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Abstract

Recent and rampant regulatory changes for sustainable development are seeking to transform current energy systems towards cleaner and greener forms of energy sources. In this scenario, alternative energy technologies are considered the building blocks towards this transformed energy system. This chapter will show how the alternative energy market since the 1970s changed, in response to external oil price shocks and to other selective pressures and institutions. It will observe that the configuration of the market has been changing since 1970s, in terms of firm-composition, size and types of technologies considered in the green energy mix. It will further provide three explanations explaining why there are changes between firms, policies and these energy technologies. These three processes are considered important in determining technological innovation among firms in clean and green energy technologies.

Key words: Renewable energy technologies, firm competition, nature of technologies, energy technologies
JEL codes: O19, O13, N70, Q01, Q55

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1. Introduction

The objective of this chapter is to look at how over the years since the first oil price shock of the 1970s, firms, the government and technologies interacted with each other. Each reacted to changes in the other, and as a result of these interactions, changes were observed in the market of alternative energy technologies. With recent surging oil prices and mounting pressures to reduce toxic gaseous emissions, both governments and firms interact with each other to move towards alternative energy solutions. Firms respond to policy measures implemented by the government, while the government on the other hand ensures that their policies stimulate innovation. Alternative energy technologies so discussed here include energy technologies that optimise energy consumption, cleaner energy technologies that reduce the amount of toxic gaseous emissions and renewable energy that sources energy from renewable sources like solar, hydro and wind. It will include renewable energy (energy from all natural sources like wind, solar, water etc.) and other alternative or cleaner forms of energy like coal gasification and liquefaction, CNG, hydrogen and bio-fuels.

The formidable task is now on the government to transform the existing fossil fuel energy system into a more sustainable form that consumes less energy or that which sources energy from clean and renewable energy technologies. Now whether it is possible to transform the existing system to one of cleaner and greener technological systems will depend on the economic and technical opportunities of new alternative technologies and how firms react to them. While polices promoting the use of these new technologies tend to make new technologies attractive to private investors, regulatory changes tend to lead the direction of change by changing the economic conditions of technologies. Firms respond to these market opportunities induced by polices and incentives by developing and diffusing these new technologies and eventually creating new markets conditions for alternative energy technologies.

Firms will play an important role in bringing about desired changes that will likely transform the energy system. The desired changes are efforts that seek to develop and use energy systems that are improved, made efficient and cost effective, and in addition to being sustainable. It is through technological innovations that designs are improved, costs and technologies made more efficient and while it is also through technological innovations that firms bring about necessary changes that will help in the evolution of the current system into a newer one. Firms bring about technological innovations through strategies which give firm access to technologies, knowledge, faster access to markets and helps them share the high costs and uncertainties of new technologies, typical of alternative energy technologies.

The first part of this chapter will look at the historical and market context of firms and its external environment, and will observe the changing configuration of the market, the development of technologies, the type of firms, the innovation strategies of firms and cross-sector participation of firms. The second part will offer explanations for the inter-connection between firm strategies, government regulations and technological innovations. Policy recommendations can be sought through insights into the historical origins of the market and actors and an understanding of the interaction between firms, governments and technology.

2. Historical Origins

The history of the alternative energy market can be analyzed as an evolutionary process of adaptation involving selective pressures, uncertainties, institutional changes and external shocks. This historical analysis will elicit how the strategies of firms are intertwined with government policies and the nature of technologies. The beginning of the analysis is traced starting from the 1970s up to the 2000s and is divided into three major epochs. The first period, roughly between 1970s - mid1980s, was one in which the first major oil crisis struck, and coupled with air pollution concerns, government directed considerable effort towards the development of alternative energy technologies like solar, wind, hydro-power, geothermal. In this period, particular emphasis was given to solar cell production for terrestrial-use and wind power development. The second period, roughly between mid 1980-1990, was characterized by a dwindling of interests in alternatives as oil prices had stabilized and more often than not lobbying by firms were successful in reducing regulatory emission criteria. The third is the period between mid 1990s-2000s, characterized by serious climate change and energy security concerns, including the biggest oil price shock in recent times that have spiraled energy prices without signs of stabilizing. These factors have forced economies to re-strategize their energy consumption patterns seeking alternatives in non-fossil energy like renewable and energy efficient technologies like CNG and co-generation processes.

