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Market-based Lock-in as a Challenge for Eco-design Strategy:

*Probing the Compatibility between Economic
and Industrial-Ecological Approaches*

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CondEcol

Report



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FOREWORD

ProSus is a strategic university programme established by the Norwegian Research Council at the Centre for Development and the Environment (SUM), University of Oslo, Norway.

The goal of ProSus is to provide knowledge and information in support of a better realization of national targets for sustainable development. The work in the current financing period is concentrated on three main tasks:

Conducting systematic evaluations of Norway's implementation of international commitments on sustainable development. Evaluations are based on three types of standards: external criteria – targets and values from international agreements and programmes; internal criteria – national goals and action plans; and comparative criteria – performance by other countries in relevant policy areas. The relationship between the demands of sustainability and existing democratic procedures is a key interpretive theme.

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In addition to books and articles in scientific journals, ProSus also publishes reports and working papers in order to disseminate the research results in an effective manner to key actors and decision-makers within the field of sustainable development.

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THE CONDECOL PROJECT

This report is published as part of the research project CondEcol – Exploring the Conditions for Adapting Existing Techno-Industrial Processes to Ecological Premises. The aim of the CondEcol project is to develop strategic management and governance perspectives for realizing product and process innovation with a high potential for improved eco-efficiency.

The CondEcol project is structured as a multi-disciplinary study of the conditions for moving existing production and consumption patterns in the direction of sustainable development. Changes are to be achieved through knowledge-sharing and partnership with industry; goals that directly reflect the focus of the programme providing extra funding for the project – RAMBU (“Conditions, Governance and Policy Instruments for a Sustainable Development”) within the Research Council of Norway. Working closely with two industrial partners, Norsk Hydro and Renewable Energy Corporation (REC), the project explores three high-profile cases of technology and product development as a basis for identifying factors that may hinder or promote innovation and diffusion of new technologies with high eco-efficiency.

An important challenge in changing production and consumption patterns is to look for solutions that reduce the environmental strain per consumed unit (eco-efficiency), and to decouple economic growth from environmental impacts. Public authorities and private enterprises have placed these ideas on the agenda, and pragmatic discourse in academia is already underway. However, there is still limited understanding of how and to what extent eco-efficiency gains at the level of specific products or production processes can be converted into eco-effective gains for society at large.

By joining a network approach with the conceptual tools of industrial ecology, economics, strategic management, and integrated governance – and by anchoring the approach in specific case studies of past and current innovation journeys – the CondEcol project aims to develop a new and comprehensive framework for identifying and communicating effective instruments for promoting sustainable production and consumption patterns. The fact that the cases in question involve major attempts by industrial actors to introduce more eco-efficient technologies, and that the cases reflect the actors own experience of the obstacles encountered, makes the CondEcol-project different. Insights from the social sciences regarding sustainable development have only recently come to bear on strategic decision-making in business, so the output of the project should have relevance for promoting more sustainable processes internally in firms as well as in the market and society as a whole.

CondEcol is an integral part of ProSus’ ongoing research and dissemination activities. It is also directly tied into the SUSLINK-project, an integrated, multi-level effort focusing on European, national, local and household aspects of sustainable production and consumption in the energy and transport sectors.

Oslo, April, 2005

William M. Lafferty
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ABSTRACT

In a previous ProSus Report, Brekke (2003) has discussed the relevance of “market-based lock-in” as a barrier to the introduction of new technology. The report emphasized the variety of different mechanisms that would give rise to lock-in, especially through “increasing returns to adoption”.

The present report discusses the importance of the factors in question for the methodological approach of the CondEcol project. More specifically, the report aims to clarify the compatibility of the market-based approach to lock-in with the strategic management approach of “ecological design”. Using empirical references from two of the case studies from the CondEcol project, Shecco and ScanWafer, the report structures a “meeting of perspectives” whereby the cases are assessed from the point of view of market-based lock-in analysis, to determine whether and how the eco-design approach incorporates similar types of information and insight.

In both of the cases we find important factors contributing to increasing returns to adoption, related to costs of local adaptation and technology-specific human capital, but most importantly to steep learning curves. Except for the learning curves, the other mechanisms are largely external to the technology. For mechanisms external to the technology we judge the eco-design strategy wheel to be largely irrelevant. The effect of the steep learning curve, however, is that the larger the number of adopters the more rapidly the product itself will improve. In this case the eco-design strategy wheel can provide an important check-list for potential improvements. In sum, the report indicates that information which is complementary to the information generated by the approach of ecological design is also necessary to understand the barriers and drivers for technological change promoting sustainable development.

1 INTRODUCTION

In a previous ProSus Report, Brekke (2003) has discussed the relevance of “market-based lock-in” as a barrier to the introduction of new technology. The report emphasized the variety of different mechanisms that would give rise to lock-in, especially through “increasing returns to adoption”. In the current paper we step down from this more general approach to discuss the importance of the factors in question for the methodological approach of the CondEcol project.¹ More specifically, we aim to clarify the compatibility of the market-based approach to lock-in with the strategic management approach of “ecological design”. Using empirical references from two of the case studies from the CondEcol project, we structure a “meeting of perspectives” whereby the cases are assessed from the point of view of market-based lock-in analysis, to determine whether and how the eco-design approach incorporates similar types of information and insight. We begin by briefly presenting the CondEcol cases, and then moving on to: first, a more general substantiation of the concept of “increasing returns to adoption” as a basis for market-based lock-in; second, an application of the approach to the case materials; and, third, a discussion and assessment of the relationship between the two approaches. Given that the major part of the paper is devoted to an elaboration and application of the market-based approach, we can preface the analysis with a brief profile of the eco-design approach.

The “eco-design strategy wheel” was designated at the outset of the CondEcol project as a key methodological instrument of the industrial-ecology approach (Lafferty, Marstrander and Ruud 2003). The “wheel” focuses on those variables thought to be crucial to a reduction of the environmental impacts of both products and production processes (UNEP 1997: See Figure 2 below). It consists of eight strategic choices (“spokes” of the wheel) which directly affect potential change in the product and technology in question. The eco-design wheel covers all relevant stages in the production, distribution, usage, and disposal of products, enabling identification of possible windows for improvement. The wheel is a comprehensive tool for understanding the ecological potential of the innovation, as well as the networks and other factors related to each strategic variable. The issue to be addressed here is the degree to which an application of eco-design methodology captures the dynamics and consequences of “market-based lock-in”. The goal is a better understanding of the strengths and weaknesses of the two approaches, so as to move towards a more comprehensive and better integrated understanding.

Given the fact that the ideas of industrial ecology are still relatively new and relatively unapplied within mainstream production and distribution, the burden of proof as to its usefulness lies with the “new-comer”. Eco-design approaches will only be broadly accepted if they incorporate and transcend existing methods of strategic planning and accounting, not try to replace them outright.

¹ A copy of the CondEdol project design (Lafferty, Marstrander and Ruud, 2003) is available at the ProSus website: <http://www.prosus.uio.no>.

1.1 The CondEcol cases: Shecco and Renewable Energy Corporation (REC)

We begin with a brief overview of the selected CondEcol case studies.

