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Shecco:

***– Mapping the innovation journey
in accordance with the research
protocol of CondEcol***

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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.

A documentation and evaluation of policy implementation that provides a basis for strategic research on barriers and possibilities. ProSus employs an integrated research model (SusLink) that focuses on the relationship within and between different arenas of governance. Research is focused on the supranational, national, and local levels of governance, as well as households and business and industry.

An information strategy based upon open and interactive means of communication to quickly and effectively disseminate research conclusions to central actors within the field of sustainable development. The goal is to highlight alternative strategies of governance and instruments for more sustainable societies locally, nationally and globally.

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, December, 2005

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INTRODUCTION¹

In 1974, Mario Molina and Sherwood Rowland put forward the hypothesis that the emission of CFC gasses (Chlorofluoromethanes) destroys the stratospheric ozone layer². The article initiated political action, and in 1987 the Montreal Protocol was signed³. New knowledge about the impact of CFC on the ozone layer was linked to existing technological solutions that could be implemented in practice (Litfin 1994). The costs of transition to the proposed chemical substitutes were also considered to be limited, and the environmental treaty – the Montreal Protocol – proved to be a success. Today the ozone layer is no longer threatened by chlorinated emissions from CFC compounds.⁴

HFC fluorinated substitutes, used in among other things air conditioning systems, were introduced, but these have a significant global warming potential⁵. It was in this setting that Gustav Lorentzen, Professor in Refrigeration Engineering at the Norwegian University of Science and Technology (NTNU), approached Norsk Hydro in 1989 with a technical solution that took into account both the ozone layer and the global climate.

Professor Lorentzen presented Norsk Hydro with an innovation that was known within SINTEF (The Foundation for Scientific and Industrial Research at NTNU) as R 2000. This was kept a secret for several years, but when the first patent was granted in 1993 it emerged that the innovation involved utilising CO₂ as working medium in refrigeration units and heat pumps. This was not in itself new technology. As early as 1850, CO₂ was discovered as a cooling medium, and was tested in practice as early as 1869. After the introduction of CFC gasses however, CO₂ disappeared from the market in the 1940's. Compared to CFC-based systems, the use of CO₂ as a working fluid required higher pressure in the heat exchanger. This created particular technological challenges for the compressor, and CFC solutions were increasingly considered as more reliable (Andersen and Zaelke 2003).

After the Montreal Protocol of 1987 the application of CFC gasses was no longer permitted, and HFC was seen as the best solution. However, Gustav Lorentzen and his colleagues at SINTEF believed that once again the time had come to use CO₂ as the working fluid in heat exchangers. They discovered that an expansion valve could regulate the efficiency of a system that worked in a transcritical cycle. However, in order for the system to work, there had to be a closed CO₂ circuit. The first patent Shecco-patent was related to just this: how to close the CO₂ loop with the help of the expansion valve. The work was financially

¹ Data collection initiated in 2003 and finalized in June 2004.

² Molina, M. & Rowland, F.S.(1974): "Stratospheric Sink for Chlorofluoromethanes: Chlorine Atom-Catalyzed Destruction of Ozone", *Nature*, pp. 810–812.

³ For more details see: <http://www.unep.org/ozone/index.asp>. (Accessed on May 1, 2004).

⁴ Further details can be obtained from: http://www.miljostatus.no/templates/PageWithRightListing_2295.aspx. (Accessed on May 1, 2004).

⁵ CFCs were also very potent greenhouse gasses.

supported by Norsk Hydro. Three patents that expanded on and improved the original innovation were subsequently applied for and granted⁶.

Shecco is an abbreviation for “Sustainable Heating and Cooling with Natural CO₂”. The innovation is registered as a trade mark with its own logo. The first patent was awarded in 1993. The original idea was to apply it to mobile air conditioning (MAC) systems in cars, but the first commercial application occurred in respect to stationary heating of domestic water in Japan in 2001. The development and commercial realisation differed significantly from that which had been originally planned. In accordance with the issues as formulated in the CondEcol project (Exploring the Conditions for Adapting Existing Techno-industrial Processes to Ecological Premises), we seek a better insight into what happened. Why is it taking such a long time to realise the ecological potential that the *Shecco* patent represents?

We have carried out this survey by linking technical considerations of both the patent as such, as well as individual subcomponents, to non-technological – economic, political, social and cultural – factors. The survey also includes key actors in the innovation journey. Thus the report aims to describe and discuss all the documented relevant circumstances that have influenced the innovation journey up to the present day (i.e. June 2004).

⁶ More information can be found at: <http://www.shecco.com/patents/patents.html>. (Accessed on 11th May 2004).

1 WHAT ARE THE MOST IMPORTANT CHARACTERISTICS OF SHECCO AS A MORE ECO-EFFICIENT ALTERNATIVE TO EXISTING PRODUCTS OR PROCESSES?

As of 2004 the innovation journey of the Shecco technology appears to have taken place in the following order: tap water heat pumps, commercial refrigerated counters, and air conditioning systems in cars. Since 1990 Norsk Hydro's marketing of Shecco has been particularly focused on air conditioning systems for cars. The project was originally called MAC 2000 (MAC is the abbreviation for Mobile Air Conditioning). The close technical collaboration with SINTEF has, however, resulted in an interesting, though unintentional, development within stationary applications in Japan, related to tap water heat pumps. With respect to refrigerated counters and cabinets, there still remains substantial unrealised potential. We shall return to this aspect in the concluding section on future plans.

There are two important characteristics that make the application of CO₂ as a working fluid in heat exchangers a more eco-efficient alternative than the HFC compounds in use today. These are related to:

1. **Climate issues**
2. **Energy efficiency**

1.1 Climate issues

Today's conventional working fluid in heat exchangers utilised in air conditioning systems and heat pumps is HFC. Of these, HFC-134a⁷ has a potential global warming potential (GWP)⁸ that is 1300 times greater than CO₂. Shecco technology utilises CO₂ as working fluid. Theoretically speaking, direct emissions of CO₂ will have a "neutral" greenhouse effect, since it is naturally present in the biosphere⁹. In practice, however, the CO₂ utilised for Shecco technology is obtained not from the biosphere but from process plants. Recovering and recycling CO₂ would not therefore disturb the current total of greenhouse gas emissions, even if CO₂-based air conditioning systems were to generate emissions. This is not the case in conventional air conditioning systems based on HFCs. Increased application of Shecco technology would therefore yield significant climate gains – something which is also an important goal in the Kyoto Protocol.

⁷ HFC-134a is mainly used in mobile air conditioning systems. A number of different mixtures are used in other kinds of air conditioning systems. For the sake of simplicity we refer in this report mainly to HFC-134a as a basis for comparison with the CO₂-based Shecco technology.

⁸ In this report global warming potential is measured in GWP over 100 years. This is also the basis for calculations in the Kyoto Protocol. If measurements in GWP over 20 years formed the basis, the global warming potential for HFC-134a would be 3,400 times greater than for CO₂ (Godal og Fuglestad 2002).

⁹ This point is expanded on in a memo written by Jostein Pettersen and Petter Neksa: "Negative og positive faktorer i utvikling og kommersialisering av Shecco technology" dated June 17, 2002.

On assignment from the European Commission, an analysis of expected emissions of so-called F-gasses (fluorinated greenhouse gasses, for example various HFC gasses, PFC gasses and SF₆) was compiled (EC 2003a). The report was prepared as a contribution to the EC's European Climate Change Programme (ECCP), where it was ascertained that the two greatest sources of relative increase in greenhouse gas emissions due to F-gasses were linked to stationary and mobile air conditioning systems which today use HFC-134a as the working fluid. Total emissions from stationary air conditioning systems in 2010 were estimated at 20.5 million tonnes of CO₂ equivalents¹⁰. This is an increase from 2.3 million tonnes in 1995. In the case of mobile air conditioning systems, an increase from 1.4 million tonnes of CO₂ equivalents in 1995 to 20 million tonnes in 2010 was estimated¹¹. These two sources alone represent 41.3 per cent of the total emissions of fluorinated greenhouse gasses. In August 2003 the EC presented the so-called framework directive to regulate the emission of greenhouse gasses from stationary and mobile air conditioning systems.

More and more cars with mobile air conditioning systems are being produced. In the proposed framework directive of August 11th 2003 the EC (2003b) presents figures that specify emissions of HFC-134a. Based on studies undertaken by Ecole de Mines, Öko-Recherche and ECOFYS Energy and Environment, the EC estimates that emissions of HFC-134a from cars will, in the course of an estimated lifespan of 12 years, be between 1178 grammes (optimistic estimate) and 2391.3 grammes (pessimistic estimate). This is equivalent to between 1531.4 and 3108.7 kg of CO₂ equivalents¹². In addition, the operation of mobile air conditioning systems requires energy, which in turn entails increased CO₂ emissions from fuel consumption. The EC estimates that, without technological changes/improvements or new regulation, the total of emissions from greenhouse gasses due to use and operation of MAC inside the EU-area alone will be between 30.4 and 53.6 million tonnes of CO₂ equivalents in 2010, and between 52.3 and 89.6 million tonnes of CO₂ equivalents in 2020. A third of these emissions will come from increased energy consumption for operating the systems. The remaining two thirds represent direct emissions of HFC-134a as already referred to (EC 2003b).

1.2 Energy efficiency

New pilot studies show that CO₂ technology is more energy efficient than conventional technology¹³. Shecco technology works under far higher pressure than conventional air conditioning systems based on HFC-143a. This provides CO₂ technology with an output temperature of approximately 100 degrees Celsius, which opens more possibilities for utilisation than conventional HFC-based technology.

¹⁰ By comparison the combined emissions in Norway for 2003 totalled 56.5 million tonnes of CO₂ equivalents (Source: Statistics Norway; <http://www.ssb.no/emner/01/04/10/klimagassn/>. Accessed on October 11, 2004)

¹¹ More details can be found in Harnisch and Gluckman (2001).

¹² For further details on the status of the framework directive, see:

http://www.europa.eu.int/prelex/detail_dossier_real.cfm?CL=en&DosId=184911 (Accessed in mid-May, 2004)

¹³ <http://www.shecco.com/artikler/co2moreenergyefficientthanhfc.htm>. (Accessed on 11th May 2004).

1.2.1 Water heating

For example, very hot water can be produced for business and industry and domestic households in a much more energy efficient way. The diesel motors or fuel cells of the future¹⁴ will not be able to produce sufficient surplus heat to heat car interiors. This will create challenges, particularly in colder climates, which could give CO₂ technology new commercial advantages.

