models. Sharp had previously been in rear projection TV business using High Temperature CGS, but it is no longer mass producing these (Sangyo Times, 2005).
2006	X					As of 2005, Sharp sells LCD TV panels to Toshiba, JVC, and By Design (Fuji Chimera, 2005).
2006	X					Quanta begins shipping LCD TV panels to Sharp (Techno Associates, 2008).
2006	X					Sharp and AUO broaden cross-license to include TV related patents (Techno Associates, 2008).
2006	X					Sharp and CMO (Taiwan) sign cross-licensing deal on LCD panel technology. They agreement covers patents, with exception of Sharp's 2 sided window technology, for a period of 5 years (Techno Associates, 2008).
2006	X					Sharp announces it will participate in joint development of flexible display technology with NEDO and 13 other firms (Nikkei BP, 2008 (Kigyo Bunseki Hen)).
2006	X					Sharp develops triple view in addition to dual view and veil view LCDs which it had developed in 2005 (Sangyo Times, 2007).
2006	X					Sharp develops very high contrast LCD with wide temperature operating range, for use in automotive applications (Sangyo Times, 2007).
2006	X					Sharp exhibits 4K X 2K resolution 108" panel at Ceatec Japan (Sangyo Times, 2007).
2006	X					Sharp introduces 32" full HD LCD TV (Nikkei BP, 2007 (Market Hen)).
2006	X					Sharp is sourcing 32" and 42" panels from CMO for TV sets to be sold abroad (Sangyo Times, 2007).
2006	X					Sharp is sourcing 37" panels from AUO for TV sets to be sold abroad (Sangyo Times, 2007).

2006		X				Sharp exhibits OLED panel with highest resolution, 202ppi, at SID 2006 (Kotani, 2006).
2006					X	Sharp increases sales of TV panels to Pioneer and Toshiba, building a stronger relationship with these firms (Sangyo Times, 2008).
2007	X					Pioneer is cooperating with Sharp, and planning to use LCD in 40" and smaller TV lineup. They each purchase equity stakes in each other, but Pioneer's stake in Sharp is less than 1%, and Sharp's stake in Pioneer is 14% (Sangyo Times, 2008).
2007	X					Sharp and Toshiba agree to supply each other with LCD panels and semiconductors (Nikkei BP, 2008 (Sangyo Doko Hen)).
2007	X					Sharp announces 20mm thick LCD TV prototype (Nikkei BP, 2008 (Sangyo Doko Hen)).
2007	X					Sharp announces it will build 10th generation LCD plant. Substrate size is 2850X3050. Sharp's investment will be approx 380 billion yen, and together with related plants attached to the facility which will be built by equipment and supply makers, total investment will be approximately 1 trillion yen. Production to start in 2010 (Nikkei BP, 2007 (Trend Hen)).
2007	X					Sharp announces world's largest LCD TV - 108" at CES (Nikkei BP, 2007 (Market Hen)).
2007	X					Sharp begins selling 22" and 26" full HD LCD AQUOS TVs (Nikkei BP, 2007 (Market Hen)).
2007	X					Sharp begins selling 120hz TV sets (5 models) with 3000:1 contrast (Nikkei BP, 2007 (Market Hen)).
2007	X					Sharp begins production at the second line of Kameyama number 2 plant with 8th generation substrate (Sangyo Times, 2009).
2007	X					Sharp begins shipping samples of 2.8mm thick 12.1" LCD panels with LED backlights (Nikkei BP, 2007 (Trend Hen)).
2007	X					Sharp developed 0.68mm thick 2.2" 240X320 pixel display (Sangyo Times, 2008).
2007	X					Sharp developed a LCD panel with built in light sensor that can be used for scanning or as a touch panel (Sangyo Times, 2008).
2007	X					Sharp developed mobile ASV panels for new one segment TV viewing on cell phones. These may sport the Aquous label. The panels may also be made in other sizes for auto navigation and digital still camera applications (Sangyo Times, 2008).
2007	X					Sharp releases THX certified LCD TV (Nikkei BP, 2007 (Market Hen)).
2007	X					Sharp exhibits 2cm deep 52" LCD TV prototype (Nikkei BP, 2007 (Trend Hen)).

2007	X					Sharp installs 3rd line at Kameyama, increasing capacity (Nikkei BP, 2007 (Market Hen)).
2007	X					Sharp passes Vizio to get top share during third quarter in North American LCD TV market (Nikkei BP, 2007 (Market Hen)).
2008	X					Sharp and Sony form JV to manufacture large LCD modules for TV sets at Sharp's plant under construction in Sakai. Sharp to take 66% stake and Sony 34%. To achieve this, Sharp will make 10th generation line a separate entity (Nikkei BP, 2008 (Sangyo Doko Hen)).
2008	X					Sharp begins production at the fourth line of Kameyama number 2 plant with 8th generation substrate (Sangyo Times, 2009).
2008	X					Sharp begins selling Aquos X Series LCD TVs with Mega ASV technology (Sangyo Times, 2009).
2009	X					Sharp exhibits flagship model LCD TV "XS" series at Ceatec Japan. It has one million to one contrast, is 22.8mm at thinnest portion, and has 150% of NTSC gamut (Nikkei BP, 2008 (Sangyo Doko Hen)).
2009	X					Sony and Sharp announce that they will delay formation of their LCD production JV from April, 2009 to March 2010 (Nikkei BP, 2008 (Kigyo Bunseki Hen)).