“Shecco™ Technology” is a trade-mark name for an energy-efficient and environmentally friendly heating and cooling technology based on natural CO₂. The use of CO₂ as refrigerant significantly reduces greenhouse gas emissions because it replaces one of the most destructive greenhouse gasses, HFC.² The technology can be used in mobile air conditioners (passenger cars and light trucks), or in mobile and stationary freezers and coolers (used, for example, in the transport and storage of food). Exploiting the technology’s heating abilities, a mobile air-conditioner can here be reversed and used to heat the vehicle itself. Finally, the technology is also being applied to water heaters where a high volume of very hot water is a necessary production factor.³

The Renewable Energy Cooperation (REC)⁴ is a significant player in the international solar energy industry. It is the only company in the world that is involved in the whole value chain from the manufacturing of solar grade polysilicon feedstock as a primary material for solar electricity generation, to the marketing and sale of photovoltaic systems. Being involved in the whole value chain, a wide range of technological attributes are here relevant for research. The CondEcol project has, in the initial phase, limited the *technological* focus to the production characteristics of REC’s subsidiary ScanWafer⁵, while at the same time studying solar energy in general for more macro-level analysis.

1.2 Outline of the report

The discussion of specific cases requires that we are specific about exactly what product or technology is being considered. After a brief discussion of these issues for both ScanWafer and Shecco we will, in chapter 2 and 3, consider the relevance of the different mechanisms discussed in Brekke (2003) for the current cases. In chapter 4 we discuss the extent to which the market-analytic approach and the eco-design approach are compatible or conflictual with respect to identifying market barriers inherent in the transition from less to more eco-friendly products and processes, particularly in relation to market-based lock-in arising from “increasing returns to adoption”. Chapter 5 discusses how one can break out of a market based lock-in.

1.3 Defining the markets

Following Brekke (2003) we focus on “increasing returns to adoption” as a potential cause of lock-in. A first question that has to be addressed is the nature and size of the “population” of “adopters”. This depends on how narrowly we define the product or

² Various blends of HFC are used in different heating and cooling applications. For simplicity we will, in this paper, refer to HFC 134a. It is the most widely used coolant in Mobil Air Conditioning (MAC) and has a GWP of 1300.

³ “Shecco™ Technology” is the trademark name of a patented production technique owned by Hydro Pronova AS. Hydro Pronova AS is a subsidiary of Norsk Hydro ASA. For more information visit the Shecco Technology website: <http://www.shecco.com> for more information (Accessed Feb 25, 2005)

⁴ Visit Renewable Energy Corporation’s website: <http://www.rec-pv.com/> for more information (accessed June 8, 2004)

⁵ Visit ScanWafer’s website <http://www.scanwafer.com> for more information (Accessed Feb 25, 2005)

technology in question. In some cases the relevant measure of adoption is the number of adopters compared to the number of adopters of alternative products or technologies (that is, the market share). But in the first of the CondEcol cases, how are we to determine the relevant market for the alternative Shecco technology? Should we focus on the share of conventional cars with such systems; or on the share of hybrid or fuel cell cars with such systems? And what about the adoption of the technology in other areas of application, such as the market for high-temperature, high-volume water heaters?

Similarly we need to define the relevant market for ScanWafer. Should the market be limited to multi-crystalline silica wafers, where ScanWafer is a major producer; or a market which also includes monocrystalline wafers and thin film technology⁶, which will leave ScanWafer with a smaller market share? Or is it a question of the total energy market, where photovoltaic electricity generation is one of the new renewable energy sources competing with fossil fuels? Or should we try to conceptualize some kind of an intermediate emerging market?

The problem is a variant of the more common issue of defining a market and determining a market share. Does Gillette, for example, have a near monopoly on razor blades; or are they simply a smaller actor on the market of “shaving equipment”? In practice, however, the concept of monopoly and market power has proved useful, despite the fact that there are no clear-cut answers to whether two products compete in the same or different markets. There is considerable room for hairsplitting, and numerous legal battles have already been fought out over the issue. Similarly with increasing returns to adoption: There is no clear-cut answer as to which product should be included when we compute the rate of adoption; yet analysts nonetheless manage to calculate useful pragmatic answers.

To resolve these issues we have to revert to the mechanisms that cause “lock-in”, and why it is the case that increased adoption makes the product more attractive to customers. If the mechanisms are purely related to the technology such that a large market share in the market for water heaters in Japan will make mobile air-conditioning (MAC) more attractive to car owners in the US, then the relevant market measure of adoption would be the amount of adoption of the technology in any application. For other mechanisms leading to increasing returns to adoption, it may be the case that the rate of adoption for water-heating in Japan is totally irrelevant for the attractiveness of other products using the technology in other markets. Hence, the relevant definition of the market depends on the specific mechanism causing the lock-in. Further, as we will illustrate below, it is also a question of determining which *product class* is most relevant.

⁶ “Thin film” solar cells are made of very thin films of silisium, cadmium or so called CIGS (Copper, Indium, Gallium, Selenium). The films are thin (1-4 micron) (mono and multicrystalline wafers are normally 220-350 micron) and have a back contact that is often a metal film and a back sheet that protects from the environment and that could be supportive (rigid or flexible). Thin film PV has, as of 2004, a 6 per cent market share.

2 POTENTIAL LOCK-IN MECHANISMS IN THE SHECCO CASE

Shecco Technology is an energy-efficient and environmentally friendly heating and cooling process based on the use of natural CO₂. The technology can be used in mobile air conditioners (MAC) for passenger cars; in mobile and stationary freezers and coolers; and in high-performance tap water heaters. The use of CO₂ as refrigerant significantly reduces global warming because it replaces use of the potent greenhouse gas HFC 134a, a refrigerant with a global-warming potential (GWP) that is 1,300 times that of CO₂.⁷ Energy efficiency is also a key aspect of the technology of Shecco heat pumps. In the case of MAC it is evident that the Shecco technology is more or equally energy efficient than conventional HFC-technology (Hafner and Nekså 2004; Wolf 2004). Hence, indirect GHG emissions due to operation of the equipment are also reduced. Energy efficiency is the main reason for the development of the tap-water heaters in Japan, where reductions are most significant in the use of electricity and gas heaters. As such, Shecco Technology may potentially contribute to the reduction of greenhouse gas (GHG) emissions in accordance with the objectives of the Kyoto Protocol.

The Shecco Technology is suitable for a variety of heating and cooling applications. At present, however, the technology is principally employed in residential tap-water heating in Japan, commercial refrigeration in super markets, soft-drink (and other refrigerated) vending machines, and mobile air-conditioning (MAC). We will here focus on the tap-water-heating and MAC applications, where the primary ecological advantages compared to competing technologies are manifest in better energy efficiency and reductions in direct GHG emissions. All of the Shecco applications have, however, a similar eco-friendly potential since they are all based on the same patents related to CO₂ as a refrigerant.

In his previous report for the CondEcol project, Brekke (2003) considered two mechanisms causing market-based lock-in: uncertainty and increasing returns to adoption. Of these the latter appears to be most relevant for the CondEcol problematic, but the issue of uncertainty, as briefly discussed below, can also prove important for specific types of technology.

2.1 Increasing returns to adoption

Having previously explored several different causes of increasing returns to adoption, we can here inquire as to how the stylized processes might account for *obstacles in getting the Shecco technology accepted in the market?* Each of the alternative processes is discussed in turn.

⁷ Measured with a time frame of 100 years in accordance with the methodology of IPCC and the Kyoto-protocol.