It was the energy efficient heating potential of CO₂ technology that attracted interest in Japan, where hot bath water is an essential part of the morning ritual. The use of CO₂-based heat pumps here provides a more efficient and faster solution, while at the same time requiring considerably less energy consumption. It is maintained that in Japan Shecco technology would require only $\frac{1}{6}$ of the running costs for conventional electric hot water heaters¹⁵.

1.2.2 Energy efficiency in MAC

In its work on the MAC directive, the EC stressed that there was uncertainty regarding the energy efficiency of CO₂ as a propellant/working fluid (EC 2003a). Shecco's response (dated 11th March 2003) pointed out that Shecco technology is better than HFC-134a under most conditions and that the energy efficiency would be considerably better if there was a requirement for heating devices in cars. Through R&D collaboration with the University of Illinois, USA, SINTEF was able to confirm that no technological weaknesses in the patented Shecco technology could be isolated and documented¹⁶. The challenges however, lie in the possibilities for this technology to seriously compete with the prevailing solutions that were acknowledged in the wake of the Montreal Protocol's phasing out of CFC gasses, though this represents more of a non-technological barrier, which we shall return to in Section 5.

1.2.3 Other possible gains

CO₂ is available in large volumes as a by-product from industry. Production of HFC-134a on the other hand occurs "synthetically", and is an energy-demanding process¹⁷. According to Marstrander, at the point

¹⁴ Toyota has installed an air conditioning system based on Shecco technology in some of its Prius models (hybrid cars) as part of a trial project. For more information see for example: <http://www.toyota.com/html/shop/vehicles/prius/> (Accessed in mid-April, 2003)

¹⁵ For more information see press release from Kyocera dated 17th March 2003 at: <http://global.kyocera.com/news/2003/0301.html> (Accessed in mid-April 2003.)

¹⁶ For a general discussion on HFC-134a, CO₂ and HFC-152a, see for example presentation by Armin Hafner (SINTEF) at: <http://www.epa.gov/cppd/Presentations/HafnerLCCP.pdf> or Stella Papasavva's presentation to the MAC Summit 2004 at: http://www.epa.gov/cppd/Presentations/Papasavva_per_cent20LCCP_per_cent20Comparison.pdf. See also John Rugh's discussion on Hafner and Papasavva's lectures from the SAE Automotive Alternate Refrigerant Systems Symposium, Scottsdale Arizona, 2004 at: <http://www.sae.org/events/aars/presentations/2004-rugh.pdf>. (All three sites accessed on 13th September 2004).

¹⁷ According to DuPont in an e-mail to ProSus dated June 3rd 2003, the energy consumption and environmental impact due to the manufacture of HFC-134a varies from country to country, but would result in emissions of around 8-10 kg of CO₂ equivalents. However, according to Petter Neks , Senior Research Scientist at SINTEF Energy Research, the manufacture of HFC-134a would result in emissions of approximately 77 kg of CO₂ for every kilo of HFC-134a manufactured.

in time when Lorentzen launched the innovation for Norsk Hydro there was no available operative capture technology for discarded products¹⁸. Recovery technology has since been developed and made commercially available, but destruction technology would be extremely energy-intensive. In order to split the atoms, the HFC gasses need to be heated up to approximately 1100 degrees Celsius and then rapidly be cooled down to approximately 400 degrees Celsius. This would entail an energy loss, as it is not possible to utilise the surplus energy in this process.

In the case of destruction, the decisive issue would be whether this would occur in processes that would have been carried out anyway, for example in the cement industry in Norway, or whether HFC would be destroyed in a separate process, as is the case in Japan. The Japanese producer, with whom ProSus has been in touch, uses neither surplus heat nor the various components of the refrigerants in other processes¹⁹. According to a representative for DuPont, this company uses processes that clean HFC-134a and send it back to the market again²⁰. The proportion that is recycled in this manner is however currently small in comparison to the amount of HFC being produced²¹.

1.3 Summary

Despite some scepticism regarding the energy efficiency of MAC, Shecco technology represents a new, more eco-efficient product concept. In the case of greenhouse gas emissions this is particularly linked to the use and disposal of mobile air conditioning systems. Even with modifications of conventional HFC technology, the EC points out that the combined emissions of greenhouse gasses are considerably higher than those from CO₂ technology (EC 2003a). The modified HFC solution reduces direct emissions compared with the baseline, by among other things preventing leakage, but indirect emissions remain almost unchanged throughout the whole life cycle.

The next chapter attempts to look closer at how, and in which arena, the advantages of Shecco technology can actually be identified. In accordance with the research methodology in the CondEcol project, we will in the next section take a closer look at relevant technological conditions. These relate to the Eco-design Wheel. In the light of the technical survey, we shall then look at different non-technical conditions,

¹⁸ This has since changed. Denso in Japan produces a series of technologies for recovering HFC and HCFC from MAC systems in Japan. Roughly "13,000 recycling and recovery systems for specified CFCs" are delivered to Denso's service stations and dealers. Approximately 7,000 of these can also handle CFC substitutes such as HFC-134a. Regarding the destruction of HFC, a representative for Teijin Fibers Ltd, one of the largest manufacturers of HFC in **Japan**, informed us that the company destroyed approximately 760 tonnes of HFCs in 2002 (e-mail to ProSus dated 19th May 2003). **Norway** has a well-run system for recovering toxic waste (refrigerators, etc) containing CFC/HCFC. The system also extends to the recovery of HFCs. The cooling media are sent to the Receiving Institute for Gas (SRG) which then forwards them to Norcem in Kjøpsvik, where CFC/HCFC is used in the production of cement. HFC is destroyed in the same process. As for cars, there is no equivalent system for recovery and destruction in Norway. But from January 1st 2003 a refundable tax on HFC was introduced (SFT 2001).

¹⁹ E-mail to Olav Mosvold Larsen at ProSus dated May 19, 2003.

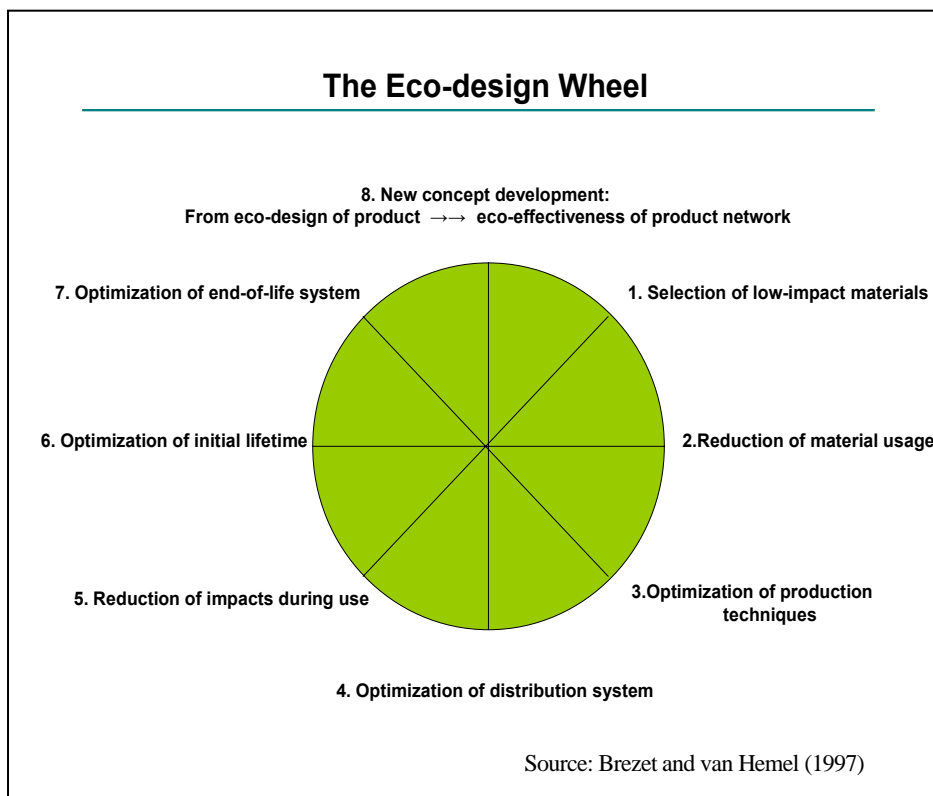
²⁰ Telephone interview with a DuPont representative June 3, 2003.

²¹ The proportion is apparently increasing rapidly, however. Neither can all the HFC be recycled by this process. If the HFC contains too much water, oil or similar, it must be destroyed (ibid).

including key actors who have impacted the product development of the patented CO₂ technology now being marketed under the Shecco name.

2 HOW CAN SHECCO TECHNOLOGY BE CHARACTERISED IN RELATION TO SPOKES 1-7 IN THE ECO-DESIGN WHEEL COMPARED WITH CONVENTIONAL TECHNOLOGY?

Shecco technology represents a new and more eco-efficient product concept reflected in the eighth spoke in the Eco-Design Wheel and substantiated in the previous chapter. Behind this new concept however, lies different technical dimensions that substantiate the possibilities to move from eco-design of individual products by way of increased eco-efficiency in product networks to system improvements with respect to both greenhouse gas emissions and energy efficiency. The MAC 2000 project was not, however, a commercial success given the time limits that were set. A closer look at individual technical conditions relating to Spokes 1-7 in the Eco-design Wheel may therefore also identify certain key actors and significant factors which at different stages have impacted the innovation journey, and hindered the commercial success of the patented CO₂ technology.



2.1 Spoke 1: Selection of Low-impact Materials

This spoke can be linked to the production and supply of materials and components that facilitate the production of Shecco technology. As pointed out in the previous section, the chemical production of HFC-134a is extremely energy demanding, both in relative and absolute terms. By using Shecco technology, the CO₂ from the ammonia and petrochemical industries could instead be reused, which would entail far lower energy consumption for CO₂ production in an applicable form (purity and pressure). It should also be added here that almost equally large units of volume (approximately 500 grammes) of CO₂ as HFC-134a are involved in a mobile air conditioning system. Once we know about estimated leakages and the relative difference in GWP, the selection of CO₂ as the working fluid would have a considerably smaller negative environmental impact. The climate advantage is obvious. This is also the basis for the EC proposal for the new framework directive (EC 2003b).

2.2 Spoke 2: Reduction of Material Usage

With respect to the reduction of material usage, there are differences between: 1) Shecco technology and conventional technology, and 2) use of Shecco technology in stationary versus mobile applications. Shecco technology could stimulate changes in material usage, but it is unclear whether this would result in a reduction of the total material usage.

1) The increased pressure in the Shecco technology requires stronger components, but this could be compensated for by smaller dimensions and volumes of piping, heat exchangers and compressors. In MAC applications the components used comprise almost exclusively the light metal aluminium. Compared with material requirements in conventional technology, the thermal properties of CO₂ could facilitate even further reductions in material usage in the future. At the present time the total weight of a MAC is practically the same, irrespective of choice of material.