2.1 Beginnings: 1970s to mid-1980s

In the first period between 1970s and early 1980s, in response to the first oil price shock, countries like Japan sought substitutes in alternative energy technologies and in optimizing energy consumption through energy efficient technologies. Alternative energy technologies that were primarily explored during 1970s were geo-thermal, biomass, hydropower (IEA, 2005) and solar and wind in addition to alternatives to produce oil and gas through coal gasification and liquefaction techniques. Coupled with energy security concerns and economic recessions the publication by the Club of Rome in 1972, *Limits to Growth*, drew considerable public attention to the predicament of scarce resource depletion like fossil fuels. During the same time, air pollution concerns were taken seriously especially in the U.S after the city of Los Angeles was found to be the most pollutive city. Several studies then documented the harmful effects of toxic air pollutants released mainly by industries and vehicles on human health alongside reports of the occurrence of acid rains in several regions.

The above-mentioned factor led to changes in energy polices and/or to the introduction of entirely new policies that sought to develop alternative energy technologies. Japan, a country solely dependent on oil imports, responded to the 1970 crisis by initiating a Sunshine Project in the year 1974. The purpose of the project was to develop new and alternative energy technologies like solar, wind and coal gasification and liquefaction. An Alternative Energy Act was enacted in 1980 that raised electricity and coal taxes whose revenues were used to develop renewable and alternative energy technologies. In response to air pollution concerns, the Environmental Agency of Japan pushed for a legislation in 1972, similar to the Muskie Act in the U.S, that forced automobile companies like Toyota, Honda and Nissan to comply with emission reduction regulations through technological innovations (Yarime et al., 2006).

Honda first began complying with in-house technological development of a new engine type called the CVCC for its motorcycles. Although it complied with all the required emissions standards, it later abandoned its production. Instead Nissan and Toyota developed a new type of catalyst, called a three-way catalyst, rather than changing the structure of the IC engines for their whole range of vehicles.

During the same time, the U.S government responded to the oil crisis of the 1970s by introducing federal and state tax credits for renewable energy and energy efficient users, and in 1978 it passed the Public Utilities Regulatory Policy Act (PURPA) to encourage efficient use of electric utility resources. PURPA created a market for non-utilities, as it required utilities to buy power from independent companies that could produce power for less than what it would have cost for the utility to generate the power, called the avoided cost. It established a Solar Energy Laboratory in 1978 to further research in solar energy technologies. Today it is the nation’s largest research center in renewable energy technologies called the NREL. The U.S Federal Wind Energy Program was initiated to encourage research in wind technologies entirely through federal tax credit. In response to air pollution concerns, the Environment Protection of America (EPA) enforced the Clean

Air Act in 1970, an amendment to the Muskie Act, a very stringent regulation, required the auto industry to reduce the amount of emissions of CO_2, hydrocarbons and N_2O to one-tenth.

U.S automakers were successful in opposing the Clean Air Act in 1970, which according to them was unrealistic and technically unsound at that time to achieve, and so finally in 1974 the mandatory emission requirements were reduced. The automakers eased regulations for their own benefit by avoiding investments in new and sustainable technologies and resorted to catalytic converters instead, that did not require any change to the IC engine. In the U.S solar industry, few small start-ups, spin-offs from solar U.S government research labs and space application programs, entered the PV production industry for terrestrial use. Solar Power Corporation, Solarex Corporation, Spire Corporation, Solec International and Solar Technology International were the few start-ups established in the early 1970s. In addition to small firms, there was interest among large oil and gas firms in developing solar cells. In 1979, ARCO Solar built the biggest solar cells and photovoltaic systems production plant through its own internal research and devlopment efforts while British Petroleum (BP) started it own solar cell production unit in 1973.