2.1.1 The cost of local adaptation

Brekke (2003) used the case of “integrated pest management” (IPM), to illustrate this particular effect. IPM is designed to fight pests without pesticides or insecticides, by using, for example, “natural enemies”. The approach requires local adaptation to find suitable plants and natural enemies. Such costs are generally too large to be born by one farmer alone, but can be much more modest when all farmers in the area share them. Note that this is not just economies of scale, where large fixed costs have to be paid irrespective of the volume of production. The point here is that if an initial farmer takes the cost of local adaptation and testing, the cost of adopting IPM will be much lower for the next farmer. In this case there are thus incentives not to be the first to adopt IPM; but if no-one takes on the burden of “initial adopter”, there will be no adopters.

The adaptation cost in the Shecco case depends on which product or sub-product we consider. Consider first mobile air conditioners in cars (MAC). To set up a production line for MAC requires big investments, so the adaptation cost seems very large. This may not in itself cause a lock-in, however, even though the high cost is clearly a barrier in itself. If an automobile manufacturer is the first to set up a MAC production line, the cost for other manufacturers to set up a similar production line will be largely unaffected. Alternatively, the second manufacturer may buy MAC systems from the first, but then there is no problem in charging the second for a share of the cost of setting up the line (through price adjustments). Similarly, if both firms buy the MAC system from a supplier, then the first customer may get just as good a deal as the second, e.g. the contract can be written such that the first customer is guaranteed not to lose from being first. There is thus no incentives to avoid being first to avoid the adaptation costs.

This argument changes once we move from the market for MAC (where the automobile industry is the customer) to the market for cars with a CO₂-based MAC. To the extent that service personnel on local garages need to be trained in maintaining and repairing these MAC-systems, the training cost has to be born by the first car manufacturer introducing such a car onto the market. This induces an incentive not to be the first to do so. The argument of high implementation costs in this respect has frequently been raised by the automotive industry. However, according to representatives for Shecco Technology⁸, costs related to hardware are marginal. The main advantage is that the propellant is cheap and can be vented, and that no special tools are needed. There is no need for mechanical collecting, cleaning and storing the propellant during maintenance as is the case with conventional HFC technology. Costs related to the training of personnel for maintenance of the CO₂ technology are, however, difficult to assess, but, compared to the conventional technology the components and systems are not that different, and training costs should not constitute a major extra burden. According to Petter Neksa⁹ at the Norwegian University of Science and Technology (NTNU), lessons learned from the introduction of CO₂-based refrigeration counters in Danish super markets show that – contrary to the initial claims of service personnel – service and maintenance of the units differs only marginally from service and maintenance of conventional counters.

The difference in perspective as to local adaptation costs may reflect different strategic positions, but they may also be an indication that the automobile industry fears there will

⁸ Telephone interview with Vice President Jan Hurlen in Shecco Technology Dec 16, 2003.

⁹ Telephone interview Dec 16, 2003. Neksa is Senior Researcher at SINTEF/NTNU.

be extra adaptation costs, until proven otherwise. It is thus important for the producer of the new product/technology to be able to demonstrate convincingly that it actually works and that adaptation costs are moderate. We will return to this below.

2.1.2 Technology-specific human capital

While tests showed that typists trained on a “Dvorak Keyboard” type 30 percent faster than typists using the standard “QWERTY-keyboard”, the latter nonetheless remains standard on virtually all modern computers. David (1985) has argued that the reason there has never been a change is related to technology-bound human capital. All users of a PC or typewriter are used to the QWERTY layout, and hence there is a considerable cost for switching. Moreover, those who are just learning to type will have incentives to learn using the dominant layout.

Are there possibly similar technology-specific human-capital barriers for the introduction of the Shecco technology? One issue here is the curriculum at large technical universities. Universities are interested in providing knowledge that students are likely to need and can capitalize on when they have finished their studies. But what do the students have to learn? What are the main technological differences?

The Shecco technology is a high-pressure heat pump, while the conventional heat pumps work under much lower pressure. According to Petter Nekså¹⁰ this is related to the basic difference between the HFC and CO₂ technology: HFC is based on evaporation, while CO₂ is based on supercritical gas cooling. Regulation and dimensioning of the units is therefore critical. The technology must be adjusted to the coolant in use to optimize the effect of the unit. For the Shecco technology it is essential that the temperature prior to the throttle valve is low and, due to the high pressure, that the units are absolutely tight. There are still challenges related to detecting minor leakages in the systems due to the “background noise” of CO₂ from other sources, for instance from human respiration. The solution to such problems will be of importance for the implementation of the Shecco technology, but tighter systems will most probably also be required by the EU and US authorities for the conventional HFC technology.

Specific knowledge about high-pressure heat pumps using CO₂ as the working fluid is thus required to adopt the Shecco technology. At the same time, as low pressure is the dominating system, this technology is likely to receive more attention in the curriculum of the typical engineering school. Thus, if a company were to adopt the new technology, they would have to train their own engineers, and engineers already in the firm might object to the change – a change that appears to reduce their own educational “capital”.

Although courses on CO₂ as a working fluid in heat pumps are still not a common part of the curriculum at the typical engineering school, the situation is about to change. This might, in the long run, have a significant impact on the specific human capital available to the industry. After Gustav Lorentzen reinvented CO₂ as working fluid in heat pumps in the late 1980’s, several universities¹¹ have included CO₂ technology as part of their graduate programs, and some probably also at undergraduate level. To our knowledge

¹⁰ Telephone interview Dec 16, 2003. Nekså is Senior Researcher at SINTEF/NTNU.

¹¹ According to Petter Nekså at NTNU/SINTEF some examples are: The Norwegian University of Technology and Science (NTNU), University of Illinois, University of Maryland, University of Padova (Italy), University of Braunschweig (Germany), University of Dresden, University of Karlsruhe, Korean Advanced Institute of Technology (KAIST) and University of Tokyo.

there are no specific courses on CO₂ as coolant available, but teaching on CO₂-technology seems to be part of the typical “Air Conditioning and Refrigeration Engineering” curriculum. Furthermore, since 1997 about 60 exchange students from Italy, Germany and France have studied at the institute started by Lorentzen at The Norwegian University of Technology and Science (NTNU), and most of these are apparently now employed in top positions in the automotive industry in Europe. Human capital is still bound to conventional HFC technology, but this might change.

2.1.3 The learning curve on new technologies

Cowan (1991) argues that a lock-in developed in light-water technology in nuclear reactors when the US-Navy adopted the light-water solution when the nuclear reactor technology was in its infancy. The example of the US Navy adoption and the corresponding improvements in technology gave light-water technology a head start over alternative technologies. As the technology became dominant it continued to develop and improve while alternative technologies stagnated, adding further to the dominating technology’s advantages. (Note that a related point here is that an actual implementation provides a demonstration that the technology actually works. We discuss this aspect below. Here the focus is on the learning that helps to improve the product or technology.)

To what extent is such a learning curve important in explaining barriers to the Shecco technology? Clearly, the existing technology is well established and most of the potential learning has already taken place, although as competing technologies arise, this may force even further product improvements. The Shecco technology has, however, gained far less experiences from actual use and mass production, and it is thus likely that the potential for further learning and product improvements is much larger with this technology. If so, the Shecco technology would become a basis for greatly improved products if more users adopted it.