2) In stationary applications introduced in Japan, copper components are used in tap water heat pumps to prevent corrosion and fouling. In a water heater that OSO Hotwater is experimenting with in Norway, stainless steel has been selected. This was also the choice for the system installed at A/S Eggprodukter in Larvik, Norway. The choice of stainless steel is a result of the suppliers' previous experience and references.

2.3 Spoke 3: Optimisation of Production Techniques

Apart from the fact that it is not necessary with primary production of CO₂ compared with the artificial production of HFC-134a - a factor which gives relatively lower energy consumption and production costs - there are no particularly relevant aspects of the Shecco technology with respect to optimising production techniques.

2.4 Spoke 4: Optimisation of the Distribution System

This spoke can be related to how the product is distributed to customers. Carrier Air Conditioning was concerned about the availability of CO₂ with respect to using Shecco technology, but later evaluations carried out by the company and other suppliers of stationary and mobile air conditioning systems indicate that this aspect does not represent any significant competitive shift with respect to conventional technology.

The US Army has for a long time been testing the technology in its High Mobility Multi-purpose Wheeled Vehicles (HMMWV). One of the main reasons for this interest is that CO₂ is cheaper and more easily available worldwide, a factor which would reduce the logistical burden. Generally speaking, CO₂ is widely distributed to restaurants, welding shops etc, and is therefore far more accessible than HFC-134a (Memory et al 2004).

2.5 Spoke 5: Reduction of Impact during Use

As suggested in the previous section in which Spoke 8 was presented, it is during actual use that Shecco technology has a clear advantage compared to conventional HFC technology. Given that the Shecco technology uses CO₂ from industry which otherwise would have been vented, leakage during use will have minimal global warming impact. This is not so in the case of HFC-134a, where greenhouse gas emissions during use are substantial. The EC estimates that the total greenhouse gas emissions from mobile air conditioning systems will increase from 1.4 million tonnes in 1995 to 20 million tonnes in 2010, measured in CO₂ equivalents, due to leakages during use and disposal (EC 2003a). The equivalent emissions from using Shecco technology would only be approximately 25,000 tonnes, though there is disagreement about the actual volume of the leakages. This could vary from one make of car to another (Horrocks and Vainio, 2004).

According to representatives for Toyota Norway, emission of HFC-134a from systems in cars is almost non-existent. The systems produced by Denso are supposed to be maintenance-free, and no leakages have been reported from the new systems. This, however, is disputed by a DuPont representative with whom ProSus has been in contact. He acknowledges that there are leakages during use²². Relevant figures for MAC based on material published by the EC give two different estimates, as referred to in the previous section (EC 2003a).

As mentioned in the previous section, there is also an energy efficiency potential in using Shecco technology compared with conventional technology, although generalisation is impossible. Even for hot water, this will vary according to boundary conditions such as how much hot water is needed and the temperature of the heat source. This can be referred to as the coefficient of performance (COP). The heat source in the system at A/S Eggprodukter in Larvik has a relatively high temperature. Therefore the evaporation temperature is high and the corresponding temperature increase is low. The COP is therefore

²² Telephone interview June 3, 2003.

very good because there is a high ratio between input of primary energy and the hot water supplied by the system²³. The most important variable is the outside temperature. CO₂ technology works best at temperatures up to 35 degrees Celsius and not as well as HFC at higher temperatures. In the case of mobile systems, tests carried out at the University of Illinois show significant gains compared to conventional technology. This, however, has been contested by car manufacturers and suppliers of conventional systems based on HFC-134a (Papasavva et al 2004).

With regard to the energy efficiency potential for Shecco technology, it appears that the CO₂-based heat pump used by A/S Eggprodukter consumes roughly $\frac{1}{5}$ of the electricity used by electric heaters. If one uses Norway as an illustration, it has been suggested that if all water were heated with the help of Shecco technology, the saving would be roughly 7 TWh per year²⁴. By comparison, the goal of ENOVA (a public enterprise owned by the Royal Norwegian Ministry of Petroleum and Energy) is to save 10 TWh by the year 2010²⁵.

2.6 Spoke 6: Optimisation of Initial Lifetime

There are no apparent differences between Shecco and conventional technology on this dimension.

2.7 Spoke 7: Optimisation of End-of-life System

Great opportunities for optimisation exist here by using Shecco technology. Even if an efficient system for recycling and destruction of HFC is developed, GHG emissions would still be created during recovery for later disposal due to the high amount of energy needed in the destruction process. If this were combined with some degree of leakage from recovery technology (connecting apparatus for service, the residue left in the tube after filling/bleeding, etc), the positive environmental impact linked to handling CO₂ as opposed to HFC-134a should be relatively greater. This is significant because even small amounts of HFC-134a have a significant global warming impact, something which is also underlined by the EC in connection with developing the framework directive. Here it is suggested that the maximum amount of emissions generated could be about 3108.7 kg in CO₂ equivalents. 556.8 kg of this would be generated through disposal. This accounts for 17.9 per cent of the expected maximum total of emissions during the car's expected lifetime of 12 years (EC 2003a).

²³ This information is based on input from Petter Neksa, Senior Research Scientist, SINTEF Energy Research who, together with colleagues and Jostein Pettersen in particular, has to a large degree contributed to the technical development of the CO₂ technology.

²⁴ Given an annual consumption for the heating of buildings of 58 TWh, and given that 10-15 per cent of the energy goes to heating of tap water. E-mail from Petter Neksa, SINTEF/NTNU to ProSus March 15, 2004.

²⁵ Energy conservation and transition to renewable energy. See also Gemini (2003).

2.8 Summary

Greenhouse gas emissions are created as a result of recycling and disposal with HFC technology, though these are not nearly as large as the emissions resulting from usage. This is linked to applications that are also important for understanding the direction of Shecco's innovation journey. At the same time we have mentioned the energy efficiency of Shecco technology compared to conventional solutions. This applies both to stationary and mobile solutions, and to both heating and cooling. However, if we really want to understand the direction of the innovation journey, we must move away from the technical surveys and comparisons with conventional technology and take a look at the various non-technical conditions. This will be done in the next section, but before that we will document more systematically – in accordance with the research protocol for the CondEcol project (see Appendix 1) - the main reasons for Norsk Hydro's decision to develop and market the innovation that is today known as Shecco. This is also important because shifts in strategic evaluations made over time can be important in understanding the progression of the innovation journey up to today's licensing orientation towards wider application of the Shecco patents.

3 WHAT WERE THE MAIN REASONS FOR THE COMPANY'S DECISION TO DEVELOP AND MARKET THE INNOVATION?

As is evident from the technical presentation, great ecological gains exist in the application of CO₂ technology. The environmental quality of the gas in comparison to HFC was also the main reason for Norsk Hydro's initial interest in the innovation. This fitted in well with the strong environmental profile that Norsk Hydro was developing at that time. Related to this was the awareness of a possible commercial potential to increase the sale of Norsk Hydro's aluminium products as a result of CO₂ technology becoming more widespread. This was particularly the case in relation to relevant tubing solutions for aluminium in heat exchangers. Hydro also assessed that significant potential revenues existed in the sale of patent licenses in connection with the technology later known under the name of Shecco.

3.1 Ecology as the main reason

The Montreal Protocol showed an example of how to solve a serious environmental problem as destruction of the stratospheric ozone layer has been reversed. CFC gasses have been replaced by HFC gasses without any negative impact on the ozone layer. However, leakage due to the use and disposal of HFC gasses represents a global warming problem. CO₂ technology could solve this dilemma, and Rolf Marstrander²⁶ is convinced that Hydro's final decision to respond positively to Lorentzen's approach stemmed from the ecology corner in Figure 1 below.

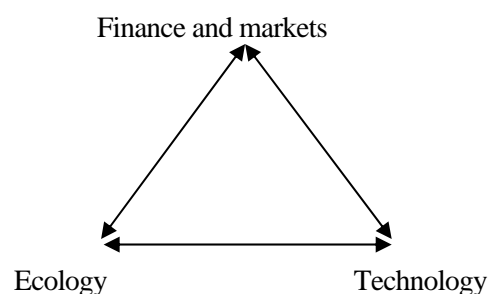


Figure 1: The triangle for corporate decision-making for ecological innovations

It should however be emphasised that although ecological considerations may have served as a basis, these had to be closely linked to financial and technological considerations. Independent of the ecological

²⁶ Former Senior Vice President for Health, Environment and Safety at Norsk Hydro and Senior Vice President at Hydro Aluminium in an interview on 11th November 2002.

potential, it was necessary to assess whether further development of the innovation was financially feasible and technologically possible. One can then imagine that the energy efficiency potential became much more important than greenhouse gas emissions, at least until an efficient regulatory regime for handling and pricing greenhouse gas emissions was implemented.

The challenge was to initiate a shift in the sense that the initiators would move towards the finance/technology axis shown in Figure 1. Norsk Hydro believed that this was absolutely possible, given what CO₂ technology represented in purely technical terms. The name MAC 2000 was adopted because the commercial realisation of MAC in the market was anticipated by the year 2000. These assessments were made at a time when Hydro was consolidating its general environmental efforts. However, relative improvements in financial parameters such as energy efficiency are important, more or less independent of isolated ecological gains.

3.2 Hydro's environmental profile and industrial priorities

Marstrander emphasises that Hydro's support of the project had to do with the company's environmental profile, which had been systematically developed since the mid-eighties. Already in 1990, Norsk Hydro published its first environmental report, and was one of the first companies in the world to do so (Gjølberg and Meling 2004). It is interesting in this connection to note that when Professor Gustav Lorentzen approached Norsk Hydro and told them: "I have a patent that can remove the gasses that are currently being discussed under the Montreal Protocol," he was *not* initially welcomed with open arms. This was due to the corporate management's opinion that it was not immediately clear as to how Norsk Hydro should find a "home" for this activity. Hydrogas, a large supplier of, among other things, CO₂, and therefore a relevant partner in the discussions, found it of little interest because of the small volumes.

The aluminium division, however, did find the technology interesting. Partly because it had an environmental potential, but also because of Hydro's role as a manufacturer of aluminum piping for, among other things, air conditioning systems for cars. According to Marstrander, Hydro Aluminium said: "Yes, ecology is and will be important", but internally they also said: "We are already involved in the technology that can translate his patent into an industrial reality that is techno-economically feasible".

3.3 Expectations for increased license revenues

It was the expectations for the license revenues alone which drove the innovation forward, but this first happened when the project was transferred to Hydro's wholly-owned subsidiary Hydro Pronova in 1998. Hydro Pronova's task was to take care of the diversity of ideas developed at Hydro, to provide the necessary help at the inception stage, and to develop defined projects for commercialising.