Year	CRT	LCD	PDP	OLED	FED	PALC	Other	Event
1974			X					Sony announces research into color PDP (Nikkei BP, 1990).
1980		X						Sony begins research on TFTs (Sangyo Times, 1990).
1982			X					Sony says it will enter into PDP and announced several PDP products (Yano Keizai, 1982).
1987			X					Sony Atsugi Technology center develops printer head TFT Technology (Sangyo Times, 1990).
1989			X					Sony develops 4" LCD TV with built-in 8mm video deck (Nikkei BP, 1990).
1990	X							Sony introduces 36" Hi Vision (Japanese analogy high definition standard) Trinitron (Jojima et al., 2006).
1990		X						Sony begins work on HTPS TFT, focusing on viewfinder and data projector applications in house (Fuji Chimera, 1998).
1990		X						Sony invests 10 billion yen, installs LCD line at Nagasaki plant. It will begin production in 1991 and manufacture 1" displays for video camera viewfinders (Sangyo Times, 1990).
1990					X			Sony began work on FED at its central research lab around 1990 (Nikkei BP, 2001).
1991	X							Sony introduces Kirara Basso TV sub-brand using Super Trinitron CRTs (Jojima et al., 206).
1992		X						Sony enters market for small TFT-LCDs, begins shipping samples of 0.55" (world's smallest) and 0.7" HTPS TFT LCDs for viewfinder and projector applications (Sangyo Times, 1992, 1993).
1992						X		Sony licenses PALC technology from Techtronix (Fuji Chimera, 2001).
1994		X						Sony develops 1.35" HTPS LCD with 1068X480 resolution for projection applications (Nikkei BP, 1994).
1994		X						Sony says that its LCD business will focus on 2-inch and smaller HTPS (Nikkei BP, 1994).
1994				X				Sony begins R&D on OLED (Sangyo Times, 2001).
1995		X						Sony is first to introduce MD (micro display) rear projection TV (Nikkei BP, 2006 (TV Hen)).
1995		X						Sony releases Pary Vision CPJ-100 home use projector with 170K dot resolution using a 1.3-in LCD (Sangyo Times, 1994).

1995		X						Sony introduces 37" HTPS LCD rear projection TV called "Flight" (Nikkei BP, 1996) with 3 LCDs in the projection unit (KL-37HW1) (Sangyo Times, 1995).
1995						X		Sony develops 25" PALC panel with 768X448 resolution for TV applications (Nikkei BP, 1995).
1995							X	Sony announced that it is jointly developing digital mirror device technology with Texas Instruments (PR Newswire, 1995; Sangyo Times, 1995).
1996		X						Sony begins work on LTPS (Sangyo Times, 1999).
1996		X						Sony and Sanyo begin producing LTPS displays through cooperative arrangement. Sony designs the displays, and Sanyo performs contract manufacturing (Sangyo Times, 2001).
1996		X						Sony develops 1.43" HTPS for projection applications (Nikkei BP, 1996). Sony exhibits 1.3" HTPS XGA for projector applications at Electronics Show (Nikkei BP, 1997).
1996		X						Sony develops 2.5" and 5.6" LTPS (Nikkei BP, 1996).
1996		X						Sony releases 50" RPTV using 3 HTPS panels. It is priced at 580,000 yen (Nikkei BP, 1996).
1996						X		Sony and Sharp agree to develop PALC and production technology related to PALC. Sony, Sharp, and Techtronix agree to sub-license of PALC technology and joint development of the technology. Philips joins the development group in 1997. The joint project is planned to last until September of 1999. Focus is on 40" class screen (Fuji Chimera, 1999, 2001; Sangyo Times, 1997, 1999).
1996						X		Sony plans to begin selling 25" Plasmatron color TV, model PZ-2500; prices is 900,000 yen (Sangyo Times, 1997). This model wins the good design award from
1996						X		Sony sells PALC display - but this is made to order. It also suffers from limited viewing angles (Fuji Chimera, 2001).
1997	X							Sony Introduces KW-32HDF9, a flat screen Trinitron based high vision TV and began using the brand name "Wega" (http://www.sony.co.jp/SonyInfo/CorporateInfo/History/sonyhistory-c.html).
1997		X						Sony and Toyota Looms established a JV to fabricate LTPS TFTs (Sangyo Times, 1998).

1997		X						Sony establishes LCD Development Center at Kokubun to develop HTPS (Sangyo Times, 1999).
1997						X		Sony, Sharp, and Philips successfully develop prototype 42" PALC with wide view area -- ASM (Axially Symmetric aligned Micro Cell mode) (Sangyo Times, 1999).
1997						X		Sony exhibits 42" PALC at Electronics Show (Nikkei BP, 1997).
1998	X							Sony begins shipping HD ready 34" CRT TV (Nikkei BP, 1998).
1998		X						Sony develops 8.6" reflective LTPS with 1024X384 resolution for portable applications (Nikkei BP, 1998).
1998		X						Sony begins selling NBPCs with LTPS panels (Nikkei BP, 1998).
1998					X			Sony and Candescent announce start of joint development efforts. The focus is FED technology. Sony will take an equity stake in Candescent and license Candescent's technology and manufacturing rights (Nikkei BP, 2007 (Market Hen)).
1998						X		Sony, Sharp, and Philips successfully develop prototype 42" PALC HDTV display and 42" VGA PALC display (Sangyo Times, 2000; Fuji Chimera, 2001).
1999	X							Sony Introduces Super Fine Pitch FD Trinitron (Nikkei BP, 2002 (Jitsumu Hen)).
1999		X						Sanyo provides contract manufacturing of small low temperature polysilicon TFTs for Sony (Sangyo Times, 1998).
1999		X						Sony begins LTPS production at ST LCD JV, focusing on DSC and Video Camera panels in 2", 2.5", and 3.4" sizes (Nikkei BP, 1999).
1999		X						Sony changes LCD organization, dividing the LTPS and HTPS efforts (Sangyo Times, 2002).
1999		X						Sony develops 14.1" XGA LTPS panel (Nikkei BP, 19999).
1999		X						Sony exhibits 15" LCD TV (Nikkei BP, 1999).
1999		X						ST produces front-lit 9" LTPS used inViao computer (Sangyo Times, 2001).
1999					X			Sony and Candescent exhibit 5.3" FED prototype with 320X240 resolution (Nikkei BP, 1999).
1999						X		Contract to cooperate on PALC ends, Philips does not renew. Sony and Sharp continue cooperating on PALC development (Sangyo Times, 2000).