The relevant market in this case will depend on exactly what kind of learning we are considering. To some extent, experiences from water heating in Japan may help improving MAC to be used in cars. But once cars with Shecco-based MAC’s are produced in a larger scale, we would expect to gain experiences that cannot be derived otherwise; e.g. how do consumers evaluate the comfort such MAC’s provide, and what kind of solutions will maximize consumer satisfaction for car customers?

The introduction of the Shecco technology to the Japanese water-heating market has provided a showcase as well as a learning arena. Components have been tested in real life and experience gained. According to Petter Neksa at NTNU¹², it is clear that development of the water-heating technology has had an impact on the overall learning curve of the Shecco-technology, both regarding material usage and component durability. There is, however, a significant difference between the tap-water heating and Mobile Air Conditioning (MAC) applications which limits the learning potential for MAC’s relative to the tap-water heating experience. MAC’s are more dependent on small size, low weight and “sturdiness” (especially when it comes to vibration) than the stationary tap-water heating systems.

But this has also been a two-way experience. Denso Corporation, which has licensed the Shecco patents in Japan, was, prior to the development of the tap-water heating

¹² Telephone interview Dec 8, 2003.

system solely a producer of car components (such as MAC units to the Japanese automobile industry), and had not previously developed technology for other markets. We do not know much about the technology development within Denso Corporation, but it is for example clear that Denso introduced the heat exchanger technology from the MAC industry to their tap-water heating units. One can assume that the lessons learned and experiences gained from the tap-water applications will be taken back to the “MAC department” in Denso.

2.1.4 Negative externalities from non-adopters

In the earlier study (Brekke 2003), the existence of negative externalities from non-adopters among farmers was illustrated by the use of late planting to deprive hibernating boll-weevils any food. This kind of insect protection is thus only efficient when all adopt it. If some farmers planted early, the hibernating insect would be able to survive the first spring weeks and then cause harm for all farmers in the area. As far as we can see, there is no parallel to this type of effect in the present case. A heat pump works equally well regardless of how other heat pumps are constructed.

2.2 Uncertainty and search costs

The development of a new technology is not just a matter of making sure that it works in theory, not even to make a prototype. The value of the technology is only known when we know what it would cost in mass production, how well it works in practice, how much maintenance is needed etc. There is thus a particular type of learning not directly related to improvements in the technology, but simply to show that it works in practice. When some adopters use a product and learn that it works well in practice, it makes the product more attractive to other potential adopters who then know that the product work.

In the Shecco case there are different technologies that can be used for cooling and heating a car or for heating water. While prototypes of the Shecco technology exist for different kinds of applications, there is still uncertainty remaining. If some volume of products using the technology is produced, this will provide much more information about reliability, potential problems of mass producing the product and of maintenance costs. A successful implementation of the technology in mass produced water heaters, will tell other potential adopters – be it potential mass producers or buyers of the final product – that the technology works.

This demonstration effect may have limited value across product types. It may not be reconfirming for a customer who consider buying a car with Shecco based MAC to know that the technology has worked well in water heaters. Fortunately, the information we have indicate that in the Shecco case the demonstration effect seems to be highly relevant across markets. Denso and Shecco have used the successful introduction of Shecco-technology to the Japanese tap water heaters as a sales argument confronting the automobile industry. As mentioned above, parts of the technology used to heat tap water was initially developed for the MAC industry, but as there was no global consensus in the automobile industry to change to CO₂, Denso decided to apply the patent on water heating in the meantime. Denso has set up a separate factory producing parts to the tap

water heat pumps. These parts can also be used in MAC's. The differences are marginal, and the technology has demonstrated that it is working.

2.3 Summary

The discussion above indicates that there may be significant increasing returns to adoption for the Shecco technology, based on cost of local adaptation, technology-specific human capital, steep learning curves and demonstration effects. We have not made any attempt to quantify the strength of these effects, and hence cannot make any predictions about what market shares would be required to break a potential lock-in. Currently, stricter regulation of the use of HFC is discussed within EU. The EU will most probably decide to phase out HFC-134a in MAC's from 2011, and to ban it altogether from 2014 or 2016. There is, however, uncertainty related to the dates as well as to which GWP level MAC refrigerants will be allowed to have in Europe. If such regulations pave the way for a wider adoption of the Shecco technology in MAC in Europe, learning and other spillovers from Europe may (or may not) initiate breaking the lock-in in other markets as well.

3 POTENTIAL LOCK-IN MECHANISMS IN THE SCANWAFER CASE

ScanWafer is a case very different from the Shecco case. ScanWafer produces silica wafers, essential parts in the production of solar energy panels. In response to the question “What is the innovation”, Erik Sauar, R&D manager at ScanWafer responds¹³ “We make a product that is marginally better, but physically identical. It is slightly better crystals, but clearly the same product as those existing before.” Thus described, the innovation sounds like a step on the learning curve of solar energy although Sauar emphasizes that ScanWafer have introduced several very important hardware and process related innovations that increase the efficiency and reduce the production costs of multicrystalline silica wafers. The innovations are amongst others related to furnaces, ceramic pots for ingots and wire saw machines.

In cooperation with the German company ALD¹⁴, Renewable Energy Corporation (REC) has developed a very effective furnace for the melting of multicrystalline silicon into blocks. The furnace is about four times the size of the competitors’ furnaces and hence produces the blocks at a faster and more cost-efficient manner. In cooperation with Vesuvius¹⁵ REC has developed high tech ceramic pots for the melting of silicon into ingots. In cooperation with HCT¹⁶, a Swiss company specializing in wire saw machines slicing the ingots into wafers, new and efficient saws are being developed. Exclusive deals on equipment from these producers makes the network and cooperation between REC and these three producers of production equipment essential to understand REC’s low costs and relatively big market share on wafers. According to Erik Sauar¹⁷ this situation makes market penetration of new actors – without access to exclusive technology – very difficult and/or capital intensive. It goes without saying that these aspects are important to take into consideration for business decision makers and product developers considering entering the multicrystalline silica wafer market.

Moreover, within the market for wafers, ScanWafer has a significant market share¹⁸, and it seems like there is no reason to talk about ScanWafer being locked-out in the wafer market. However, the learning curve for solar energy as an alternative to fossil fuels has everything to do with potential lock-in in the energy market, and hence we define the relevant case for our purposes to be the solar energy in general.

¹³ Telephone interview March 3, 2004.

¹⁴ <http://www.ald-ag.de/> (Accessed Feb 25, 2005)

¹⁵ <http://www.vesuvius.com> (Accessed Feb 25, 2005)

¹⁶ <http://www.hct.ch> (Accessed Feb 25, 2005)

¹⁷ Interview June 26, 2003.

¹⁸ According to ScanWafer about 50 per cent of all solar panels are made with multi crystalline wafers. ScanWafer has a share of about 30 per cent of the multi crystalline wafer market. (More information at: <http://www.scanwafer.com/index.php/4904>. Accessed Feb 25, 2005)

3.1 Increasing returns to adoption

3.1.1 Cost of local adaptation

Solar energy's modular design makes it suitable to decentralized production, e.g. individual households may put panels on the roof. The energy is produced during daytime, often while the household's energy demand is low. A traditional stand-alone system requires storing of energy, making the total system expensive. In an integrated system where the excess capacity can be supplied on the grid, need for storage is avoided, but requires that the local energy system is adapted to such decentralized production.