In response to the oil crisis, federal research and development activities also resulted in the design, fabrication, and testing of 13 different small wind turbine designs (ranging from 1kW to 40kW), five large (100kW - 3.2MW) horizontal-axis turbine (HAWT) designs, and several vertical axis (VAWT) designs ranging from 5-500 kW (Murphy, 2004). Many wind turbine manufacturers were attracted to the conducive wind policy environment of

California. The National Energy Act of 1978 and the California Acts provided a 15% federal energy tax credit and a 25% California energy tax credit for investment in renewable energy sources. In addition to these tax incentives, California utilities, acting in compliance with PURPA, offered attractive rates for the purchase of power from independent electricity producers, further encouraging the development of wind systems (A.J Cox et al, 1991).

Danish firms had an advantage in the U.S market, with its long history in wind turbine design and development of the improved three-blades Gedser mills. Their wind turbines were officially endorsed most reliable as compared to other windmill manufacturers of that time. In 1979, the government of Denmark offered an investment subsidy for up to 30 percent of the cost of wind turbines, biogas digesters and solar panels, that spurted interested among investors especially in the wind industry. Interests were shown by three groups mainly: private and individual owners of turbines who set-up a turbine in their back-yard or invested in shares in cooperatives and power companies were forced to comply with new regulations when the Parliament legislated a purchasing price of 85% of the retail price of electricity. Most started the development of wind turbines but most were not commercially successful except for that of SEAS, which helped finance the Gedser three-blade design (c) diversification of agricultural equipment firms like Vestas, Nordex, Nordtank, Bonus and Micon into wind turbine manufacturing. The companies are in the top-15 list of manufacturers today. And by 1986, the Danish wind turbine manufacturers had 50% of the U.S market share.

So this period saw *four* distinct firm characteristics respond to the external environment of oil price shocks and policy support at that time:

- Independent solar PV start-ups
- Large electronics and semiconductor firms
- Oil and gas firms
- Agricultural equipment firms

2.2 Downside: Mid-1980s – mid-1990s

But soon after, in the mid-1980s, when oil prices stabilized, interest in alternatives fell. In the late 1980s, Japanese firms Hitachi, Toshiba and NEC withdraw from PV business. For these firms growing markets of semiconductors and computers were much more important than the unpromising future market of PV according to O. Kimura & T Suzuki (2006). During this period, the mandatory requirements of the Clean Act act of 1970 coupled with the energy crisis plunged American automobile manufacturers into a deep depression. They asserted that the necessary technolgy to comply with the regulation did not exists and the use of catalytic convertors were instead suggested. Car consumers were turning to Japanese and European cars that consumed less oil. So the Federal government then relented and eased air pollution standards and automobile manufacturers inserted catalytic convertors into the exhaust pipe of vehicles.

Such were the makeshift solutions or end-of-pipe solutions towards which development led during this period. Emission norms, product standards and bans and in some cases charges and subsidies were insufficient measures that led to the development and use of cleaning technolgy such as end-of-pipe instead of ‘clean’ technolgy or cleaner production processes (Soete & Kemp,1992). The concept of the selection environment explains why developments along the internal combustion (IC) engine trajectory were not easily abandoned by the U.S automobile manaufacturers. According to Kemp (1994), moving to a new trajectory, will require new skills, education and training, and hence drop-in innovations are easily adopted. It also explains why there are developmenst directed towards finding CFC substitutes rather finding an alternative to the whole refrigeration technolgy of today.

An incentives programme in the form of capital grants for installation of wind turbines was established in the late 1970s, but was abolished in 1989. And when the California wind programme ended in 1985-86, a large number of the 20-odd manufacturers went bankrupt, having few alternative markets for their products. Incentives that were provided to home producers of solar and wind energy under the U.S Energy Tax Act in response to the oil crisis of the 1970s were phased out in the mid-1980s as a result of new policies to leave energy conservation and renewable energy decisions up to market conditions (gosolar.com). It has been documented that between 1974 and 1981 the wind energy program in the U.S had been most efficient and successful as it built 13 small systems and 4 large wind turbine designs were developed and tested. But in the years between 1981 and

1988 despite millions of federal tax credits – only 4 new wind turbine designs were developed in the U.S (Murphy, 2004).