2000	X							Sony begins selling 32" and 36" Vega TVs with super fine pitch FD trinitron CRTs. Sony fills out its Vega Trinitron CRT TV line to cover 14 inch to 38 inch models (Nikkei BP, 2000).
2000		X						Sony begins selling 15" XGA LCD TV for 198,000 (Nikkei BP, 2000).
2000			X					Sony announces it will take an equity stake in Fujitsu Hitachi Plasma Display. Fujitsu 42.5%, Hitachi 42.5%, Sony 15% is the new stake percentages (Sangyo Times, 2001); the firm later backs out.
2000				X				As of the end of 2001, Sony plans to develop mass production technology for OLEDs to allow production of 20 and 30" panels, by the year 2003 (Nikkei BP, 2001 (Senryaku Hen)).
2000					X			Candescent exhibits 5.3" QVGA and 13.2"SVGA color FEDs at SID 2000 developed in cooperation with Sony (Nikkei BP, 2001 (Senryaku Hen)).
2000					X			Sony exhibits 13" FED at SID 2000 (Sangyo Times, 2001).
2000						X		Sony closes Mizunami (Gifu Prefecture) location where Sony and Sharp had cooperated on PALC R&D (Sangyo Times, 2002).
2000							X	Sony has received rights to develop, produce and sell relating to MEM displays from Silicon Light Machines of the US (Business Wire, 2000; Sangyo Times, 2004)
2001		X						Sony ends LTPS procurement from Sanyo (Sangyo Times, 2002).
2001			X					Sony began selling its first PDP TV in May, 2001. The price was around 1 million yen, and it was 42" in size (Nikkei BP, 2001 (Senryaku Hen)).
2001			X					Sony released new PDP TVs in 32" and 42" sizes using ALIS panels in Japan in October, 2001 (Nikkei BP, 2001 (Senryaku Hen)).
2001				X				Sony and Universal Display agree to jointly develop phosphorescent OLED materials to improve brightness efficiency (Fuji Chimera, 2002; Sangyo Times, 2002).
2001				X				Sony announces 1.4 mm thick 13" prototype full color OLED TV panel with small particle materials and LTPS (Sangyo Times, 2004; Nikkei BP, 2001 (Jitsumu Hen); Nikkei BP, 2007 (OLED Hen)).
2001				X				Sony exhibits 10.2" color OLED panel using small particle materials (Nikkei BP, 2001 (Jitsumu Hen)).

2001					X			Candescent exhibits 13.2" XGA color FED at SID 2001 developed in cooperation with Sony (Nikkei BP, 2001 (Senryaku Hen)).
2001					X			Sony's joint development with Candescent ends with original contract (Sangyo Times, 2005).
2002	X							Sony will develop home audio video products centered around the use of flat screen Vega CRTs according to President Idei (Sangyo Times, 2003).
2002	X							In seminar at LCD/PDP International Okami deputy president of Sony's Home Network company says that CRTs will be gone in 10 years (Nikkei BP, 2002 (Jitsumu Hen).
2002		X						According to President Ando, Sony will obtain (outside) supplies of a-Si TFTs and PDPs by working together with other firms (Sangyo Times, 2003).
2002		X	x					Sony begins selling large FPD TVs including 50" PDP, and 30" LCD models (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X						Sony begins selling LCD video projector using new 0.87" panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X						Sony releases 50" HD RPTV with HTPS LCD (Nikkei BP, 2002 (Jitsumu Hen)).
2002		X						Sony starts HTPS production on 12" wafers at Kumamoto Technology Center (Sangyo Times, 2002).
2002			X					According to President Ando, Sony will obtain (outside) supplies of A-Si TFTs and PDP by working together with other firms (Sangyo Times, 2003).
2002			X					Sony decides not to invest in Fujitsu Hitachi Plasma Display. The firm decided that it was better to concentrate investment in future display technologies OLED and FED rather than investing in PDP, where it was already behind other firms (Sangyo Shimbun, June 6, 2002).
2002			X					Sony is negotiates with NEC to cooperate on PDP (Nikkei BP, 2002 (Jitsumu Hen)).
2002				X	X			2002 is the year that Sony changed course and introduced a number of different FPD based TVs (Nikkei BP, 2002 (Senryaku Hen)). Sony's strategy for "post trinitron" displays for homes focuses upon strengthening development of FED and OLED technologies (Sangyo Times, 2003). It is about 2 years behind competitors (Jojima et al, 2006).

2002				X				Sony will develop small and mid sized OLED products before working on other OLED applications (Nikkei BP, 2002 (Senryaku Hen)).
2002						X		Sony and Sharp discontinue joint development of PALC in the face of rapidly declining PDP manufacturing costs (Fuji Chimera, 2002).
2002							X	Sony develops Micro Electro Mechanical System (MEMS) technology that will be combined with Sony's laser diode technology to allow for large projection images. The more detailed name of this device is called Grating Light Valve. It uses a micro ribbon array. Although similar to TI's DLP, it is simpler and more easily mass produced according to Sony (Sangyo Times, 2003).
2002							X	Sony develops Vega Engine to increase quality of digital signals (reduce noise, etc.) -- it is designed to work with multiple display technologies (Sangyo Times, 2003).
2003		X						As of 2003, LG Philips is Sony's lead TV Panel vendor (LG is using IPS technology) (Fuji Chimera, 2003).
2003		X						Sony and Samsung agree to form S-LCD joint venture to produce a-Si TFTs for TV applications. They will build a generation 7 plant in Korea (Fuji Chimera, 2005; Techno Associates, 2008).
2003		X						Sony builds HTPS module assembly plant in China (Sangyo Times, 2003).
2003		X						Sony develops 0.78" FHD reflective LCD panel for projection TV applications (Sangyo Times, 2005 (Senryaku Hen).
2003		X						Sony develops LCOS for projector applications, plans to begin shipments within the year (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X						Sony is selling HTPS based rear projection TVS in US, Canada, Mexico, and in 2004 China and Europe (Sangyo Times, 2005).
2003		X						Sony is starting production of LTPS with system on glass (SOG) for cell phone applications (Sangyo Times, 2004).
2003		X						Sony releases 42" LCD TV with HD resolution (Nikkei BP, 2003 (Senryaku Hen)).