Germany has a system where households with solar panels on the roof top can supply excess electricity on the grid. The system was initiated at a political level¹⁹, and the households are guaranteed a fixed high price for the energy they supply. These feed in tariffs are substantial and provide strong incentives for the households. We do not have data on the local adaptation cost in this case, but it is likely to be low. More on these incentives in section 3.1.3 below.

3.1.2 Technology-specific human capital

In areas where solar energy in private households is rare, the knowledge of how to install them may be equally rare. Still, we cannot see that technology human capital should be an important barrier. Any electrician should, with a minimum of training be able to install a solar panel. All that is needed is a solar panel with a regulator and an inverter that produce the correct current. In Germany a huge number of craftsmen have the competence in question and easy access Internet resources are available for the planning and calculation of the solar panel installation process²⁰.

3.1.3 Learning curve on new technologies

Products or technologies with steep learning curves may have the potential to become superior to existing technologies, but still be locked out of the market, simply because they initially are too expensive or have poor quality. The cost reductions on solar energy have been formidable, but still solar energy is more expensive than the main alternatives for regular electricity production. If accumulated installed capacity continues to grow, the cost reduction is likely to continue, and in a not to far future, solar energy may compete favorably with almost any existing electricity technology. The bad news is that if the installation of more solar energy production capacity stops, the cost reduction is likely to stop too. And as solar energy remains expensive, the incentives to install more capacity will be low. Currently, however, the market is growing at an annual rate of at least 20 to 30 %, and there is no sign of any slow down.

¹⁹ When the Red-Green coalition won the elections in 1999, the Green party demanded subsidies for renewable energies to join the government. The coming policies were announced, which lead to a total stand still in the PV energy market for about 10 months. Nobody wanted to invest in panels when they knew that a subsidy arrangement was coming up.

²⁰ For example the official "100.000 roofs program" <http://www.100000daecher.de/> (Accessed Feb 25, 2005) and related internet sites give an overview of how much solar energy that can be produced from a rooftop installation and gives a calculation of costs related to it.

The current market growth rate is largely due to policy interventions. Subsidies on installation of solar energy in countries like Japan and Germany have triggered a substantial volume growth in these markets. Both countries also have a feed-in tariff, where the households are guaranteed a fixed high price for the energy they supply. In Germany the fixed price is EUR 0.51 per kWh, about four times the current electricity price the household is facing when buying electricity. If such strong policy interventions are introduced in other countries too, we would see a similar market growth there, but the question here is whether the volume growth in Germany and Japan will have impact beyond these markets, due to increasing returns to adoption and especially the steep learning curve.

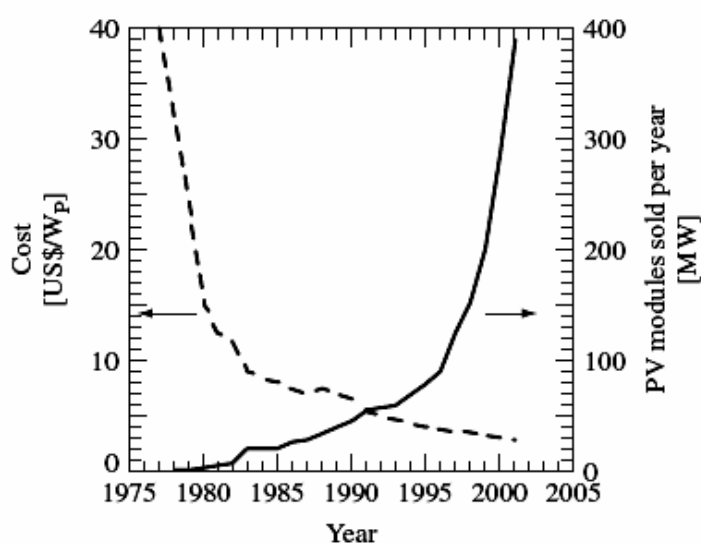


Figure 1: Historical trends of cost per Watt for solar cells and volume of production. Data from various sources. Beware: these costs are for PV modules not completed systems, which typically increase by a factor 2 to 3. (Figure and text taken from Hegedus and Luque (2003: 16).)

According to ScanWafer's web page²¹ the efficiency of multicrystalline wafers has increased with about 25 % in the period from 1997 to 2003. In the same period prices on wafers is reduced with about 20 per cent while the prices on silica raw material has risen from about 10 USD to 25 USD. This reflects a general trend in the industry. As Figure 1 above indicates, prices on photo voltaic electricity is significantly reduced during the last 30 years, while at the same time numbers of PV modules sold has increased. The cost reduction per Wp (peak watt) has been about 5% per year the last five years, according to Hegedus and Luque (2003). Information from Erik Saunar²² report a cost of about EUR 0.22 per kWh in an area with 1700 hours of sun per year (Southern Japan) and with a life length of 50 years and 5 % interest rate. This cost is similar to the electricity prices to households in Japan.

²¹ <http://www.scanwafer.com/index.php/4740> (Accessed Feb 25, 2005).

²² E-mail to Olav Mosvold Larsen at ProSus, March 3, 2004

3.1.4 Negative externalities from non-adopters

Like in the Shecco case, this does not seem to apply, as the amount of solar energy produced from installments on one roof would be independent of how the neighboring house is supplied with energy. (The only such direct externality we can think of is when smoke from a coal fired electric utility plant cast shadows on a solar panel, but we would think that such effects are unlikely and small.)

3.2 Uncertainty and search cost

Solar energy is in use in many places, and there is no need to demonstrate that the technology works and is almost free of maintenance. Still, there may be uncertainties remaining, e.g. it is expected that the solar cells will maintain their production capacity almost unchanged for decades, but we have to wait several decades more for the proof. A more recent demonstration is the adoption of solar energy in Germany, where solar energy is integrated into the electricity grid.

3.3 Summary

Like in the Shecco case there may be significant increasing returns to adoption for solar energy: the cost of local adaptation is low, there is no need specific human capital installing the solar panels, the learning curve on the technology is still steep, and there is a significant potential for cost reductions. Solar energy has moved from one niche to another and is rapidly growing while the cost is declining. At this stage, the case appears to represent a trajectory which is successfully breaking a market-based lock-in.

4 LOCK-IN AND THE ECO-DESIGN WHEEL

A main objective of the CondEcol project is to cast light on potential barriers to new and environmentally friendly technologies. The concept of market-based lock-in presents one such potential barrier. A key methodological device of the CondEcol project is the application of the “eco-design strategy wheel” (Figure 2) as a check-list for mapping key variables related to the innovation in question, and for describing the difference between the technology in question and alternative technologies (Lafferty, Marstrander and Ruud 2003). The wheel is based on the eco-design strategy developed at the Delft University of Technology (Brezet & van Hemel. 1997) and later substantiated by Stevels (2000). It consists of 7+1 interrelated strategies (“spokes” of the wheel), with each strategy related to different aspects of the production and distribution system of the product and/or technology in question. The eco-design wheel covers all relevant stages in product development, enabling identification of possible windows for improvement. The instrument can be viewed as a comprehensive tool for comparative studies of different products or technologies, or of the same product at different stages in time.