This is the current status, to which we shall revert to in the concluding section. First, however, let us attempt to comprehend the innovation journey in a more systematic way. We will start out by presenting the

key actors who have influenced the product development up to the point when Hydro Pronova had to realise the potentials of the Shecco technology.

4 WHICH KEY ACTORS HAVE INFLUENCED THE PRODUCT DEVELOPMENT?

In this section we will highlight some of the important key actors who have influenced the innovation journey for Shecco's CO₂ technology. We have opted to delimit the focus to key actors who were associated with: a) technology and manufacture; b) the market; c) financing; d) regulatory bodies; and e) cultural and social organisation.

4.1 a) Technology and manufacture

Marstrander stresses that once the stopwatch was started, i.e. after registering the four basic patents during the period 1989-92 and the product development was no longer a secret, the most important task became to forge as many alliances as possible. This entailed forging:

- 1) **technical alliances** to develop the technology, testing and test production.
- 2) **commercial alliances** (we will return to this point in Section 4.2).

Technical alliances with sections of the car industry were developed. An emphasis was placed on building a "rival" network in a global perspective, concentrating on USA, Japan and Europe. To begin with the collaboration was restricted to air conditioning systems in cars, and SINTEF signed a project agreement with Denso, a supplier of automotive technology, systems and components, in 1994²⁷. Denso is a part of the Toyota group of companies and, with its 80,000 employees, is a prominent actor in the production of components and parts for the car industry. This initiated a technical collaboration with SINTEF, and Denso has emerged as a key actor in the innovation journey of Shecco technology. Also in 1994, several European car manufacturers, including DaimlerBenz and Volkswagen, took the initiative of entering into a research and development collaboration, supported by the EC, under the name of RACE (Refrigeration and Automotive Climate Systems under Environmental Aspects). The EC supported this R&D consortium through its industrial and material technology programme, and this became relevant for Hydro, since the focus soon settled on CO₂ as a possible alternative working fluid for use in air conditioning systems in cars. Hydro did not however participate in RACE, because the company's lawyers decided that such collaboration might entail Norsk Hydro losing the head start it had gained as owner of the patents. At the same time RACE was to represent a challenge because DaimlerBenz in particular had developed heat exchangers at its research centre in Stuttgart according to the specifications in the system patent which Hydro and Gustav Lorentzen had been awarded in 1993. Jürgen Wertebach from Daimler-Benz was a central figure in the

²⁷ For more details about the company see: <http://www.denso.co.jp/en> or <http://www.globaldenso.com/en/>. (Both accessed on 10th May 2004).

initial phase and, as in the case of Denso, is still important in the current development work. Denso and Daimler's experiences during the period 1994–2000, however, were quite different. Whereas Denso sought closer collaboration with SINTEF and Norsk Hydro on stationary applications too, DaimlerBenz tried to develop the CO₂ technology within the RACE project without entering into a license cooperation with SINTEF and Norsk Hydro. This situation has since been cleared up to Shecco's advantage, something we will return to later.

Concurrent with the work on mobile air conditioning systems, alternatives for more stationary applications of the technology were developed, for both stationary refrigeration and air conditioning (RAC) systems and for heat pumps. Once Petter Nekså had completed his doctorate on the use of CO₂ technology in hot water heat pumps, SINTEF received financing from the Research Council of Norway (RCN) to make a prototype in collaboration with the Norwegian refrigeration group Finsam, of which Frostmann is a subsidiary. The prototype was completed at SINTEF Gløshaugen in 1995/96. A state-financed R&D contract between SINTEF, Frostmann/Finsam, SND (current part of Innovation Norway) and NVE (The Norwegian Water Resources and Energy Directorate) resulted in the first tap water heat pump being installed at A/S Eggprodukter in Larvik in 1999 (Gemini 2001). Denso was not involved in this project, but worked concurrently on developing Shecco technology for full application in tap water heat pumps in Japan.

Around 1995 Hydro was, according to Marstrander, partially aware that network constellations linked to developing the CO₂ technology were extremely important. At the same time, Hydro was totally dependent on SINTEF's technical expertise. Marstrander says that the first patent would not have been granted had it not been for the work that Jostein Petterson in particular had put in²⁸. Petter Nekså, who later became leader for that area of research, was also very active in developing the technical networks. The patent applications met considerable opposition, however, both in Europe and USA.

Since 1996 Obrist Engineering in Austria²⁹ has been one of the leading developers of components for MAC without being directly connected to the car industry. The work done there attracts attention and, combined with the work carried out at the University of Illinois³⁰, can probably be characterised as representing the cutting edge of the research being done on MAC. With respect to the warming potential of the technology and its applications in cars, Modine³¹, USA, appears to be way ahead. Thus the technical alliances that were initiated in the beginning of the 1990's are still constantly growing, and this can prove to be decisive on the way towards commercialising Shecco technology in MAC.

²⁸ Formally speaking it is SINVENT in Trondheim who owns the patent, but an agreement with Norsk Hydro on global exclusive rights to its commercial application has been signed. Net revenues from the patent shall be divided equally between the two parties.

²⁹ See: <http://www.obrist.at>. (Accessed on 11th May 2004). The presentation given by Frank Wolf at the MAC Summit 2004 is available at: http://www.epa.gov/cppd/Presentations/Wolf_per_cent20Development.pdf. (Accessed on 9th June 2004).

³⁰ The Air Conditioning and Refrigeration Center (ACRC) at the University of Illinois, Urbana. URL: <http://acrc.mie.uiuc.edu/>. (Accessed on 13th October 2004).

³¹ <http://www.modine.com/> (Accessed on 11th May 2004). Presentation given by Steve Memory at the MAC Summit 2004 is available here: http://www.epa.gov/cppd/Presentations/Memory_per_cent20SUV_per_cent20CO2.pdf (Accessed on 9th June 2004).

As already mentioned, Denso has had an important role in the development of the tap water heat pumps that are now commercialised in Japan. Denso had contact with SINTEF during 1994-97, but then everything went quiet for a long period of time. We do not have in-depth knowledge of the technology development going on internally at Denso, but it is clear that Denso had never before produced technology for markets outside of the car industry. Furthermore, it is clear that the company used heat exchangers and compressors from the car segment in the development of tap water heat pumps. Contact between Shecco and Denso was re-established in 1999, and a license agreement was signed in 2000. Denso later sub-licensed its technology to use for hot water for companies like Sanyo and Daikin.

4.2 b) The market and the patenting challenge

Marstrander stresses that one had to make a commercial construction with which Hydro could guarantee access to the CO₂ technology. At the same time one had to impart that the company did not wish to abuse the knowledge it had acquired about the purchaser's interest in the use of that technology. The focus on piping and the industrial considerations which Hydro Aluminium had used as a basis were therefore pushed into the background. By so doing, one avoided any internal conflicts of interest within Norsk Hydro between the different markets one wished to serve. It was also agreed that SINTEF³² should act as an advisor, explaining to customers and other commercially interested parties what the technology was actually about in practice.

In parallel with this, Hydro entered into a cooperation agreement with other actors, and the letter of intent with Denso was signed as early as in 1994. An initiative was also taken within the RACE collaboration, but no genuine license agreements were entered into until after the turn of the millenium. From 1999 the commercial development of Shecco and entering into of license/user agreements was totally handed over to Hydro Pronova.

Inspired by RACE, which incidentally Hydro opted to stay out of because of the ownership situation with respect to the patented Shecco technology, efforts were concentrated on air conditioning systems in the car sector, so-called MAC. It should be noted here that, at the point in time when RACE was established, the phasing out of CFC-12 as a working fluid in favour of HFC-134a was almost completely accomplished in Europe. The demand for CO₂ technology had to be created entirely by Hydro in close cooperation with SINTEF. The forging of alliances became therefore important.

From the time when the first initiatives at building alliances were taken in 1994, the focus was placed on USA. Ford in particular became an important collaborator in this early phase, and made its best test car available for a test rig based on MAC. A MAC programme was carried out at the University of Illinois

³² Norsk Hydro has for many years collaborated extensively with SINTEF, and has been one of SINTEF's best clients. Nonetheless it should be pointed out here that Lorentzen had had no previous contact with Norsk Hydro. The cooperation between Norsk Hydro and SINTEF over Shecco cannot therefore be viewed as a direct continuation of the extensive collaboration that had gone on in Norsk Hydro's core activities within light metal, oil, petrochemicals and natural gas.

during the period 1996-98, with a Ford system as the point of reference. The project was wholly financed by Hydro, but with Ford as co-evaluator (see also Section 4.3).

Apart from the fact that DaimlerBenz tried to develop technology that would circumvent Hydro's patents, there have been no eco-design competitors. DaimlerBenz' work on CO₂ as a working fluid has, however, been described in the book *Industry Genius. Inventions and People Protecting the Climate and Fragile Ozone Layer*, written by Stephen O. Andersen and Durwood Zaelke. The book was published in the summer of 2003. In Chapter 3 we find "DaimlerChrysler: The champagne of natural refrigerants" In this chapter a footnote is entered regarding US patent # 5.245.836, awarded to Gustav Lorentzen and Roar S. Bang on 21st September 1993, entitled "Method and Device for High-Side Pressure Regulation in Transcritical Vapor Compression Cycle". This was the decisive CO₂ patent. It is also interesting to note what the authors add in the same footnote: "Other methods, already in the public domain or patented by DaimlerChrysler and others, may achieve the same performance". (Andersen and Zaelke, 2003:59). We sense the contours of powerful networks, exemplified by RACE, in which Norsk Hydro opted not to participate. But at the same time openings were created for Hydro Pronova and Shecco, particularly in Japan; a situation which stimulated continued commercialising.

The RACE collaboration project was developed without any influence from Hydro and SINTEF but, if we take a closer look at what happened in Europe, Hydro got to participate as an industrial sponsor in the COHEPS projects³³ through the EUREKA cooperation. This project opened for new application possibilities for the Shecco technology. COHEPS I demonstrated the potential of CO₂ within four areas: 1) heat pump water heaters for commercial applications, for which SINTEF had the technical responsibility; 2) heat pump driers for laundries, for which the University of Essen had responsibility; 3) heat pumps for retrofitting high temperature hydronic heating systems, with particular focus on radiators in Germany, where FKW Hannover had responsibility; and 4) CO₂ heat pumps for air heating systems in residential buildings, for which the University of Graz had responsibility. In COHEPS II the first three were tested in the field, and A/S Eggprodukter in Larvik became the test case for the project for which SINTEF and Petter Neksa had responsibility. This project was aimed at the heating of tap water. At this point in time SINTEF had a good collaboration with Denso.