2003			X					NEC receives capital 5 billion yen from Sony to pay for part of investment in new TV PDP production line. NEC supplied PDPs to Sony (Fuji Chimera, 2003, 2004).
2003			X					Sony presents warning to PDP producers - firm thinks PDP revenues will shrink in future as LCD increases (Nikkei BP, 2003 (Jitsumu Hen)).
2003			X					Sony releases 61" PDP TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003				X				Sony announces 24.2" OLED display made by tiling 4 smaller panels (Nikkei BP, 2007 (OLED Hen)).
2003				X				Sony develops Super Top Emission OLED technology (Sangyo Times, 2004).
2003					X			Sony announces plans to sell Spindt type FEDs in 2004 (Komoda, 2005).
2004		X						As of 2004, Hitachi Displays is selling TV panels to Sony and Tatung (Fuji Chimera, 2004).
2004		X						At opening ceremony, Sony CEO Idei comments that S-LCD's new 7th generation LCD line is a major world's first, and not just about Japan and Korea "small talk" (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X						Samsung Electric and Sony agree to sign cross licensing agreement covering over 10,000 patents (Fuji Keizai, 2005; Nikkei BP, 2005 (Jitsumu Hen)).
2004		X						Sharp and Sony share lead in WW LCD TV shipments at 11.9% each. Sharp is a leader in numerous specific size ranges. (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X						Sony has 50% share of world digital still camera display market with its LTPS (Sangyo Times, 2004).
2004		X						Sony is first to sell a commercial LCD television with LED backlighting. Two models, 40" and 46" use RGB LEDs from US firm Lumilens, achieve 105% of NTSC color gamut (Sangyo Times, 2005).
2004		X						Sony releases 42" RP TV with HTPS panel (Nikkei BP, 2004 (Jitsumu Hen)).
2004		X						Sony releases 70" FHD RPTV with LCOS panel. Sony's LCOS technology is called SXRD (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X					Sony is selling 42" PDP TVs in the US market using Korean-made panels (Deutsche Bank, May 6, 2006).
2004			X					Sony releases 50" HD PDP TV (Nikkei BP, 2004 (Jitsumu Hen)).

2004			X					Sony announces it will exit PDP TV in spring, 2005 (Daily Yomiuri, 2004).
2004				X				Sony plans to build OLED line at ST LCD. It will invest roughly 9 billion yen without Toyota involvement. The focus is small OLEDs to be used in Sony products -- no TV application is considered at this time (Sangyo Times, 2004).
2004				X				Sony builds OLED line at ST LCD (Sangyo Times, 2004). Sony will use panels in new Clie PDA (Nikkei BP, 2004 (Jitsumu Hen)).
2004				X				Sony begins producing full color 3.8" OLED panels to be used in Clie PEG-VZ90 PDAs (Sangyo Times, 2005). It is 3.8" 480X320 pixel resolution, largest to be used to date in a product sold on the consumer market. Uses Sony's "Top Emission" technology with small molecule OLED materials (Fuji Chimera, 2005).
2004				X				Sony exhibits 12.5" OLED prototype with RGB color materials (Nikkei BP, 2005 (Jitsumu Hen)). Another report suggests panel used white OLED plus color filters (Nikkei BP, 2005 (Jitsumu Hen)).
2004						X		Sony plans to develop MEMs related products in 2004. Production will be at Sony Kokubun (Sangyo Times, 2004).
2005		X						Sony and Chimei bought all the shares of Display Technology Inc. for 18.5 billion yen. ST Display took over the Nozu plant and its employees, and renamed it ST Mobile Display. Production of LTPS displays will be done there for use in Sony's mobile display business using low temperature polysilicon displays (Sangyo Times, 2005, 2006).
2005		X						As of 2005, Sony sources LCD panels from Hitachi and CMO in addition to S-LCD (Fuji Chimera, 2005).
2005		X						Samsung and Sony agree to joint development of LCD panels using Samsung's mass production knowledge and Sony's video technologies (Techno Associates, 2008).
2005		X						S-LCD begins shipments (Techno Associates, 2008).
2005		X						Sony begins selling 42" and 50" HD RPTVs using HTPS panels in Japan (Nikkei BP, 2005 (Senryaku)).
2005		X						Sony develops 0.61" FHD reflective LCD panel for projection TV applications (Nikkei BP, 2005 (Senryaku Hen)).

2005		X						Sony exhibits front projection HTPS panel (Nikkei BP, 2005 (Jitsumu Hen)).
2005		X						Sony releases 46" Full HD LCD TV with S-LCD panel and live color creation backlight system (Nikkei BP, 2005 (Jitsumu)).
2005				X				Sony and Idemitsu agree to cooperate on OLED materials development - as part of the deal they also cross license OLED patents (Nikkei BP, 2005 (Jitsumu Hen)).
2005				X				Sony ends development of Clie line of PDAs. OLED production also stops (Sangyo Times, 2006, 2007).
2005				X				Sony establishes Display Development Department directly under the control of electronics president Chubachi (Osada, 2006). Sony's OLED business preparation office is integrated into this department (Sangyo Times, 2007).
2005				X				Sony is said to be contemplating which technology (OLED or FED) to pursue as future TV display device (Sangyo Times, 2009).
2005				X				Sony puts OLED development at the center of future display development in mid-term management plan (Osada, 2006).
2005				X				Sony releases NW-E series portable music player with OLED panel (Nezu, 2005; Nikkei BP, 2007 (OLED Hen)).
2005				X				Sony's OLED team members are redirected to focus on LTPS for mobile displays (Sangyo Times, 2007).
2005				X				Sony announces 19.2" SXGA FED using Spindt emitters (Nikkei BP, 2007 (Market Hen)).
2005							X	Sony has set up a MEMS production line at its Kokubun location (Sangyo Times, 2005).
2005							X	Sony uses MEMs technology at Laser Dream Theatre exhibit in the Aichi Banpaku exhibition (Sangyo Times, 2006).
2005							X	Sony announces it plans to increase shift more TV manufacturing internally from contract manufacturers in the Sony Group Mid-term business plan. Sony aims to make the TV business profitable in 2006 (Osada, 2006).
2005							X	Sony's first quarter 2005 results show TV business with 29.3 billion yen loss, CRT and LCD sales both lower than expected (Nikkei BP, 2005 (Jitsumu Hen)).