2.3 Upside: Mid-1990s- 2000s

A series of intergovernmental conferences focusing on climate change had begun in the late 1980s and went on onto the early 1990s in response to a growing scientific understanding of climate change. The UN called for the start of treaty negotiations wherein a Convention was started to build a framework on climate change. The impact on climate change caused by human activities like de-forestation and pollution was brought to public attention with much controversy but the issues and concerns behind the cause were more widely debated than ever before.

"The concerns and issues related to the environmental impact of growth and technological advance have suddenly re-emerged in a context very different from that of the mid-1970s…the evidence on the environmental damage in terms of air, water and soil pollution is by far more overwhelming …and public perception of the environmental problems is far more acute." (Soete & Kemp, 1992, pg. 454)

Such conferences urged several Western European countries to adopt national targets of greenhouse gases emission reduction, for example, the former West Germany's target to reduce 30% of its emission from 1987 by 2005, and France and Australia to reduce 20% by 2005 (Kimura & Suzuki, 2006).

In the 1990s, Japanese regulatory barriers against the deployment of distributed power generators were removed and simple procedures for grid-connection was called for so as to expand renewable energy deployment. The original target to supply 1.6**%** of the total energy demand from alternative energy in 1990 was raised up to 5**%** in 1990 and 7**%** in 1995. There was a strong commitment by the Japanese government to introduce PV stimulated private investments (Watanabe, 1999). Japanese firms like Kyocera, Sanyo and Sharp that continued PV developed despite the downside in the late 1980s had by the late 1990s become top-ranking PV producers.

In 1991, the U.S government broadened research areas to include renewable and energy efficient other than solar. It renamed the Solar Energy Research Institute to National Renewable Energy Laboratory to advance several renewable energy technologies. In the 1990s, the Bush Administration encouraged and resumed the funding of the under-funded wind energy sector. The management of the federal wind program was shifted to NREL. The California Air Resources Board (CARB) enacted the Low emissions vehicle regulation in 1990, which required seven large automobile manufacturers including Japanese cars to include a small percentage of their sales to zero emissions vehicles (ZEV). The targets for the introduction of ZEVs were set at 2% after 1998, 5% after 2001 and 10% after 2003.

There were several technological developments by Japanese carmakers in response to the regulations implemented by the Environment Agency of Japan and those set by CARB for ZEVs. According to Yarime et. al (2007), the number of patents filed by Toyota, Nissan, Honda, Mazda, Mitsubishi and Fuji Heavy Industry in electric vehicles increased in early 1990s but it declined sharply in the 2000s. Electric vehicle technologies had technical glitches in battery performance and cruising range, and were therefore abandoned. Besides, Japanese carmakers began to file for fuel cell vehicle patents in the middle of 1990s, the number increased sharply in the 2000s, reflecting the changes in regulations influencing the research focus in the auto industry. The Californian Fuel Cell Partnership was started in 1998 that began development of fuel cell vehicles between CARB, automobile manufacturers (DaimlerChrystler, Ford, GM, Honda, Nissan, Toyota, Volkswagen and Hyundai), oil companies (Shell Hydrogen, BP, ChevronTexaco, Exxon Mobil) and fuel cell producers (Ballard and UTC). Partnerships of this form has the advantage of developing fuel cells through shared costs and uncertainties and a faster move towards standards creation for early stage-technologies.

Starting from the mid-1990s, many new wind development firms sprung up in various countries like Spain, Germany, India and China in response to their policy environment. The government of India gave tax exemptions to imports of wind turbines and a tax holiday for five years for those who developed and manufactured renewable energy technologies. For a new firm like Suzlon to enter the already established world wind market, it had to adopt various strategies to innovate. It acquired wind turbine technologies through strategies like buying licenses and joint developed. Chinese firm, Goldwind, also obtained most of its technology by buying patents through strategic partnerships with other firms and through acquisitions.