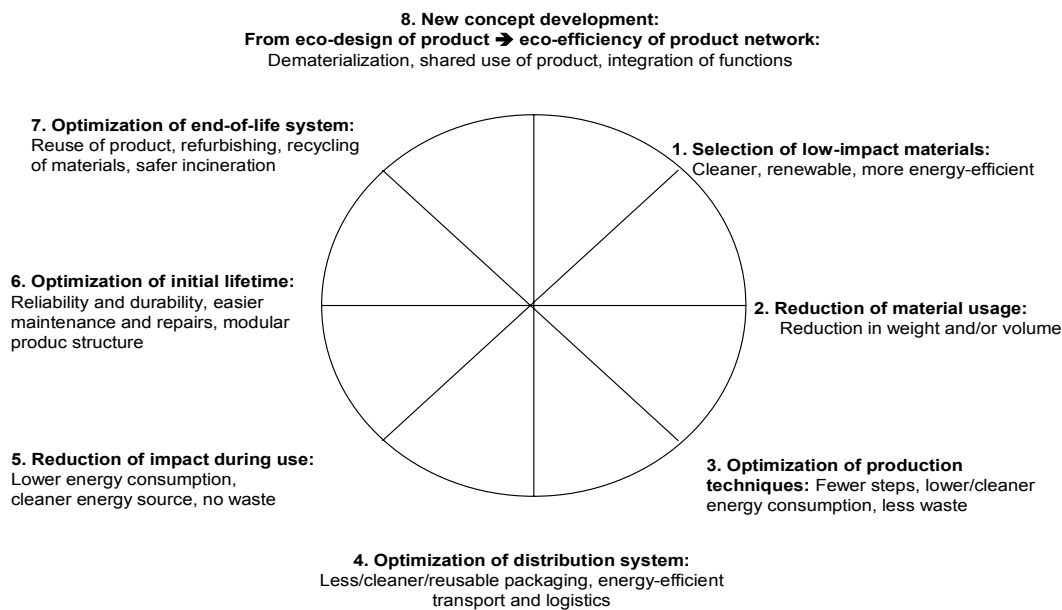


Figure 2: The Eco-design Strategy Wheel²³

Brezet and van Hemel et al. (1997) propose seven steps for helping companies to introduce and strengthen eco-design strategy:

1. Organizing an eco-design project

²³ See “Module A: eco-design strategies” in Brezet and van Hemel et al. 1997, pp. 139-164. Note that Lafferty, Marstrander and Ruud (2003) have designated the 8th “spoke” of the Brezet and van Hemel wheel to involve a move from “eco-design of product to eco-efficiency of product network”. This is in line with the goals of the CondEcol project, and is in full accord with the open (product-dependent) nature of this “spoke” in the Brezet and van Hemel approach.

2. Selecting a product
3. Establishing the eco-design strategy
4. Generating and selecting product ideas
5. Detailing the concept
6. Communicating and launching the project
7. Establishing follow-up activities

The seven steps run more or less parallel to the traditional product-development process and are intended to guide a company through its first eco-design initiatives. Each step is dealt with in depth, and Step 3 “Establishing the eco-design strategy” is further divided into eight “improvement options” for enhancing sustainable production and consumption (Brezet and van Hemel 1997: 81-88). The improvement options are more or less identical with the “spokes” of the Eco-design wheel.

A key question in this report is the extent to which the eco-design wheel is helpful in identifying the aspects of the new technology versus the old one that are essential for potential market barriers, and in particular for market-based lock-in. Looking at the different mechanisms behind increasing returns to adoption, we can distinguish between two types of mechanisms: a “technology-based” approach and a “market-based” approach. A typical technology-based mechanism is the “steep learning curve”. The idea here is that experience can be gained from existing products, and that these experiences can be used to improve the technology and thereby the quality of the products.

The alternative approach is the use of market-based mechanisms. This applies when one technology appears more attractive to customers due to a higher rate of adoption, *even when the technology or the product itself does not change*. These mechanisms are thus more related to the market for the relevant products itself, and not the technology as such. Personal computers of the IBM type were more attractive than Apple’s Mac to many users, simply because this was the dominating platform. More software was available for that platform, and it was easier to share files and documents with others when using the same platform. Hence, Windows-based PC’s gradually came to dominate the computer market totally, even though the Apple-Mac platform was widely recognized to be much more reliable and user friendly.

When considering market-based lock-in mechanisms, we must, therefore, realize that strategic ploys which exclusively build on the eco-design approach will come up short in relation to this particular barrier. The reason why PC’s have a dominant market position is not related to material use, production or distribution system, impact during use, lifetime or end of use system – but to the alternative modes of usage among customers and effects this has on suppliers, distributors, etc. Whereas the eco-design strategy focuses mainly on how to reduce the environmental impact of the product and the production processes, the learning-curve approach is much more general. When large volumes of a product are produced and distributed, there is a much greater volume of, and potential for, learning. This can involve changes that increase consumer satisfaction or reduce production costs, without affecting environmental impact. A methodology that only focuses on environmental impact may thus be well suited to document differences in impact between two products, but not to grasp the importance of the learning potential in general. Hence, even with technology-based lock-in mechanisms (of the type confronted in the CondEcol cases), application of the eco-design wheel – as an isolated strategy mechanism – is too narrow.

To illustrate the point, we can return to the two CondEcol cases for an assessment of the kind of information that would be needed to spot the mechanisms that may cause market-based lock-in for ScanWafer and Shecco Technology. To what extent is the eco-design strategy wheel able to generate this type of information and insight?

4.1 Cost of local adaptation

The cost of local adaptation is of some potential importance in the ScanWafer case, where one potential cost is integration of solar energy into the local electricity grid. This is primarily a market-based factor. Adaptation costs will be largely independent of technological changes in the wafer technology. The relevant information about such costs is thus not directly reflected in the information-gathering categories of the eco-design strategy wheel.

4.2 Technology-specific human capital

The issues raised with respect to the human-capital aspects of the two cases were the curriculum at engineering schools and the availability of qualified personnel for installing and repairing the relevant products. We would not expect these types of information to be generated by a check-list designed for technological improvements. The categories of the eco-design wheel would, however, here contribute to a more systematic comparative approach.

4.3 The learning curve for new technologies

Learning and the consequences of learning for technological improvements is important in both the cases considered. While market forces here can significantly inhibit learning, the consequences are also technology relevant, so that an approach like the eco-design wheel would be more appropriate. Let us therefore (by way of illustrating the point) look more closely at the individual categories (“spokes”) of the approach.

Spoke 1: Selection of low impact materials

The selection of materials represents a potential for learning, where improved materials replaces those previously used. There is, however, no reason for a particular focus solely on low-impact materials. Take for example the REC/ScanWafer case: If solar energy were to replace fossil fuel on a large scale that would of course be very good news for the environment. But it could also be good news for the environment if the market penetration was achieved by producing wafers with cheaper materials but higher impacts. Monocrystalline wafers have better energy efficiency performance than multicrystalline wafers and hence less impact. But the latter are cheaper and thus make market penetration more probable. Finding cheaper materials that work almost as well²⁴ is thus one possible mode of beneficial learning. A more nuanced spoke in terms of simply “selection of materials” could thus provide information which is both more variegated and potentially more useful for judging possible “rebound effects”. There is thus in this light no

²⁴ Measured in terms of energy efficiency.

need to limit the focus to “low-impact materials” – *provided*, that is, that the responsible “strategist” is interested in the total effectiveness of the transition, and not simply a more limited product eco-efficiency.