Also at this time attempts were made to take out other related patents, e.g. for a container that could both hold CO₂ under high pressure and function as a fire extinguisher in the engine room, but DaimlerBenz had already taken out a patent for this. The reason why both were granted patents was that the one system used the liquid phase (SINTEF/Norsk Hydro) whereas the other used the gas phase (DaimlerBenz), a fact that illustrates how market dynamics must to a great extent be linked to the patenting processes.

Also, in 1995, a cooperation agreement was signed by Hydro's piping customers. This happened for among other reasons because Hydro's customers began to ask: "Are you about to produce heat exchangers in

³³ The EUREKA cooperation is a pan-European network for market oriented industrial R&D, initiated by the EU. For more information see: <http://www.eureka.be/>.

competition with us?" This thought had probably crossed the minds of certain internal actors, and it was also a relevant point of reference when Hydro Aluminium "inherited" the question from Gustav Lorentzen. It soon became clear that this was not Hydro's intention. There was little internal interest in promoting the development of more integrated solutions aimed at heat exchangers, especially when the light metals division was reorganised into Hydro Aluminium Extrusion (HAEX) and Hydro Aluminium Metal Products (HAMP) in 1996 (see also Section 5.3). Hydro's intention was rather to continue to be the piping supplier it always had been. At the same time, potential new markets for CO₂ technology were investigated and questions were raised as to whether there were components linked to Shecco technology which Norsk Hydro did not produce, or if they instead should further develop the system thinking and solution that Shecco technology represented in cooperation with other manufacturers? Hydro Pronova's takeover of Shecco led to the latter option being chosen.

4.3 c) Financing of the project (defined as the technological development)

During the 1990's Norsk Hydro put as much as 6-7 million annually into the project. This was done to promote the idea, as well as to sustain a technology base in Trondheim, and also to look at possibilities for developing better piping at Hydro's own research centre. It gradually became important to separate the industrial priorities on the pipe development side from the subsequent commercial development undertaken by Hydro Pronova. During the period 1996-98 resources were also used to set up a project at the Air Conditioning and Refrigeration Center (ACRC) at the University of Illinois. This initiative was taken both to create an increase in demand in the USA and to consolidate technical user competence. As already mentioned, Ford was co-evaluator here, and the project proved to be decisive in subsequent dialogue with the EC on the development of the MAC framework directive presented in 2003.

Once Norsk Hydro had formed a US-based R&D network in close collaboration with Ford, DaimlerChrysler and Jürgen Wertenbach subsequently joined in with large resources. Daimler and Toyota spent some money on SINTEF in cooperation with Jostein Pettersen and Petter Nekså. In addition, Ford spent quite a lot of money in its own laboratories and at the University of Illinois on developing the technology. It gradually emerged that both Toyota and Mercedes had appointed enormous in-house staffs to develop the technology. By spending this money at the University of Illinois as Norsk Hydro had decided to do, a network-based dynamic emerged, something which led to the overall commitment to developing new CO₂-based products being substantially strengthened.

Despite a lack of dialogue internally in the RACE consortium, Norsk Hydro still managed to attract Daimler's interest through self-financing. Norsk Hydro received no direct state aid for financing the Shecco project. In relation to the NOK 500 million spent annually by Norsk Hydro's aluminium division on R&D, approximately NOK 35 million per year came from the Norwegian Research Council (RCN). Norsk Hydro did not, however, approach RCN for direct financing (it was SINTEF who fronted RCN), although Norsk Hydro's financing does seem clearly to have motivated RCN's attitude. We can refer here to "fresh" resource

funds of NOK 35 million from RCN that were transferred to Norsk Hydro's own research network, primarily at NTNU/SINTEF. One can thereby see a kind of indirect state financing as a direct consequence of the company's own financing. How much of this went to Shecco is however uncertain as long as this was oriented towards aluminium and aluminium applications, primarily linked to pipe development and traditional industrial applications undertaken by Hydro Aluminium. The resources that were used on developing the Shecco technology were entered under other items, and this became apparent when Hydro Pronova took over responsibility in 1998.

In 2002 a new project was initiated under the KMB programme³⁴. The primary goal was to test new applications of CO₂ technology as well as to educate two or three doctors of engineering. The project has an annual budget of NOK 2.5 million over four years, and was co-financed by RCN (60 per cent) and Shecco (40 per cent).

According to Per Døvre at the Norwegian Pollution Control Authority (SFT)³⁵, there were in fact resources available for demonstration projects through SFT's programme for environmental technology during the period 1991-1998. The project management at SFT were aware of the work being done on CO₂ technology, but never received an application from Norsk Hydro.

Some state financing was however linked to the system that was established at A/S Eggentraler in 1999. The system established there was partly financed by the company itself (which invested as much as a conventional system would have cost) and a state-financed research and educational contract between Frostmann, NVE and SND. It was also partly linked to an EC project. There was no connection between Denso and A/S Eggentraler.

4.4 d) Regulatory bodies

Norsk Hydro made three major approaches to "regulatory bodies":

- 1) The Norwegian Ministry of the Environment ;
- 2) the US Environmental Protection Agency (US EPA);
- 3) the EU.

So far, however, these approaches have led to very few directly relevant results. This being said, the dialogue with the EU on preparation of the framework directive has given rise to new expectations for an increased market potential for Shecco technology in MAC systems.

4.4.1 Norwegian authorities: the Ministry of the Environment, the Ministry of Trade and Industry and the Norwegian Export Council.

Norsk Hydro used a lot of time on the Ministry of the Environment (MD) because it was reasoned that, as the regulatory body, this ministry should to be able to influence the progression of the development of

³⁴ Kompetanseprosjekter med brukermedvirkning (Competence Projects with User Participation).

³⁵ Statement made at a meeting at the Ministry of the Environment, May 5th 2004.

CO₂ technology, particularly with respect to cars. Marstrander, Kolrud and Hurlen had a meeting with the then Minister of the Environment Thorbjørn Berntsen in 1996³⁶. Berntsen found this very interesting and said he would take the matter up with his German Minister of Environment. Norsk Hydro's intention with the meeting was to inform the minister on the environmental political opportunities that the Shecco technology represented, and hoping that political backing could create new cooperation partners in Germany, despite the RACE consortium's negative attitude to Norsk Hydro's ownership of all the relevant patents. However, Norsk Hydro never received any concrete feedback from MD, and there has since then been no formal contact between Norsk Hydro and MD regarding Shecco technology. There has been no contact with MD, nor support from other relevant national authorities, in connection with the project that was tested at A/S Eggprodukter in Larvik. There was no contact between Norsk Hydro – regarding Shecco – and those responsible for innovation policy, industrial policy or export subsidy schemes run by the Ministry of Trade and Industry either. At the same time Norsk Hydro took steps to strengthen its representation in Japan, and paved the way for partial financing when Svein Grandum was appointed Trade and Industry Attaché in 2001. This has little significance for technology development, but the resource was important for monitoring licenses that had been granted.

4.4.2 US Environmental Protection Agency (US EPA)

The other, much heavier, actor with whom Norsk Hydro attempted to consolidate a dialogue was the US Environmental Protection Agency (US EPA). When it was decided to consolidate technological cooperation with the ACRC at the University of Illinois, this was not done solely to improve the cooperation with Ford. It was known that the US EPA was also very interested in the R&D activity being carried out there. Already at an early stage, however, the US EPA made it clear that American authorities would not go in for measures that could promote the use of Shecco technology. At the same time the US EPA was a co-evaluator in the Illinois project, though it was not a financial contributor. It should be noted here that DuPont's technological development of HFC gasses was an important premise for the Montreal Protocol agreement. This is pure speculation, but there could be grounds for suggesting that US EPA's reticence towards Shecco technology could be related to the fact that the American authorities did not want to challenge an international environmental regime that provided important commercial opportunities for national suppliers of HFC-134a, DuPont in particular. In this context the handling of greenhouse gas emissions and the obligations with respect to the Kyoto Protocol were given less weight.

4.4.3 The Japanese authorities

Apart from the negotiations concerning the patents, Norsk Hydro did not approach the Japanese authorities. It chose instead to enter into direct licensing negotiations with those companies who wished to

³⁶ Thorbjørn Berntsen was Minister of the Environment for the Brundtland government, from November 3rd 1990 to October 25th 1996.

use the technology in their products. It is interesting to note here that the Japanese authorities employed measures that may have had a positive influence on the launching of the tap water heat pump developed by Denso on the basic license from Hydro Pronova. Investment aid schemes entail a cost reduction for consumers of approximately 35,000 yen, which is equivalent to approximately NOK 2,000. This amounts to approximately 15-20 per cent of the costs. This is scaled down, and the consumers eventually have to cover all the costs. But it could function as an instrument for increasing the application of Shecco technology.

4.4.4 Contact with the EU was also eventually established

Based on Norsk Hydro's experience with RACE, the company chose at first not to approach the EU. Under the Kyoto Protocol of 1997, the EU has also made commitments. In concrete terms, EU must reduce greenhouse gas emissions by 8 per cent of the 1990 level within the period 2008-2012. In 2000 a working group that was to evaluate measures for reducing HFC emissions from cars was set up. This group recommended drawing up a joint legislation for the EU – a MAC directive – which was subsequently included in the proposed framework directive. Active dialogue in this connection took place between Hydro Pronova – particularly Kjell Stansstadvold – and the relevant EU point of contact, Matti Vainio. A draft directive was presented on 11th August 2003.

Although the result of the European Parliament's first ballot was rather discouraging, the MAC Summit in February 2003 opened for renewed activity vis-à-vis political agencies. In her opening speech at the MAC summit EU Environmental Commissioner Margot Wallström³⁷ said: "It is no secret that we are seriously considering phasing out hydrofluorocarbons from mobile air conditioning," but that the industry would be consulted on this. In the consultation paper that was prepared for the MAC summit in February 2003 (EC 2003a:9-15) several alternatives for reducing emissions of greenhouse gasses from MAC systems were discussed, such as: a) improving existing technology; b) introducing technology based on hydrocarbons; c) HFC-152a; and d) CO₂. Some EU member countries, including Austria, have already taken steps to set restrictions on the use of HFC in air conditioning systems from 2008, but the proposal for regulations in Article 95 gives the individual countries few opportunities to promote pro-active efforts beyond any resolutions made by the EU.

When the framework directive will come into force is still uncertain, but phasing out conventional HFC-based technology will probably not take place until after 2009, and the EU is not set to prohibit the use of HFC gasses in mobile air conditioning systems before 2014. There is nothing to be done here but await the final administrative processing by the EU. The first proposal has been voted on in the European Parliament, with many proposals for amendments, and a common position from the European Council is awaited before a second reading and final decision, probably during the first half of 2005.