In the biofuels industry, most advancements and interests first came from Brazil. Although small efforts were made in biofuels in 1930s, the actual implementation took off in the 1970s, soon after the first major oil embargo. Low price of sugar in the international market coupled with strong political pressure from sugar cane producers, Brazil implemented the Brazilian Program of Alcohol (PROÁLCOOL) (Teixera et. al, 2007). In the mid-1980s, with oil prices stabilizing, interest in biofuels cooled off, and many technological advances made during this period "were discrete and not harmonized." However, the industry received much buoyancy in the 1990s, when international oil prices rose and climate change and pollution policies became mandatory particularly in Europe. A bio-diesel program was mandated.

The mid-1990-2000s are witnessing *several and more* diversified characteristic of firms enter the alternative energy market, as opposed to that witnessed in the 1970s:

- Large electronics and semiconductor
- Oil and gas firms
- Automobile manufacturers
- Agricultural export firms
- Biotechnology firms
- New start-ups in solar, wind, bio fuels
- Flat screen manufacturers
- Laser CD manufacturers
- Glass manufacturers

3. Explanation for the changing configuration since 1970s

The factors that are causing the energy market to change over time are understood when one observes the interrelation and interplay between firms, technology and the government. Therefore, in essence, the explanation for the changing configuration is given to (a) the nature of the technologies (b) the nature of competition between firms (c) and the nature of government support and incentives.

3.1. The nature of the technologies

The nature of technologies allows for the inclusion and combination of different science-based technologies like nanotechnology, laser and optical fiber technology and genetics. The combinatorial nature of the technology is characteristic of new wave technologies, which has three defining features: their science base, patent activity and system embeddedness (Mytelka, 2003). We observed the combinatorial nature of technologies in the convergence between IT and telecommunications and between pharmaceutical and biotechnology in the late 1980s and early 1990s. The extent to which these technologies can be cross-applied or applied in other areas depends on the technical and economic opportunities or on the technological paradigm (Dosi, 1982) or scientific paradigm (Khun, 1962) so defined by the parameters of science. In fact, it is the nature of technologies themselves that will determine the range within which products and processes can adjust to the changing economic conditions (c.c Soete & Kemp, 1992) and adjust to the changing nature of technologies themselves. Each technology emerged within the paradigm of the earlier mechanically base and now are beginning to incorporate nano-level technologies, and new wave technologies are developed through a combination of several distinct trajectories with significantly different scientific roots (Mytelka, 2003). The combinatorial nature of technologies requires both a wide range of different knowledge inputs and a strong science and engineering base. And hence the establishment of a dominant design in such new wave technologies depends upon innovations from across sectors. The combinatorial nature of technologies is seeing a cross-sectoral participation of firms with different expertise and knowledge base as exemplified in the examples above: solar cell production, bio-fuels and hydrogen fuels. The solar cell technology is developing along its own technological trajectory but whose advancement and movement is strongly integrated with the development path of the semiconductors and optical laser trajectories.

The combinatorial nature of technologies and their integration into the products and processes of other technological systems opens the way for larger firms to play a more prominent role in shaping the technological trajectory and the speed with which new technologies are incorporated into the production processes than in the past (Mytelka, 2003). Large firms like Shell, Royal Dutch and BP are being transformed into energy companies and their presence in the renewable energy market will mark the evolution of alternative energy technological systems because of their enormous size, huge investment abilities and vested interests. The path of the microprocessors, laser, audio/visual and more recently the application of biotechnology in pharmaceutical has been shaped by only a handful of large firms like Sharp and Du Pont. Thus in brief we see that the nature of competition between them is leading to an increase in the cross-sectoral participation of firms and in the engagement of large established firms from other sectors.