2005							X	Sony discontinues WegaTV brand and launches Bravia TV brand worldwide (Nikkei BP, 2005 (Jitsumu Hen)).
2005							X	Sony targets 30% Japanese domestic market share for its Bravia TV brand (Nikkei BP, 2005 (Jitsumu Hen)).
2006		X						AUO begins making LCD TV panel shipments to Sony (Techno Associates, 2008).
2006		X						Sony and Samsung agree for S-LCD JV to build generation 8 plant (Techno Associates, 2008).
2006		X						Sony has 40% share of Projection TVs in US (Nikkei BP, 2006 (Senryaku Hen)).
2006				X				Sony releases NW-S and NW-A series portable music player with OLED panels (Nikkei BP, 2007 (OLED)).
2006					X			Sony announces plans to sell a Spindt FED high quality monitor (Nikkei BP, 2007 (Market Hen)).
2006					X			Field Emission Technologies Inc. is established through "carve out" from Sony (Fuji Chimera, 2007). FE Technologies will continue development of FEDs (Sangyo Times, 2007).
2007		X						Sony dissolves small and medium size LCD panel JVs, ST Display and ST Mobile Display, and integrates different production assets into a single company (Nikkei BP, 2007 (Market Hen)). New firm is called Sony Mobile Display. Sony has 86% stake and Toyota 14%. Sony plans to have 100% stake by 2009 (Sangyo Times, 2008).
2007		X						S-LCD's 8G plant begins production (Techno Associates, 2008).
2007		X						Sony announces new Bravia TV production including 15 full HD and a 70" LED backlit model (Nikkei BP, 2007 (Market Hen)).
2007				X				At SID 2007, Sony announces new technologies for large panel OLED - these were Microcyrstal Si (TFT technology) and laser induced pattern-wise sublimation (Nikkei BP, 2007 (Trend Hen)).
2007				X				Sony announces flexible AM-OLED prototype made on film. It is 2.5" QQVGA (Nikkei BP, 2007 (Trend Hen)).
2007				X				Sony develops OLED display with organic TFT - a world first (Sangyo Times, 2008).
2007				X				Sony exhibits 27.3" OLED TV prototype at CES and Display 2007 (Nikkei BP, 2007 (Trend Hen); Sangyo Times, 2008).

2007				X				Sony introduces XEL-1, 11" OLED TV (Sangyo Times, 2008).
2007							X	Sony announces it will exit the rear projection TV business (Reuters, 2007).
2008		X						Sharp and Sony form JV to manufacture large LCD modules for TV sets at Sharp's plant under construction in Sakai. Sharp to take 66% stake and Sony 34%. To achieve this, Sharp will make 10th generation line a separate entity (Nikkei BP, 2008 (Sangyo Doko Hen)).
2008				X				Sony and Idemitsu jointly developed blue OLED materials - announced improved efficiency at SID 2008 (Nikkei BP, 2007 (Sangyo Doko Hen)).
2008				X				Sony announces professional use video camera monitor using OLED display based upon XEL-1 (Nikkei BP, 2007 (Sangyo Doko Hen)).
2008				X				Sony exhibits 27" OLED TV at Ceatec 2008 (Nikkei BP, 2008 (Kigyo Bunseki Hen)).
2008				X				Sony invests 22 billion yen in OLED production equipment to pursue large, high density panel production (Nikkei BP, 2007 (Sangyo Doko Hen)).
2008							X	Rear projection TV production ends at Sony (Sangyo Times, 2008).
2009		X						Sony and Sharp announce that they will delay formation of their LCD production JV from April, 2009 to March 2010 (Nikkei BP, 2008 (Kigyo Bunseki Hen)).

Year	LCD	PDP	Other	Event
1998		X		NEC and Thomson announce agreement to cooperate on development of PDP, PDP-TV, and PDP monitors. NEC will supply Thomson with Plasma panels (Fuji Chimera, 1999).
1998		X		Thomson introduces 42" plasma TV using NEC PDP in US and European markets (Sangyo Times, 1999).
2000			X	Thomson reports it is the second largest producer of large and very large TV color picture tubes in the world (Thomson Annual Report, 2000).
2000		X		Thomson is performing PDP related research at its location in Moirans, France (Thomson Annual Report, 2000).
2001		X		NEC and Thomson Multimedia agree to establish a 50-50 JV to develop, produce, and sell PDP globally (Sangyo Times, 2002). This plan was never carried through (Fuji Chimera, 2002).
2004	X			Thomson releases 30" HD LCD TV (Nikkei BP, 2045 (Jitsumu Hen)).
2004			X	Thomson (RCA) releases 61" HD RPTV with DLP (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X	Thomson exhibits 70" RPTV at CES (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X	Thomson contributes its TV business to a joint venture with TCL of China (Thomson Annual Report, 2008).
2005		X		As of 2005, Pioneer (after acquiring NEC's plasma business) was shipping panels to Thomson amongst others (Fuji Chimera, 2005).
2006	X			Chimei acquires a license for Thomson's LCD monitor technology (Techno Associates, 2008).
2008			X	Thomson reduces its stake in TCL to less than one percent, effectively eliminating all exposure to the TV set business (Thomson Annual Report, 2008).