Spoke 2: Reduction in material use

Reduction in material use is a potential cost saver, and hence improvements on this area may make the product more attractive to potential adopters. We must here note, however, ScanWafer’s strategy, which is relevant for both this and the previous spoke. In the choice between mono- and multi-crystalline silica wafers, ScanWafer has chosen the multi-crystalline solution even though the mono-crystalline has higher energy efficiency. In terms of “per-watt-produced” the multi-crystalline solution uses more material; but multicrystalline wafers produce electricity at a lower cost. From an environmental perspective, therefore, with respect to market penetration, it is probably more important to choose the low-cost alternative – as, in fact, ScanWafer has done. With this choice, solar energy competes better with alternative energy sources. It should also be noted, however, that one of ScanWafer’s key innovations is a wire-saw that cuts the wafer in much thinner slices than conventional technology with much less material waste. At the moment the wafers produced at ScanWafer plants are one third of a millimeter thick (330 micron), and the target is to produce wafers which are only 220 micron thick by 2010. This in itself represents a substantial reduction in material used.

Spoke 3: Optimization of production techniques

This is obviously important for the learning curve. As larger volumes of a product are produced, more is learned about the production and the scope for improving the production techniques.

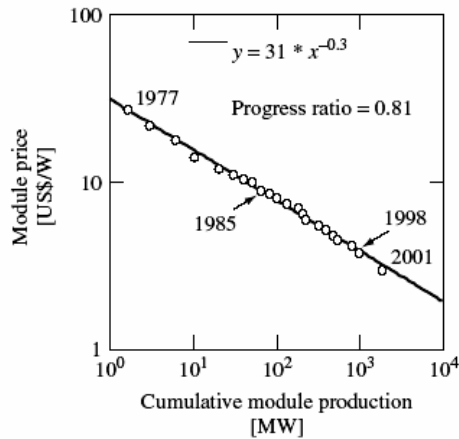


Figure 3: Experience curve for photovoltaics from 1976 until 1998.²⁵

For the Photo Voltaic energy Saunar argues that “the volume drive” is the main driving force in the cost reduction. A possible interpretation is: the demand for solar energy installations is rapidly increasing, and this increasing demand is a driving force for reduced production costs. Such a view is consistent with a view that solar energy is on a rapidly increasing part of the learning curve, and also consistent with Figure 3 above which indicates a clear correlation between accumulated capacity and module price. The solid line indicates that a log-linear relationship between cumulative production and module price represent a good fit to the observations. The parameters of the fitted line imply that a 10% increase in cumulative production will be followed by a 3% reduction in module price.

For the Shecco technology, Ruud and Larsen (2003) report no major differences for this spoke between conventional air conditioners and heat pumps and CO₂ based ones.

Spoke 4: Distribution system

Ruud and Larsen (2003) report no major differences on this spoke for the Shecco technology. Distribution systems are much more important for solar energy. The system is modular, ideal for decentralized production. By comparison, existing electricity production exhibit huge economies of scale with very centralized production, in Norway related to the location of existing streams and water falls. The existing system requires huge capital investments in distribution. With more solar energy on the grid, it will be important to optimize the integration of these two systems, an integration where there may be significant potentials for learning.

In addition to issues related to distribution of energy, the distribution and installation of panels is a potential area for learning and improvement as the market grows.

Spoke 5: Reduction of impact during use

With respect to the Shecco case the information collected here is on the direct emissions of HFC due to leakage, and lower CO₂ emissions for heating water, as well as lower indirect emissions during use of MAC's due to decreased use of fuel for drifting the MAC-

²⁵ The straight line in the figure indicates a fit at an experience factor of $1 - 2^{0.3} = 19$. The figure and text are taken from Parente et al (2002), as reproduced in Hegedus and Luque (2003: 17).

units. Actually, it seems like the HFC technology has benefited more than the CO₂ technology from learning or product development at this point. The “threat” of the CO₂ technology and other “natural” coolants²⁶ has forced the HFC-industry to develop tighter and more energy-efficient units; to optimize technology and maintenance routines; and even to develop a new coolant (HFC 152a) with significantly less global-warming potential.

For the ScanWafer case there is nothing to report on this spoke as it is widely documented that there is no impact during use of solar panels.

Spoke 6: Optimization of initial lifetime

Ruud and Larsen (2003) report no major differences on this spoke for the Shecco case. For the ScanWafer technology, the solar panels have a very long life time with hardly any maintenance.

Spoke 7: Optimization of end-of-life systems

For the Shecco case, the information here is similar to that on leakage during use, and the assessment very much the same. If HFCs are vented they cause global warming, but there are national variations in procedures for the recovery and disposal of the propellants at their final disposal. Most countries do not have such procedures in place at all. Recycling technology is also available. But, although numbers are rising, it is not yet widely in use on a global scale. Hence, conventional heat pump technology requires a regime for final disposal of HFC, and, even if the HFC's are recovered, the destruction process is energy intensive. CO₂ does not need special infrastructure at service or at end-of-life disposal to avoid greenhouse gas emissions.

Regarding solar energy, we are not aware of any relevant aspects related to this spoke.

4.4 Summary

Looking at the different mechanisms behind increasing returns to adoption, we have distinguished between two types of mechanisms: technology-based and market-based lock-in. The market-based mechanism involves a product which is more attractive to consumers the larger the number (or share) of adopters, even when the product or technology itself does not change. The technology-based mechanism occurs when adoption has a feedback on the technology. We have concluded that, if confronted with market-based lock-in mechanisms, there is little help for transition to be expected from technology- and materials-oriented approaches like the eco-design strategy wheel.

Lock-in factors related to “costs of local adoption” and “technology-specific human capital”, are also mainly market driven, but here, even though the relevant information in the cases considered is not directly tapped by eco-design wheel, the approach does help in nuancing and systematizing vital decision-making information.

Finally, it would appear that the eco-design approach is most relevant for adoption processes related to the “learning curve on new technologies”. We have here discussed each spoke of the wheel and found that relevant learning information is generated by

²⁶ Ammonia, hydrocarbons (propane, isobutene) etc.

most of the categories. Even here, however, it appears that the wheel, as an isolated device, has important limitations. As presented within the literature on industrial ecology, the eco-design strategy wheel focuses mainly on how to reduce the environmental impact of the product and the production processes. We have made the point, however, that a wider adoption of eco-friendly products by reducing costs can be an important alternative to simply reducing the environmental impact of the individual product. Such a perspective has been very significant in the ScanWafer case where the environmental impact of the product is initially very low.

Using the wheel as a baseline for developing an alternative product/production concept could, therefore, lead in a sub-optimal direction vis à vis overall eco-effectiveness. In short, whereas the eco-design strategy wheel may be a necessary tool in determining barriers to and alternatives for eco-friendly production and distribution, it is clearly not a sufficient tool – and could, if used too one-sidedly, lead in counter-productive directions.

5 BREAKING MARKET-BASED LOCK-IN²⁷

In further pursuing the implications of the case analysis for market-based lock-in, we can elaborate on the overall development of the technologies and products in question. Photovoltaic energy has moved from different niches and currently enjoys an impressive annual growth rate of approximately 30 per cent. The technology allows highly decentralized adoption, with small installations. In contrast, the adoption of the Shecco technology for mobile air-conditioning would require that large automobile manufacturers adopt the technology on a large scale. This has not yet been the case. As pointed out the first commercial adoption of the technology has been for tap-water heating systems in Japan.