3.2. The nature of competition & market entry

Firms in this industry have adopted various innovative strategies to extract value from new technologies and maintain their competitive advantage. The sudden need to change in response to rising oil prices and climate change concerns, have forced firms to reconsider the organization and management of their internal research and devlopment and their strategies of capturing knowledge, technologies and products from external innovators. The way in which this industry is evolving especially in terms of the nature of technologies involved is also changing the way firms are strategizing in response. Rapid development of alternative energy technologies and the combinational nature of the technologies has created and shaped inter-firm relationships between pure-play alternative energy, established oil and gas firms, large agricultural and electrical firm and new and small entrants. So the changing nature of the technologies is seeing a corresponding change in the strategies of firms – it is giving rise to a different type of strategy which is not only that of internal research and development but that of external activities with other firms that maybe upstream input firms, downstream users and infrastructure and other kinds of firms that constitute a new energy system.

So along with these new changes and new requirements came changes in the traditional way of market competition among firms based on price and product differentiation. The need to reduce investment costs so as to quickly achieve an optimal production size and research and development is leading firms to strategic partnering of two kinds: (a) competition through the creation of consortiums amongst a group of rival firms (b) two-way partnerships with a focus on knowledge production and sharing rather than a one-way transfer of technology. Both these modes of knowledge-based competition are resorted to as a means to reduce production costs and technological risks. These modes of competition is affecting market competition as they act as 'entry barriers' to new entrants and have given firms, particularly large firm, access to new technologies and markets. In fact modes of competition of this nature determine the speed with which a dominant design emerges, costs are reduced and systemic constraints are removed (Delapierre & Mytelka, 1998).

The research and development intensive nature of the new technologies is forcing firms to share the initial high costs of research and product development and thus reduce uncertainty. The creation of consortiums or group alliances is a form of new competition that is speeding up the process of innovation and shaping the development path of a trajectory rather than resort to internal research and development is associated with high costs, market risks and uncertainties. An example of such a consortium is the California Fuel Cell Partnership, which is a technical collaboration of 31 members like automobile manufacturers, energy providers, government agencies and fuel cell system firms that jointly develop and commercialize hydrogen fuel cell vehicles. Members are Ballard Power Systems, Daimler Chrysler, Ford Motor Company, BP, Shell Hydrogen and Chevron Texaco that formed the partnership in 1999.

For a long time, internal research and development was considered to be the only source of knowledge for innovation Mowery (1983) and Griliches (1979) with c.f. Arora & Gamberdella (1990). Unto the 70s most technological innovations introduced by large firms were from in-house research and development investments but in the past two decades firms were unable to internalize all their resources to produce and commercialize technologies (Arora & Gamberdella, 1990). Now firms develop technological know-how through their competitors, suppliers and other organizations through contractual arrangements like licenses, research and development agreements and joint ventures (Pisano, 1990). The ability to exploit external knowledge becomes critical to firm innovation (von Hippel, 1982; Cohen and Levinthal, 1990; Teece, Pisano; Sheun, 1997; Chesborough, 2003). Firms thus became aware of the necessity to cooperate with other firms and organizations in order to obtain expertise which otherwise cannot be generated in-house. Cooperation with other firms in the form of alliances and joint ventures broadens a firms' strategic option (Mitra, 2007) especially in a time of much technological uncertainty as in the alternative energy industry.

Firms that are trying to keep up with rapid and costly technological progress engage in partnerships (Dussauge, et al., 1987). Especially in high tech industries, high costs of research and development, steep learning curves and shortening of product and technology life cycles urge firms to share development costs and thus reduce lead times for their innovative products (Duysters, 2001). Empirically, it has been shown that high tech firms that cooperate with others tend to be more innovative than firms that don't (Kotabe & Swan, 1995). Also considering the uncertainties about the profitability and stability of these new emerging technologies, it makes sense for private investors to share the initial costs of risk venturing like costly and time-consuming basic research.

Thus is brief we see that the nature of competition and nature of entry coupled with the nature of technolgies is leading to (a) knowledge-based modes of competition and (b) rise of alliances and joint ventures.