Year	LCD	PDP	OLED	FED	OTHER	Event
1980	X					Toshiba begins TFT research (Sangyo Times, 1993).
1983	X					Toshiba enters LCD business and begins mass producing STN-LCDs (Sangyo Times, 1992, 1993).
1986	X					Toshiba develops and begins commercialization of laptop computers (Menzawa et al., 2008).
1986	X					Toshiba and IBM establish LCD R&D joint venture focusing on TFT-LCD development (Murtha et al., 2001).
1986		X				Toshiba begins selling laptop computers with single color DC-PDP displays (Nikkei BP, 1998). Matsushita supplied Toshiba with PDPs for this (Weber et al., 2008).
1987	X					Toshiba begins production of TFT-LCDs (Sangyo Times, 1992).
1989	X					Toshiba announces 10.4" multicolor STN\-LCD panels with VGA resolution (Nikkei BP, 1990).
1989	X					Toshiba begins production of 6.5" color TFT-LCD panels (Nikkei BP, 1990).
1989	X					Toshiba begins production of 10" color TFT-LCD panels for aviation applications (Nikkei BP, 1990).
1989	X					Toshiba and IBM announce 11.2" TFT multicolor LCD panel with VGA resolution (Nikkei BP, 1990).
1989	X					Toshiba and IBM establish joint venture Display Technologies Inc. (DTI) to produce TFT-LCDs (Sangyo Times, 1992).
1989	X					Toshiba finishes building large TFT pilot line in Himeji (Sangyo Times, 1994).
1990	X					Toshiba establishes LCD Business Unit (Sangyo Times, 1990).
1991	X					DTI's first line begins production (Sangyo Times, 1994).
1992	X					DTI invests 10 billion yen in R&D and construction of a pilot TFT line at Fukaya (Sangyo Times, 1997).
1993	X					Toshiba licenses its STN-LCD technology to Orion Electric of Korea (Sangyo Times, 1995).
1993	X					Toshiba develops 9.4" VGA TFT-LCD panel with low power usage for NBPC applications (Nikkei BP, 1993).
1993	X					Toshiba exhibits 13.8"wide viewing angle color TFT with 1152X900 resolution at Electronics show 1993 (Nikkei BP, 1993).
1993	X					Toshiba plans to begin mass producing 7.8" VGA TFT-LCD panels for subnotebook applications in April, 1994 (Nikkei BP, 1993).

1993	X					DTI's Fukaya pilot line enters production (Sangyo Times, 1994).
1994	X					Toshiba develops 10.4: TFT-LCD with SVGA resolution (Nikkei BP, 1994).
1994	X					Toshiba develops 5" TFT-LCD with 240 X 234 resolution for automotive applications (Nikkei BP, 1994).
1994	X					Toshiba develops 7.8" reflective single color MIM-LCD for portable applications (Nikkei BP, 1994).
1994	X					DTI's second line begins production (Sangyo Times, 1994).
1994	X					DTI plans to invest 40 billion yen in new LCD plant in Noya, begins construction (Sangyo Times, 1997).
1994	X					Toshiba transfers STN technology to CPT of Taiwan (Sangyo Times, 1997).
1994	X					Toshiba closes color STN line at Fukaya, exits STN (Sangyo Times, 1999).
1995	X					Toshiba develops 12.1" TFT-LCD with 800X600 resolution (Nikkei BP, 1995).
1995	X					Toshiba develops 15" color TFT for TV applications (Nikkei BP, 1995).
1995	X					Toshiba begins development of LTPS LCD technology (Sangyo Times, 1998).
1996	X					Toshiba develops 12.1" XGA TFT for NBPC application (Nikkei BP, 1996).
1996	X					Toshiba develops 15" XGA TFT-LCD for monitor applications (Nikkei BP, 1996).
1996	X					DTI's Noya LCD plant enters full production (Sangyo Times, 1997).
1996	X					Toshiba outsources 12.1" TFT production to Hyundai due to capacity limitations (Sangyo Times, 1997).
1997	X					Toshiba exhibits 12.1" LTPS XGA panel (Nikkei BP, 1998).
1997	X					Toshiba exhibits 8" TFT for automotive use (480X234 pixels) (Nikkei BP, 1997).
1997	X					Toshiba is first to successfully develop reflective LCD with 3 color layers (Sangyo Times, 1998).
1997	X					Toshiba establishes LCD Development Center at Fukaya to develop leading edge LCD technologies (Sangyo Times, 1998).
1997	X					Toshiba begins pilot production of LTPS at Fukaya LCD Development Center (Sangyo Times, 1999).
1997	X					Toshiba beings construction of Number 1 LTPS line at Fukaya (Sangyo Times, 2001).
1998	X					Toshiba began shipping LTPS panels from its new 400X500mm line (Nikkei BP, 1998). Toshiba is first to successfully produce large displays using LTPS technology (Sangyo Times, 2002).

1998	X					Toshiba develops 8.4" LTPS color panel with 800X600 resolution for portable applications (Nikkei BP, 1998).
1998					X	Toshiba commercializes "Face" flat screen television (Menzawa et al., 2008).
1998	X					Toshiba and IBM provide technologies related to TFT production to Jilin Electric (China) (Sangyo Times, 1999).
1998	X					Toshiba agrees to provide Walsinlihwa Corp of Taiwan with technology and technological assistance related to producing large TFT displays. Walsinlihwa plans to start a new company to manufacture LCDs based upon this technology transfer (Sangyo Times, 1999).
1999	X					Toshiba exhibits 15" LTPS TFT with 1600X1200 resolution for NBPC applications (Nikkei BP, 1999).
1999	X					Toshiba exhibits 4" VGA LTPS panel for portable applications (Nikkei BP, 1999).
1999	X					Toshiba's second LTPS line at Fukaya begins production (Sangyo Times, 2000).
1999			X			Toshiba establishes OLED project team in the LCD Development Center at their Fukaya Plant (Sangyo Times, 2001).
1999				X		Toshiba and Canon announce plans to jointly develop SCE (Komoda, 2005).
2000	X					Toshiba exhibits 2.2" reflective LTPS panel for cell phone applications (Nikkei BP, 2000).
2000	X					Toshiba was profitable in LCD panel related business during 2000 (Nikkei BP, 2001 (Jitsumu Hen)).
2000	X					Toshiba invests 38 billion yen to increase LTPS volume at Fukaya plant - making Toshiba the world's largest LTPS manufacturer (Sangyo Times, 2001).
2000	X					Philips and Toshiba cross license patents on display cells, circuits, and extend this to LG-Philips LCD (Techno Associates, 2008).
2000	X					Toshiba is providing HannStar (Taiwan) with a-Si TFT technology. HannStar's 550X650mm plant will begin production, and HannStar will provide contract manufacturing of A-Si for Toshiba (Fuji Chimera, 2000).
2000			X			Toshiba begins producing single color OLED for car audio applications (Sangyo Times, 2000).
2000			X			Toshiba makes prototype 2.85" OLED display with green color using large molecule materials (Sangyo Times, 2001).
2001	X					Toshiba exhibits 3.5" reflective TFT panel (Nikkei BP, 2001 (Jitsumu Hen)).