³⁷ Introduction to the MAC Summit, Brussels, 10th-11th March 2003. The full speech is available at: <http://europa.eu.int/comm/environment/air/mac2003/pdf/wallstrom.pdf> (Accessed at beginning of June 2003).

Correlating with our technical survey, the European Commission states that an introduction of Shecco technology would eliminate greenhouse gas emissions and that the energy consumption required to produce the working fluid would be small. It also states, however, that there is still uncertainty concerning the energy efficiency of CO₂ as a propellant, and that introducing this technology would be rather expensive, but affordable. This brings us to future challenges associated with political regulation, something we shall return to in the conclusion. This was also emphasised by the car industry and other advocates of conventional technology, and was also conveyed by Erin Birgfeld from US EPA during the winter meeting in Saalfelden, Austria in February 2004³⁸.

4.5 e) Cultural and social organisation

According to Marstrander one can go as far as saying that cultural and social key actors outside the company do not exist in this technological world. Greenpeace did however, request Norsk Hydro's involvement in part of its work to promote the achievement of the targets set out in the Montreal Protocol; a CFC-free refrigerator based on propane, known as the Greenfreeze Project. Eagerness was expressed both on the research level and higher up in the Norsk Hydro system, that Marstrander should strengthen collaboration with Greenpeace. Nevertheless, such collaboration never materialised. According to Marstrander, a possible introduction of Greenfreeze funded by Norsk Hydro would have placed the company in a difficult position with respect to the car industry and other commercial actors³⁹.

Marstrander's general experience is that once one comes down to the level of individual products, one has moved away from the area in which cultural and social key actors play any role. Shecco, however, is not a product, but a concept. Cooperation with NGOs may for this reason be possible. As Marstrander mentioned, the real problem is in the relationship between the NGOs and the car manufacturers. Nevertheless, no cultural or social actor has actively influenced the product development of Shecco.

4.6 Summary

The key actors in the product development of the Shecco technology are to be found internally at Norsk Hydro, at SINTEF/NTNU, and within the technical alliances/networks that were developed with the car industry after the patents were applied for. With respect to SINTEF/NTNU it is clear that people such as

³⁸ The material from the winter meeting [was disseminated by Shecco](#).

³⁹ According to Tarjei Haaland at Greenpeace, Denmark (telephone conversation on 26th February 2004), Greenfreeze ended up with hydrocarbons as the working fluid, and the technology is today widespread throughout Europe and parts of Asia. According to Siemens/Bosch in Norway (telephone conversation with a representative from their Sales Division, 26th February 2004) 99.9 per cent of all refrigerators sold by them to the domestic market today are run on isobutane. This tallies with figures from Denmark, where 81 per cent of all refrigerators in Energy Class A on sale in 2000 were based on Greenfreeze technology. Since the launching of Greenfreeze in 1992, 55 million refrigerators with this technology have been sold. As at 2002 the annual production of refrigerators with this environmentally friendly technology was approximately 15 million.

Jostein Pettersen and Petter Neksa have been instrumental from the first phase of the product development and up to the present day. Internally at Norsk Hydro it was Dag Flaa, Rolf Marstrander, Jakob Kolrud and later Jan Hurlen who were immensely important to keeping the project moving forward in the first phase. The important actors at present are Kjell Stenstadvold and Jan Hurlen.

With respect to MAC, the technical networks have been invaluable. Together with the contacts that were established at ACRC at the University of Illinois, people such as Jürgen Wertenbach have been important. Research and development in the field has gradually expanded and there is reason to believe that most car manufacturers are now carrying out significant R&D work internally. When it comes to MAC, Obrist Engineering is at the forefront with respect to applying the technology, while Modine and others are way ahead with respect to technology for car heating. On the tap water heating side, certain personnel at Denso have been important, but the process here has been far more closed, and we do not have sufficient information about the progression.

Otherwise it is interesting to note that it was Norsk Hydro itself that came up with the investments necessary for taking out the patent worldwide and who also initiated the activity at ACRC. In addition, the RACE project, and subsequently the COHEPS projects, contributed to significant technological developments. Governmental authorities were not involved, neither in Norway nor USA, but it is clear that the Japanese authorities' subsidising of EcoCute was necessary for introducing it to the Japanese market, and that the forthcoming EU regulations will prove decisive for the introduction of MAC with Shecco technology to the market.

SINTEF/Norsk Hydro/Shecco have been the forerunners in the concept development, while industry (equipment manufacturers) has been at the forefront of the product development. The challenge for Shecco has been, and still is, to be motivator behind and integrator between, concept development and product development.

5 WHAT HAVE BEEN THE MOST SIGNIFICANT FACTORS, BOTH POSITIVE AND NEGATIVE, THAT HAVE INFLUENCED THE INNOVATION JOURNEY SO FAR?

We have now carried out a survey on the techno-ecological advantages of the CO₂ technology compared with the use of HFC gasses as the working fluid in heat exchangers used in air conditioning systems and tap water heat pumps. We have also ascertained that these advantages were the main reason for Norsk Hydro's decision to support further project development. At the same time we have stressed that ecology must be linked to more traditional economic evaluations. In the preceding section we have identified some of the key actors in the innovation journey towards the technology we know today as Shecco. These persons and institutions are associated with technology development and commercialising, financing, various regulatory bodies and social and cultural organisation. The question is whether a strengthened cooperation with individual key actors could create problems with respect to Norsk Hydro's existing and potential customers. In accordance with the CondEcol research protocol, we will now take a closer look at this issue by looking at the significant factors, both positive and negative, that have influenced the innovation journey up to the present day.

5.1 a) Input factors: Concrete supplier constellations

By input factors we mean concrete external supplier constellations that can influence the technology development. It could be imagined that the supply of CO₂ could have been provided and potentially influenced by external interests, but Norsk Hydro has not used any external suppliers in connection with Shecco. The CO₂ was supplied from Norsk Hydro's own ammonia and petrochemical operations. The piping problem was pushed into the background and, under Hydro Pronova's direction, concentration was centred on developing the system patents that the Shecco technology represents. None of the market suppliers of heat pump equipment have been motivators during the course of the innovation journey. It was actually Norsk Hydro who approached suppliers of heat exchangers, such as Danfoss, in order to create an increase in the demand for Shecco technology. Different measures were taken here and, in the case of MAC, there was close cooperation with SINTEF and the R&D-based technical network closely associated with ACRC at the University of Illinois in Urbana. In the case of the tap water heat pumps, the orientation was directed more towards Japan and in close cooperation with Denso.

SINTEF can be said to be a supplier of know-how and an important motivator. This evolved in connection with the patent specifications and a running dialogue with Norsk Hydro. Supplier constellations are important, but mostly so with respect to conventional technology and supplies of HFC-134a.

5.2 b) Technology and manufacture: a few, but major, hindrances to MAC

In its work on the MAC directive, the EC stressed that there was uncertainty regarding the energy efficiency of CO₂ as a propellant/working fluid (EC 2003a). Shecco's response (dated March 11th 2003) pointed out that Shecco technology is better than HFC-134a under most conditions and that the energy efficiency would be considerably better if there were a requirement for heating devices in cars. Through R&D collaboration with the University of Illinois, USA, SINTEF was able to confirm that no technological weaknesses in the patented Shecco technology could be isolated and documented. The challenges, however, lie in the technology and the possibilities for seriously competing with the prevailing solutions that were acknowledged in the wake of the Montreal Protocol's phasing out of CFC gasses.

The major hindrance for the Shecco technology can namely be linked to the recommended chemical solutions for which the Montreal Protocol left the way open. By means of transition programmes (HCFC), the focus was rapidly concentrated on HFC-134a for mobile air conditioning systems. HFC-134a was the American chemical industry and DuPont's solution, and it was unquestionably successful in reducing the depletion of the stratospheric ozone layer. At the same time it set specifications and standards for new air conditioning systems which posed major hindrances for the introduction of Shecco. It is important to underline here that we are talking about alterations which are in some cases expensive. Even though the transition from CFC-12 in favour of HFC-134a was technically speaking less challenging, there were substantial transition costs. At the same time, the market demand protects an infrastructure which Shecco technology cannot supply. Old infrastructure using CFC-12 could, with few modifications, be regenerated for HFC-134a as working fluid. Promoting a transition to CO₂ technology also requires new hardware, because the technology works under higher pressures. This results in a lock-in of the market due to a preference for certain technical specifications.

It is also important to stress here that air conditioning systems that are adapted to HFC-134a can still be run on the prohibited CFC-12 – a fact that could pose a substantial challenge in countries that fail to enforce the intentions of the Montreal Protocol. A transition to Shecco technology would not, however, provide the same possibility, and would therefore represent a more secure solution to preventing continued use of CFC-12. In this respect Shecco technology could more easily meet the environmental political targets as formulated and adopted in the Montreal Protocol, and at the same time make significant contributions to meeting the Kyoto Protocol targets for reducing greenhouse gas emissions.

Shecco technology represents a significant ecological opportunity, but the prevailing infrastructure hinders its introduction to the air conditioning systems market. It is therefore interesting to observe that the technical cooperation with Denso has proved successful. In 1998 Norsk Hydro and SINTEF discovered that Denso had developed an alternative application of Shecco technology in a completely different segment; tap water heat pumps. In this market SINTEF and Hydro Pronova obtained confirmation that no technological weakness could be documented, and the solutions were implemented without having to face the same lock-in problems that exist in the MAC segment.

5.3 c) Internal actors

As already mentioned, Gustav Lorentzen approached Norsk Hydro with the Shecco technology in 1989. Responsibility for further internal development work at Norsk Hydro was given to Hydro Aluminium's extrusion division (HAEX) in 1990. Responsibility for the technology was transferred to Hydro Aluminium's R&D division in 1992, under the direction of Rolf Marstrander. The technology remained there until 1997/98 when an internal reorganisation resulted in the technology being transferred to the central R&D division under the direction of Bjørn A. Sund. In 2000, Shecco Technologies was established as a separate company, wholly owned by Hydro Pronova (Marstrander 2003).

In conversations with ProSus⁴⁰, Bjørn Arne Sund from Norsk Hydro points out that the internal actors in the company were important. However, from his position in Norsk Hydro, Marstrander contends that this is not correct. Kjell Stenstadvoll, on the other hand, is of the opinion that internal actors were very important because of the long timeline of the project and the shifting ownership within the company. Stenstadvoll points out Dag Flaa, former boss of Hydro Aluminium, and Rolf Marstrander, R&D director, as vital to moving the development forward towards serious commercial introduction, in cooperation with license holders such as Denso. The innovation was introduced to Norsk Hydro in 1989, but it has been stressed that finance managers and budget officers were very concerned about using money that did not yield returns within a reasonably short space of time. It was with this background and much internal scepticism that Flaa and Marstrander managed to carry on the development work, for example by releasing resources to SINTEF so that Jostein Pettersen and Petter Neksa could realise Gustav Lorentzen's plans.