3.3. Nature of government support and incentives

Wider and intensive research support from governments is making technologies attractive for private firms because the market by itself will not generate a move from the dominant and inferior technology in which it is locked-in as exemplified in the example of Cowan and Gunby (1996) of the difficulty of farmers to switch to a better IPM system from a dominant and inferior chemical spraying method of pest control. The market is locked into a comfort zone of localized learning, uncertainty and unpredictable pay-offs associated with new technologies. And addition, the existence of interrelated technological trajectories or systems (Rosenberg, 1989) or the embeddedness of the combinatorial nature of the technologies (Mytelka, 2003) is making the switch to a new technology even more difficult. New technologies face major barriers because the positive externalities involved develops over time and are prevented from doing so by the existing dominant technological trajectory (Soete & Kemp, 1992). Government subsidies and incentives can help direct resources away from these dominant and less superior technologies.

There has been an increase in government spending in alternative energy technologies in terms of research funding and infrastructure building and in the availability of subsidies like tax incentives and feed-in tariffs and of stringent regulations that support utilities that make use of renewable energy through on-grid connections. But with such uncertainties about the stability and profitability of these new markets private investors are unwilling to take risks. Here the role of the government becomes important to mitigate the investment risks by providing production incentives and research subsidies as well be involved in accelerating the development of new renewable technologies until the market becomes stable for firms to make profits. So to share the initial risks associated with research and development investments and to gain a first mover advantage, many firms are found to collaborate with other firms, research organizations and governments to develop these technologies.

Because of the nature of technologies and their system embeddedness, the role of government funding and policy support are important constituents in transforming the current fossil fuel based energy system to one towards cleaner and greener forms of energy source.

4. Conclusions

We saw that over the years the configuration of the alternative energy market has been changing, to include more and more firms, the types of firms have changed and the number of technologies considered has increased manifold. The expertise and experience of the firms entering this market are playing a major role in directing advances in these new energy technologies. With such a diverse knowledge base it becomes increasingly important, particularly by policy makers, to recognize ways in which knowledge is appropriated in this market, and mainly because such knowledge has the capacity to shape technological innovation. In the period between 1970s and 1980s, we saw firms respond to policy changes and make technological changes, namely by resorting to end-of-pipe solutions and catalyst converters, rather than actually innovate in new and clean energy technologies. But soon with changes in the nature of technologies, like the advent of biotechnology, nanotechnolgies, and the systemic nature of information technology, the way in which firms responded changed. In fact, the complexity of the nature of technologies has opened up possibilities for firms, particularly large ones with financial, organizational and knowledge edge over smaller firms from across sectors to become involved in the alternative energy market. Their sheer ability and strategic efforts have allowed them to easily integrate new external capabilities and compete in the alternative energy market despite several uncertainties and risks. As for smaller firms, it was possible to integrate their research and technological capability with larger firms, so as to share the initial high development costs and market uncertainties. The way in which firms are competing to innovate and responding to policies, and the way in which the nature of technologies determine the way firms should innovate and the way policies are designed, allow us to see the interplay between firms, technologies and policies. Considerations of the interplay between these three processes are infact important determinants of the process of innovation.

5. References

AEI (2001), *Turning The Corner: Energy Solutions for the 21st Century*, Alternate Energy Institute

Ander sen, D., Borup, and Ole sen H. (2006), Innovation in Energy Technologies, Denmark, *Risø Energy Report 2006*, Risø National Laboratory

Bill, M. and Wüstenhagen, R. (2004), Innovative and Sustainable Energy Technologies: The Role of Venture Capital, *Business Strategy and the Environment*, 13, 235-245

Cowan, R. and Gunby, P.(1996), Sprayed to Death: Path Dependence, Lock-in and Pest Control Strategies, *Economic Journal*, 106 (436), pp. 521-42

Cox, A.J and Blumstein, C.J and Gilbert, R J. (1991), Wind Power in California A Case Study of Targeted Tax Subsidies, *Regulatory choices: A Perspective on Developments in Energy Policy*, Ed. RJ. Gilbert, University of California Press