2001	X					Toshiba begins mass producing 14.1" XGA NBPC use LTPS panels (Sangyo Times, 2002).
2001	X					Toshiba lost a small amount of money in LCD panel business during 2001 (Nikkei BP, 2001 (Jitsumu Hen)).
2001	X					Display Technologies Inc. is dissolved at the end of the JV contract by IBM and Toshiba (Sangyo Times, 2002).
2001	X					Toshiba and Matsushita Denki Sangyo agree to form a JV to produce LTPS in Singapore. Total investment is 123 billion yen. Toshiba has 67% stake, Matsushita 33%. Production to be used for NBPC, monitors, LCD TVs. Substrate size is 730X920mm (Sangyo Times, 2001).
2001	X					As of 2001, Toshiba is receiving roughly 30% of HannStar's LCD Production (Sangyo Times, 2001).
2001		X				Toshiba releases 42" PDP TV using color filters and with 853X480 resolution (Nikkei BP, 2001 (Jitsumu Hen)). Not known where panel is sourced from.
2001			X			Toshiba exhibits a 2.85" 260K color OLED using large particles on and LTPS backplane (Sangyo Times, 2002).
2001			X			Toshiba develops world's first full color OLED to use large particle materials (Sangyo Times, 2002).
2002	X					Toshiba and Matsushita establish Toshiba Matsushita Display Technology JV (TMDT), integrating LCD operations from both firms. Toshiba holds a 60% stake and Matsushita a 40% stake in the JV, which integrates LCD activities from development to sales (Fuji Chimera, 2002).
2002	X					TMDT develops 14" LTPS VGA panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					TMDT exhibits 229ppi LTPS panel at Ceatec trade show (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					TMDT exhibits LTPS panel for LCD TV application (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Toshiba Matsushita Display Technology announces that it plans to enter TV with LTPS, and will continue work on developing OCB technology (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Toshiba and Matsushita's JV plant in Singapore "Advanced Flat Panel Display" begins mass production - is largest LTPS plant in world (Sangyo Times, 2001).
2002	X					Toshiba announces bendable large LTPS LCD panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Toshiba announces it will begin selling 15" LCD TV in May (Nikkei BP, 2002 (Jitsumu Hen)).
2002	X					Toshiba begins selling 20" LCD TV (Nikkei BP, 2002 (Jitsumu Hen)).

2002	X					TMDT has loss for year (Sangyo Times, 2005).
2002		X				Toshiba begins selling 35" PDP TV with 853X480 resolution (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X			TMDT exhibits 2.2" 176X220 128pp large particle OLED panel (Nikkei BP, 2002 (Jitsumu Hen)).
2002			X			TMDT announces 17" OLED panel made using ink-jet printing at EDEX 2002 trade show (Nikkei BP, 2005 (Oyo GijutsuHen)). Development for this was done at Fukaya location (Sangyo Times, 2003).
2002			X			Toshiba-Matsushita had an OLED pilot line Fukaya plant (Fuji Chimera, 2003).
2003	X					TMDT says it hopes to achieve profitability at its Singapore plant in 2004 (Nikkei BP, 2003 (Senryaku Hen)).
2003	X					TMDT exhibits LCD Panel that can also function as scanner (Nikkei BP, 2004 (Jitsumu Hen)).
2003	X					TMDT begins selling lead-free industrial use TFT panels (Sangyo Times, 2004).
2003	X					Toshiba release 37" LCD TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003		X				Toshiba releases 42" PDP TV with HD resolution (Nikkei BP, 2003 (Jitsumu Hen)).
2003			X			Toshiba Matsushita Display Technology exhibits 3.5" color OLED panel using small particle materials (Nikkei BP, 2003 (Jitsumu Hen)).
2003			X			TMDT shows two small particle AM-OLED panels at EDEX 2003; a 2.2" 176X220 panel and QVGA 3.5" panel (Sangyo Times, 2004).
2003				X		Toshiba's president Okamura suggests that SED may first enter monitor or medical display markets before the TV market (Nikkei BP, 2004 (Jitsumu Hen)).
2003				X		Toshiba and Canon announce new SCE panel product to come out in 2003 (Komoda, 2005). It does not materialize.
2004	X					TMDT exhibits 23" and 32" OCB LCD panels. 32" has HD resolution (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					TMDT begins mass production of OCB TFT panels for TV applications (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					Toshiba releases 32" HD LCD TV (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					TMDT exhibits LCD prototype on 0.2mm glass substrate (Nikkei BP, 2004 (Jitsumu Hen)).
2004	X					TMDS wins Advanced Display of the Year Award for its 0.3mm thick polysilicon display at Flat Panel Production Technology show in Tokyo (Sangyo Times, 2005).