Right from the start, industrial considerations had an influence on Norsk Hydro's interest. Once the rights to the patents were secured, Aakvaag, the then president and CEO, recommended creating a situation in which Norsk Hydro could achieve its own production based on the patent. This was also what Gustav Lorentzen originally had in mind. In 1990-91 the initial plan was that Norsk Hydro could sell the products with piping solutions from Hydro Aluminium. Surveys were carried out to find other potential products, but the divisions within Norsk Hydro that would have been able to supply such extruded products were not interested in the Shecco project. This also had to do with the general perception that such an industrial strategy would conflict with Norsk Hydro's established customer relations.

It is relevant in this connection to take account of the internal reorganisation that had taken place. It was decided that Hydro Aluminium, then led by Dag Flaa, should be divided into separate business areas, with Hydro Aluminium Metal Products (HAMP), based at Vækerø, Norway and Hydro Aluminium Extrusion (HAEX), based in Lausanne, Switzerland, as the dominant units. HAMP was to have responsibility for all upstream activities and the production of primary aluminium. HAEX was to focus on production and other market-oriented downstream activities based on extruded products. The relevant units within Norsk Hydro that could potentially realise the industrial plans for Shecco were within HAEX, where customer orientation

⁴⁰ CondEcol project meeting, April 2002.

with respect to the sale of tubing was consolidated⁴¹. The Shecco project did not, therefore, gain a foothold in HAMP. Further development was in fact managed centrally at Norsk Hydro until 1998, when the project was transferred to the R&D division under the direction of Bjørn A. Sund. There were, however, no ambitions for industrial connections to the rest of the Norsk Hydro system. Bjørn A. Sund therefore handed the project over to Hydro Pronova, and in 2000 Shecco Technologies was established as a separate company. Jan Hurlen was originally employed by the R&D division to promote Shecco, particularly in relation to Denso and the Japanese market, and went over to Pronova.. Later the Shecco project team was complemented by Kjell Stenstadvold in overall charge and Morten Sæther on the technical side.

5.4 d) Financing Internal/external

According to Marstrander, the external financing was quite negligible in proportion to the overall size of the project, and self-financing is today of little relevance in proportion to status and technology. Marstrander doubts that putting the patents on the market will require further financing of any notable dimension on Norsk Hydro's part. This is due to the fact that any further commercial development of Shecco will occur on the basis of the license revenues.

5.5 e) Market characteristics

Today's market opportunities are to a large degree created by the Kyoto Protocol and various national and regional greenhouse gas mitigation measures. This is also heavily focused on in Japan, but here it is also linked to energy efficiency. The work done by the EU on the MAC framework directive may prove to be crucially decisive for Shecco, something we shall take up again later on. The situation vis à vis USA is still pending. Despite the scepticism expressed towards the Kyoto Protocol, significant greenhouse gas mitigation measures are being initiated. This could also open new market opportunities for the Shecco technology.

5.6 f) External infrastructure

The infrastructure for the product comprises enterprises that can produce, repair and service, knowledge of existing technology, etc. It was knowledge in particular which Norsk Hydro perceived to be a considerable hindrance when discussing Shecco technology. This was referred to in Section 5.2, but we shall return to this point in Section 5.9.

Moreover, Norsk Hydro discovered that the technology that was available did not function on its own. The heat exchanger itself functions in a non-technical system comprising various manufacturers, suppliers, customers and regulatory authorities. As an example, Carrier would not consider CO₂ because supply was

⁴¹ An overview over the relevant activities in HAEX can be found at: <http://www.hydroaluminiumprecisiontubing.com/en/> (Accessed on 13th October 2004).

assessed to be unreliable. But they were also negative because they thought they would have to handle aluminium tubing instead of copper. In retrospect their concerns have been shown to have been unfounded. For example, copper tubing is used in the tap water heat pumps based on Shecco technology in Japan. It has also emerged that Carrier has developed compressors adapted to Shecco technology which are advantageous when used in large systems.

It is also important to mention consumption propensities influenced by investments in existing infrastructure. The prevailing market preferences were upheld by the agreement reached in the Montreal Protocol. When market shares increase, as explained by Brekke (2003), it will be even more difficult to change conventional market preferences. The so-called lock-in will therefore be further strengthened because increased returns on, and profits from, the prevailing market selection will stimulate even more consumers to choose the same established market alternatives.

Hindrances that are created by prevailing market preferences and related servicing infrastructures are of immense significance. Furthermore, underlying attempts to undermine confidence in Shecco, taken by certain industrial actors interested in HFC technology, should not be ignored. The test carried out at the University of Illinois showed good results. At the same time the Oak Ridge National Laboratory⁴², in close cooperation with a conglomerate of refrigerant producers in USA (including DuPont), was commissioned by the US Department of Energy to investigate the environmental consequences of heat pump technology with different refrigerants. The results for CO₂ technology were very unfavourable, particularly in the car segment. Despite several claims from the experts at SINTEF, and Jostein Pettersen in particular, that the models used were suspect, the report was published without any significant amendments. The suppliers of HFC could then use these findings as institutional points of reference – knowledge-based infrastructure – in subsequent marketing of HFC-based solutions to both customers and governmental authorities.

A similar example exists in connection with CO₂ technology's energy efficiency in MAC. In a survey published in the autumn of 2002 it was asserted that CO₂ technology was not as energy efficient as conventional HFC technology. However, other specialist communities protested that the survey was biased because the HFC technology had been tested with better and newer components than that which was used for the CO₂ technology. A group of researchers from the Society of Automotive Engineers (SAE)⁴³, in cooperation with NTNU/SINTEF, Audi, BMW, Denso and others, carried out new tests in which state-of-the-art equipment was used on both technologies. The tests showed that the CO₂ technology was more energy efficient than conventional technology based on HFC under most conditions (Pettersen and Nekså 2003)⁴⁴.

⁴² Oak Ridge National Laboratory. See URL: <http://www.ornl.gov/>.

⁴³ For more information about SAE, see: <http://www.sae.org/> (accessed on 26th February 2004).

⁴⁴ The results were presented at a conference organised by SAE in July 2003.

5.7 g) Legal/political framework

According to Marstrander, the legal and political framework meant almost nothing for the part of CO₂ technology's innovation journey in which he was involved, i.e. up to 1997. He considers it interesting to observe that the political system does not reach down to the product. It may be relevant here to make a reference to the Norwegian government's own interpretation of the recommendations made by the World Commission on Environment and Development (WCED) in its report entitled "Our Common Future". On page 90 of the White Paper no. 46 concerning Norway's follow-up of the WCED report, it reads: "The Government will continue to provide support for prototypes of and pilot projects for heat pumps" (White Paper no. 46 (1988-89)). Yet we can state that there was no contact with the Ministry of the Environment before 1996, when the support of the then Minister of the Environment was requested to consolidate contact with Germany, partly because competition from DaimlerBenz was perceived. It could therefore be said that there was a lot of truth in Marstrander's assertion but, on the other hand, Norsk Hydro itself did not make particularly strong overtures to Norwegian innovation or environmental authorities. What about the rest of Europe?

Given that the EU has committed itself to reducing its greenhouse gas emissions by 8 per cent in proportion to the 1990 level by 2008-2012, joint regulations have also been recommended to reduce emissions from mobile air conditioning systems. The framework directive has been voted on for the first time in the European Parliament, yet at the same time it is stressed that more research is required before it is possible to reach any final conclusions. The cost estimates for various alternatives named by the EC are claimed to be unreliable. Something that is very reliable is the legal/political framework implemented and followed up in Japan.

The application in Japan of tap water heat pumps based on Shecco technology is influenced by a different political energy regime than is the case in Norway. In Japan there are differentiated tariffs operating within the same customer segment at different times of the day. It is more expensive to use energy during the day than it is at night. The Japanese require a lot of hot bath water at the same time each morning. By using Shecco technology it is possible to reduce the energy consumption at that time. Also, Shecco technology provides a very high output temperature of water, up to 90 degrees Celsius, and that is something quite new for Japanese manufacturers. Related to this we should not forget the health aspect: the hot water in the heater, over 70 degrees Celsius, prevents bacteriological contamination more efficiently than traditional heat pumps. We shall let this lie, however, and concentrate now on the eco-efficient dimensions. If one uses Norway as an illustration, it has been suggested that if all water were heated with the help of Shecco technology, the saving would be roughly 7 TWh per year⁴⁵. By comparison, ENOVA's goal is to save 10 TWh by the year 2010⁴⁶. According to the information magazine for NTNU/SINTEF (Gemini 2001), this is

⁴⁵ Given an annual consumption for the heating of buildings of 58 TWh, and given that 10-15 per cent of the energy goes to heating of tap water. E-mail from Petter Neksa, SINTEF/NTNU to ProSus, dated 15th March 2004.

⁴⁶ Energy conservation and transition to renewable energy. See also Gemini (2003).

equivalent to two and a half gas power plants of the type designed “Naturkraft”,⁴⁷ or 7 per cent of Norway's annual hydroelectric production.

5.8 h) Culture and society

Marstrander emphasises that there are powerful influences behind the economy–technology relationship in Figure 1 as presented in chapter 3.1 which can be linked to ecological considerations. At the same time, Marstrander stresses that society in general, which should influence the ecology dimension, is a non-actor when it comes down to this technological level. According to Marstrander, NGOs such as Bellona or others more detached from environmental issues have no function when it comes to this kind of discussion. This point is however arguable, considering that Bellona has signed many cooperation agreements with individual enterprises within the B7 Cooperation and, for example, with the Federation of Norwegian Process Industries (PIL).

Likewise, Greenpeace has been heavily involved in the development of isobutane-powered refrigerators in Europe, the so-called Greenfreeze Project. This came as a result of Greenpeace being approached by an East German refrigerator manufacturer in the early 1990's. He wanted a market survey undertaken in order to find out whether there was potential for environmentally friendly refrigerators in Europe. With a lot of help from the stringent taxes on HFC in Denmark and Austria, this enterprise has developed and grown, so that in Europe today it is almost exclusively environmentally friendly isobutane refrigerators that are sold.