Compared to other sources of electricity generators, solar energy has obvious advantages. It is silent, almost free of maintenance, and ideal for decentralized systems. For some markets these characteristics leave solar energy with almost no competitors. The modern era of photovoltaics (PV) started in 1953 at Bell Labs²⁸. The technology was first developed for the US space program, where the willingness to pay was very high and solar energy delivered reliable energy where no other sources were available. In 1958 the NASA Vanguard Satellite had a PV back up array, and in 1966 the NASA Orbiting Astronomical Observatory was launched with a 1 kW array. The worldwide oil crisis in 1973 spurred many nations to consider renewable energy sources, including PV. In the 1980s the technology began to mature and emphasis on costs and manufacturing grew. As the technology improved prices came down. For a period the main market was remote villages in developing countries and mountain cabins in Norway²⁹. In these cases installations were located far from existing electricity grids, with no real alternative for electricity for lighting. The driver in the Norwegian market, however, had probably more to do with luxury and technological curiosity than necessity.

Another early development that helped many companies was the application of PV cells to calculators, pioneered by Japanese researchers in the early 1980s. This probably also had an impact on the general acceptance in the public as to the applicability of photovoltaics. The technology continued to improve, the cost continued to decline, and solar energy gradually became more attractive in new markets. Since the turn of the millennium the success of grid-connected residential applications has been possible because several countries, lead by Germany, have introduced schemes to subsidize the PV electricity produced by solar installations in private houses. In addition, German banks provided generous loans for purchasing the installation. The success has been even bigger in Japan where the government has been giving 30 per cent rebates of the total PV-system cost. In addition, Japanese electricity bills are determined by the utility using the “net-metering”, with the customer only paying the net difference between what is used and what is generated. Interestingly, government support of photovoltaic energy generation in

²⁷ A substantial part of the description of the history of photovoltaics in this chapter is based on Hegedus and Luque (2003: 11-15)

²⁸ <http://www.bell-labs.com> (Accessed Feb 25, 2005)

²⁹ According to Erik Saunar in an interview June 26, 2003, BP Solar had 25 percent of its annual sales in Norway at that time, and it was important for the development of the PV technology.

Japan has been decreasing while the market for PV in homes has continued to show an impressive growth rate. According to the information provided by Erik Sauar from ScanWafer (section 4.1 above), the cost of solar energy is about level with electricity prices, both at about Euro 0.22 per kWh for households in Southern Japan. From this perspective, it seems clear that the PV-case provides crucial information on breaking a market based lock-in.

The Shecco case is quite different. The initiative from Gustav Lorentzen came as a response to the Montreal Protocol which replaced CFC's with HCFC's and later HFC's. In the 13 years since the first patent application was filed⁵⁰, there has been no widespread adoption of the technology for mobile air conditioners. Toyota has, however, mounted CO₂-based MAC's in some of their hydrogen-concept cars. When the technology eventually was adopted for tap-water heating, this occurred in a market where the Shecco technology has distinct advantages over the HFC-based technology. Whereas the latter can only be used for cooling, CO₂-based heat pumps are also efficient when reversed and used for heating. In the initial adoption it was this characteristic that was essential. The use of the technology for water heaters in Japan is the first significant niche for this technology. In May 2001 Denso introduced Shecco technology for tap-water heating applications in the Japanese market, where there are several needs for high volumes of high-temperature water. At the same time water heating in general comprises 35 percent of energy consumption in Japan, and no energy saving solutions had been applied to water-heating equipment. Denso's attention was drawn to SINTEF's successful experiments with the use of CO₂ heat pumps. The technology is capable, due to the high working pressure, to deliver water at temperatures well above 70 degrees Celsius. In cooperation with Tokyo Electric Power Company⁵¹ Denso developed the "Eco Cute", a small, neat and efficient water heater and a license agreement between Hydro and Denso on heat pumps for tap water in Japanese homes was signed in 2001. Compared to a gas-fired⁵² hot-water system the Shecco technology provides a reduction of CO₂ emissions by 50 percent. Furthermore, the Shecco technology has low running costs: Denso claims in fact that running costs may be reduced by up to 80 percent in the Japanese market. As of spring 2004, Denso has set up one factory for manufacturing vital parts for the heat pumps, and the system has annually sold in the thousands by companies like Mitsubishi, Hitachi and Toshiba. Whether or not this marks the definitive takeoff of the technology remains to be seen.

⁵⁰ Patent application submitted in 1991. More information at: <http://www.shecco.com/patents/patents.html> (Accessed Feb 25, 2005)

⁵¹ More information on TEPCO available at: <http://www.tepco.co.jp/en/index-e.html> (Accessed Feb 25, 2005)

⁵² Methane and LPG.

6 CONCLUSIONS

In the current report we have further substantiated the mechanisms that may potentially cause market-based lock-in, and then tried to draw out the implications of the process for the two CondEcol cases: Shecco and ScanWafer. The point has not been to document actual lock-in, but to focus on those factors related to “increasing returns to adoption” which may potentially cause lock-in.

We have seen that the history of the two innovation paths is very different. The Shecco technology has been adopted in tap-water heaters, but has still not been adopted for mobile air-conditioning by any automobile firms, the initial key target market. Solar energy by contrast, has moved from one niche to another and is rapidly growing while the cost is declining. At this stage, the case appears to represent a trajectory which is successfully breaking a market-based lock-in.

In both of the cases we find important factors contributing to increasing returns to adoption, related to costs of local adaptation and technology-specific human capital, but most importantly to steep learning curves. Except for the learning curves, the other mechanisms are largely external to the technology in the sense that the product becomes more attractive the larger the number of adopters, even when the product is left unaffected. For mechanisms external to the technology, however, we judged the eco-design strategy wheel to be largely irrelevant. The effect of the steep learning curve, however, is that the larger the number of adopters the more rapidly the product itself will improve. In this case the eco-design wheel can provide an important check-list for potential improvements.

Yet, while the eco-design wheel is relevant for assessments of the learning curve effect, it is also important to stress that information which is complementary to the information generated by the wheel is also necessary. The ScanWafer story illustrates the point: Solar energy has much lower environmental impact than fossil fuel, and the main issue is not to further reduce the environmental impact of solar energy, but to make solar energy economically viable for more consumers. In this case the spoke “low-impact material” should be redefined as “selection of material” in general. “Cost” should, for example, include costs of maintenance (even though this is not a major issue for solar energy).

In the concluding presentation above we have focused on lock-in as a market barrier to new and environmentally friendly technologies. But the same lock-in can also be viewed as an opportunity. Solar energy illustrates a case where policy interventions have induced significant volume growth accompanied by substantial cost reductions. If cost reductions continue at the same pace, solar energy will be the natural choice for households in countries that initially did not support the technology. A small group of countries could thus cooperate to initiate a new lock-in on a new and radically improved environmental technology, with no need for further governmental initiatives to ensure that the technology is chosen. Compared to the political problems associated with first negotiating, and then operationalizing and ratifying an agreement such as the Kyoto Protocol, such a cooperative, market-based approach represents both a new approach to

international agreements (see Barrett 2003) and a new cross-disciplinary area of research for combining the efforts of economists, political scientists and industrial ecologists.

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