2004	X					TMDT develops LCD panel which has variable (controllable) viewing angle for ATMs and other applications where privacy is an issue (Sangyo Times, 2005).
2004	X					Hitachi, Toshiba, Matsushita sign formal agreement to JV, will name it IPS alpha technology. (Initial Announcement: August, 2004, formal announcement: October, 2004) (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X			TMDT exhibits 3.5" AM-OLED using small particle materials at Ceatec Japan 2004 (Nikkei BP, 2004 (Jitsumu Hen)).
2004			X			TMDT announces it will begin mass producing 3.5" AM-OLEDs display for portable AV applications in 2005 (Nikkei BP, 2004 (Jitsumu Hen); Sangyo Times, 2005).
2004			X			TMDT began participating in a NEDO project from its mid-point presentation. The project is on making large, thin and light displays using organic materials. The project began in 2002, and will continue until 2006. Topics for research include ink jet printing of OLED materials in display manufacture (Sangyo Times, 2007).
2004				X		Canon and Toshiba exhibit 36" SED prototype at press conference (Nikkei BP, 2004 (Jitsumu Hen)).
2004				X		Canon and Toshiba establish JV production company, SED Inc. Canon has a very slight majority stake (Sangyo Times, 2006).
2004				X		SED invests 20 billion yen in Canon's Hirazuka location for initial "mass" production (Sangyo Times, 2006).
2005	X					TMDT increases LTPS production at Ishikawa plant, increasing its focus on LTPS and decreasing a-Si focus (Nikkei BP, 2005 (Senryaku Hen)).
2005	X					TMDT begins construction of 3rd line at Ishikawa plant. New line is 730X920mm substrate; LTPS (Sangyo Times, 2007).
2005	X					Toshiba releases 47" full HD LCD TV (Nikkei BP, 2005 (Jitsumu Hen)).
2005	X					As of 2005, Sharp sells LCD TV panels to Toshiba, JVC, and By Design (Fuji Chimera, 2005).
2005	X					As of 2005, Hitachi displays sells LCD TV panels to Sony, Toshiba, and Matsushita (Fuji Chimera, 2005).
2005	X					Hitachi Displays, Matsushita Denki, Toshiba established IPS Alpha Technology. IPS Alpha plans to produce 23" IPS panels starting in q2, 2006 (Fuji Chimera, 2005).
2005		X				As of 2005, Matsushita sells PDPs to Toshiba and others (Fuji Chimera, 2005).
2005			X			TMDT exhibits 3.5" OLED panel (Nikkei BP, 2005 (Jitsumu Hen)).

2005			X			TMDT exhibits prototype 20.8" OLED with large particle materials from CDT on LTPS backplane (Nikkei BP, 2005 (Jitsumu Hen)).
2005			X			TMDT states it plans to mass produce OLEDs in 2008 (Nikkei BP, 2005 (Senryaku Hen)).
2005			X			TMDT beings producing small volumes of 3.5" small molecule OLEDs for personal music players. Production is at Ishikawa plant, where OLED development also is. Backplane is produced at Fukaya (Sangyo Times, 2006).
2005				X		Toshiba and Canon announce 55" SCE FED (Nikkei BP, 2007 (Market Hen)).
2005				X		SED begins production at Hirazuka (Sangyo Times, 2007).
2006	X					TMDT begins production of LTPS at new Ishikawa line (Nikkei BP, 2006 (Senryaku Hen)).
2006	X					TMDT announces it will invest 30 billion yen to build an additional LTPS line at Ishikawa - it is planned to enter production in late 2007 (Sangyo Times, 2007).
2006	X					TMDT develops 0.99mm thick LTPS LCD for cell phone application - world's thinnest. Samples are planned to ship in 4/2007 (Sangyo Times, 2007).
2006	X					TMDT develops new low power LCD driving technology for mobile PCs together with Intel (Sangyo Times, 2007).
2006	X					Toshiba begins selling Regza brand LCD TVs (Menzawa et al., 2008).
2006				X		Toshiba decides not to exhibit 55" SED panel at CES next year (Nikkei BP, 2007 (Market Hen)).
2006				X		Toshiba President Nishida says they will not let SED become commoditized (Nikkei BP, 2007 (Market Hen)).
2006				X		Toshiba and Canon announce plans to put off sales of SCD FED based TV until 2007 (Nikkei BP, 2007 (Market Hen)).
2007	X					Sharp and Toshiba agree to supply each other with LCD panels and semiconductors (Nikkei BP, 2008 (Sangyo Doko Hen)).
2007			X			TMDT develops 21" large particle AM-OLED, shows it at Display 2007 in Tokyo. The display uses inkjet printing on LTPS. Resolution is WXGA. This display was part of project funded through NEDO (Sangyo Times, 2008).
2007			X			TMDT will receive large molecule OLED supply from CDT for new 21" panel (Nikkei BP, 2007 (Market Hen)).
2007			X			TMDT is planning to mass produce OLEDs in 2008-9. It will use small particle OLED technology first in consumer products, and continue performing R&D on large particle OLED technology (Sangyo Times, 2008).

2007				X		Canon buys Toshiba's stake in SED, will continue on its own. Reason for this is the lawsuit from US based Nano Proprietary regarding patent licensing - they say that Canon broke the agreement by involving Toshiba (Sangyo Times, 2007).
2008	X					Toshiba sold its stake in IPS Alpha to Panasonic (Toshiba Annual Report, 2008).
2008				X		TMDT and Idemitsu jointly developed OLED materials (Nikkei BP, 2008 (Sangyo Doko Hen)).
2008				X		TMDT decides to make 16 billion yen investment in Ishikawa line to mass produce OLED, using part of an existing LTPS line (Nikkei BP, 2008 (Sangyo Doko Hen)).
2008				X		TMDT announces it plans to begin shipping small particle OLED displays in October, 2009. Production will be done at a new line at the Ishikawa plant (Sangyo Times, 2009).
2008				X		Toshiba announces it plans to make 32" OLED TV using large particle materials in 2009 (Nikkei BP, 2007 (OLED Hen)).

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