Delapierre, M. and Mytelka,L.(1998), Blurring boundaries: new inter-firm relationships and the emergence of networked, knowledge-based oligopolies, in Colombo, M.G. (Eds), *The Changing Boundaries of the Firm*, London: Routledge Press

Dodgson, M. (1992), Strategy and technological learning: an interdisciplinary microstudy, in Coombs, R. et al. (Eds.), *Technological Change and Company Strategies: Economic and Sociological Perspectives*, London: Harcourt Brace Publishers, pp. 136-163

Dosi, G.(1988), Sources,Procedures,and Microeconomic Effects of Innovation, *Journal of Economic Literature*, Vol. XXVI

Dosi,G. (1984), *Technical Change and Industrial Transformnation*, Macmillan Press Ltd.

Duysters, G. and Versapagen, B. (2004), *The Small Worlds of Strategic Technology Alliances*, Technovation, 24:563-571

Duysters G. and de Man, A. M.(2003), Transitory allainces: An insturment for surviving turbulent industries?, *R & D Management*, 33 (1), pp. 49-58 (10)

Ernst, D. and Halevy, T. (2000), When to think alliance, *McKinsey Quarterly*, Washington D.C

Hagedoorn J. and Schakenraad, J.(1994), The Effect of Strategic Technology Alliances on Company Performance, Strategic Management Journal, 15 (4), pp. 291-309

Hagedoorn, J. and Schakenraad, J. (1994), The Effect of Strategic Technology Alliances on Company Performance, Strategic Management Journal, 15 (4), pp. 291-309.

Jan, F. (2000), Paper 1, Innovation, *Handbook for Innovation*

Kemp, R. (1994), *An Economic Analysis of Cleaner Technolgy: Theory and Evidence,* Amsterdam: Free University

Kemp, R. and Soete,L. (1992), Greening of Technolgical Progress: An Evolutionary Perspective, *Futures*, 24(5), pp. 437-57

Kimura, O. and Suzuki,T.(2006), Thirty years of solar energy development in Japan: co-evolution process of technology, policies and the market, paper presented in Resource Policies: Effectiveness, Efficiency, and Equity, Berlin

Kotab, M. and Swan, K.S. (1995), The role of strategic allainces in high-technology product development, *Strategic Management Journal* ,16 (8),pp. 621-636

Kotabe, M. and Scott Swan, K. (1995), The Role of Strategic Alliances in High-Technology New Product Development, Strategic Management Journal, Vol. 16, No. 8., pp. 621-636.

Murphy, P. (2004), Peak Oil? Peak Technology, Energy Bulletin, www.energybulletin.net

Mytelka, L. (2006), Divides and Rules: The impact of new wave technologies on learning and innovation in the south, *Journal of International Development*, 18, pp. 861-876

Mytelka, L.(2004), *Catching up in new wave technologies*, Oxford Development Studies, 32(3), pp.389-405

Nelson, R. and Winter,S. (1982), *An Evolutionary Theory of Economic Change*, Cambridge, MA: Harvard University Press

Nooteboom, B. (1999), *Inter-firm alliances: Analysis and Design*, London, New York and Canada: Routledge

Pisano, T. and Shuen, A. (1997), Dynamic Capabilities and Strategic Management, *Strategic Management Journal*, (18) 7, pp. 509-533

Pisano,G. (1990), The research and development boundaries of the firm: an empirical analysis - research and development - Technology, Organizations, and Innovation., *Administrative Science Quarterly*

Rip, A. and Kemp, R. (1998), Human Choices & Climate Change, Technological Change, in Rayner, S., & Malone, E. (eds.), *Resources and Technology*, Vol. 2, Battelle Press

Rosenberg, N.(1983), *Inside the Black Box: Technology and Economics*, Cambridge University Press

Sijn, J.P.M. (2002), *The Performance of Feed-in Tariffs to Promote Renewable Electricity in European Countries*, Energy Research Center of the Netherlands (ECN), The Netherlands

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