Few, if any, NGOs would make propaganda for specific patented technologies. The focus is often on environment, not concrete solutions. Unn Orstein at Hydro Energi said in a meeting with ProSus and Bjørn Arne Sund⁴⁸ that Norsk Hydro was completely dependent on the NGOs to achieve a transition to a hydrogen society. This is not however linked to the level specifically referred to by Marstrander, and can thus explain the differing perceptions that have prevailed within Norsk Hydro⁴⁹.

5.9 i) Other issues

The lack of curriculum – prevailing knowledge – is a very important factor in itself and an underestimated dimension in discussions about technological change. This was particularly decisive during the first decade of the innovation journey, i.e. up to 1999. The teaching provided on CO₂ as a working fluid in technical education was hopelessly inadequate, but since 1998 there have been pilot projects on both stationary and mobile systems. NTNU later concentrated the focus on this type of teaching. Since 1997, for example, over 60 exchange students from Italy, Germany and France have studied at the Department of Energy and Process Engineering at NTNU. According to Petter Neksa most of these students now have

⁴⁷ Further details in http://www.naturkraft.no/default.asp?V_DOC_ID=708.

⁴⁸ Meeting between CondEcol and Norsk Hydro's Bjørn Arne Sund and Unn Orstein on 2nd May 2003.

⁴⁹ The only exception known to ProSus is the Natural Resources Defence Council (NRDC), a California-based ENGO that gave a presentation at the MAC Summit 2004 in Washington, DC. More information on NRDC is available at: <http://www.nrdc.org/>. (Accessed on 11th May 2004).

good positions within the European car industry. The teaching of CO₂ as a working fluid in heat exchangers and air conditioning systems is still not standard curriculum on engineering courses, but this may be about to change. In the past few years more and more technical universities and colleges have put CO₂ technology on their curricula⁵⁰. Despite this, the prevailing international technical competence – particularly in USA – is still poor compared to that in conventional cooling media. As long as many different contributors to policy formulation prefer the established and familiar solutions because they are supported by prevailing knowledge, this situation gives rise to other forms of lock-in.

There has been a lot of focus on MAC, but if we shift the perspective to Residential Air Conditioning (RAC) or tap water heat pumps, the challenges could be even bigger as long as the actors who provide technical recommendations are many and diverse. Even though technical alternatives in water heaters, heat pumps or air conditioning systems are less eco-efficient, they can still be favoured because they represent familiar solutions with predictable maintenance routines and easy access to spare parts. Given this situation, that which is familiar will be chosen because a physical and knowledge-based network exists to sustain and further develop the preferred technology. At the same time it is clear that great opportunities lie in RAC and the tap water heat pump industry, because there one is far less likely to be faced with such powerful networks or requirements for one (or few) standard(s), as is the case in the car and chemical industries.

Another argument which can be linked both to knowledge and infrastructure is that there is a need to improve the knowledge of which processes occur between consumer and heat pump before, during and after installation. Such processes could provide answers to a number of questions, such as: what needs to be done so that the heat pump works as it is supposed to, what it means to be a heat pump user, and what installing a heat pump actually means for central energy and environmental issues. Also it is bad publicity if the heat pump must constantly be repaired, or if the consumer is under the impression that heat pumps demand so much maintenance that one ends up acting like a caretaker in one's own home (Holden 1998). The massive increase in the sale of heat pumps in Norway in 2003 suggests that this could be about to change, but this will happen only if the consumer is satisfied with his purchase.

⁵⁰ According to Petter Neksa 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.

6 WHAT HAVE BEEN THE IMPORTANT DECISIONS AND INSTANCES IN THE DEVELOPMENT OF THE PRODUCT SO FAR, i.e. AS OF APRIL 2004?

Based on our investigations, the following dates have been crucial to the development of Shecco:

- **1989:** Lorentzen approached Norsk Hydro with his concept for heat pumps based on CO₂.
- **1991:** Lorentzen's idea was handed over to Hydro Aluminium for further development, and Jostein Pettersen was asked to write the patent application, which was then sent off later in the year.
- **1993:** The first patent was granted.
- **1994:** A cooperation agreement with Denso was signed.
- **1997:** The Kyoto Protocol with a broader focus that included HFC gasses.
- **1997/98:** The patented innovation was transferred to Norsk Hydro's central R&D unit. The industrial ambitions for a linkage between the sale of tubing and CO₂ technology was abandoned.
- **1998:** Shecco was transferred to Hydro Pronova. The industrial strategy was formally abandoned.
- **1998:** Denso sought a license for commercial utilisation of tap water heat pumps.
- **1998:** A/S Eggprodukter in Larvik began to use tap water heat pumps based on Shecco technology.
- **2000:** License agreement with Denso.
- **2003:** MAC Summit in February.
- **2004:** First reading in the European Parliament on March 31st.
- **2004:** MAC Summit in April.

7 WHAT ARE THE CURRENT PLANS FOR FUTURE PRODUCTION AND MARKETING?

With regard to plans for further production and marketing, Marstrander believes that this may have to do with two conditions: The first concerns the handling of knowledge generated from existing and subsequent patents. It is important for Norsk Hydro to get a clear picture of the prevailing marketing and production plans for introducing the technology in the products of the future. Any such studies should be specified both geographically and in terms of product. The other condition emphasised by Marstrander has to do with the production and marketing of hardware. In concrete terms this means relevant tubing solutions and heat exchangers. From Norsk Hydro's standpoint the question is what perspectives are involved in participating in hardware production as a consequence of possessing the patents, and how this ought to transpire.

Strategic decisions that were gradually made by Norsk Hydro clearly show that the second condition concerning hardware has been abandoned. Aakvaag, Flaa and Marstrander have also left Norsk Hydro. In our opinion it is important to take a closer look at the branding that is then selected as an alternative to further patenting. A branding strategy represents something novel and considerably more risky, both in terms of formulation and implementation. Our argument is that in this context one ought not to underestimate the importance of non-technical conditions, and networks in particular. This applies to current and future markets, current and future financial sources and investors, technological development and R&D competence, as well as current and future political processes, be they national, regional or global. We mentioned networks, but the most important thing is to establish an understanding of how different members of a network interact at different points in time. The tentative conclusion that should be kept in mind is based on the observation that the pattern of interaction between market, technology, finance and politics has developed in completely different ways in different regions. This will most probably continue to be the case.

As illustrated in the chronological overview, it is difficult to discuss the future development of Shecco technology in terms of one integrated process. To go in for mobile air conditioning systems in cars with MAC 2000 as a business strategy was somewhat of a venture, though it is with the tap water heat pumps in domestic residences that commercial success is taking place. In addition Shecco has a third leg, the one on which Shecco actually focuses; refrigerators/refrigerated counters for grocery stores and/or convenience stores. This clearly creates a demand for more specific analyses.

With respect to MAC, the future innovation journey is largely dependent on factors over which Shecco has no control, namely the political decisions made by the EU and USA. Let us therefore take a closer look at applications in mobile air conditioning systems before we then take a quick look at future possibilities for the technology in water heating and in refrigerating cabinets/counters and soft drinks vending machines.

7.1 MAC – mobile

7.1.1 The EC directive on the phasing out of HFC-134a in MAC

Should the MAC directive be formulated in favour of Shecco technology, this in turn could create new opportunities for MAC. A lot still remains unsettled, but the status on the EC 's work (after the first reading in the Parliament) is that HFC-134a will be phased out. Hydrocarbons (HC) such as propane and isobutane are not candidates because they are too flammable. We are then left with two serious alternatives in the EU: HFC-152a and CO₂. In its proposal the EC wanted an upper GWP of 120 for the cooling medium. This was amended by the Parliament to 150. This proposal therefore leaves the door open for HFC-152a, which has a GWP of 140. The directive is planned to come into force from 2005. The EC proposed that phasing out should commence with a quota system in 2009, while the Parliament amended this to apply to all "new models", with a ban from 2014. Clarification from the EC was expected in the course of autumn 2004 (Horrocks and Vainio 2004). The date for phasing in CO₂ technology will however be of considerable financial importance to Shecco Technologies. If the phasing in does not commence before 2011, the company will probably miss out on a lot of revenue, because the first patents already expire in 2009.

7.1.2 Developments in USA after the MAC Summit in 2004

Developments in USA have taken a different direction. After the MAC Summit in Washington, DC in 2004, it looks as if US EPA will choose enhanced HFC-134a technology initially. According to Stephen Anderson at US EPA, prohibiting HFC-134a is out of the question. Also, there are tight links between US EPA and the car and chemical industries; something which could lend a political sway to the situation. Among other things, this has led to a relatively large research project being carried out to improve prevailing HFC-134a technology (Enhanced 134a MAC Project). The project aims at finding solutions that entail significantly reduced leakage during operation, improved energy efficiency and an improved system for collection and recovery at service time and end-of-life, as well as other improvements to the passenger compartment (insulation etc). The goal is to reduce leakage and fuel consumption by 50 per cent and 30 per cent respectively. The project is co-financed by the state and industry⁵¹. The belief is that one can thereby "buy time" because enhanced HFC-134a is the most expedient alternative. According to American interests, a new generation of MAC will take time to achieve. Improving current technology is therefore very important because it will reduce global greenhouse gas emissions in the short term. At the same time there is a wish to wait for research on HFC-152a and CO₂. Both of these appear to be considered as the new generation of MAC, and in USA it seems fairly certain that a tendency towards a phasing-out of HFC-134a will come, but the commitment to enhanced HFC-134a now taking place, will probably pave the way for the new generation of MAC. Considerable resources are being put into finding satisfactory solutions for HFC-

⁵¹ Central actors are: US Department of Energy, US Environmental Protection Agency, DuPont and General Motors. For more information see Drigotas (2004).

134a which can be more or less directly transferred to HFC-152a. This seems to be in the interests of all the American actors, but it will also create challenges to realising the potential that lies in the Shecco technology – at least in the USA.

It therefore seems that we are looking at a possible dual-standard situation in the global car industry, which is clearly not in their best interest. Nevertheless, Shecco technology can establish a foothold for MAC in Europe. This will bring the long journey for Gustav Lorentzen's original idea to its conclusion; a conclusion which, though probably too late to generate significant revenues from patent licensing for Shecco Technologies, may still perhaps manage to contribute to improving the climate. At the same time it does look as though only a ban on existing working fluids would ensure the commercial success of the original MAC 2000 project now known as Shecco.

7.2 Tap water heat pumps - residential

The experiences gained from the Japanese authorities' subsidising of tap water heat pumps are also relevant. As far as we understand, this was crucial to them being put into production in Japan. A subsidy of 30 per cent is equivalent to approximately NOK 20,000 for buying the tap water heat pumps. This aid is then gradually reduced. Given the energy efficiency and investment backing, a market demand that could overcome lock-ins is created. Seen in this light, political decisions could create cost advantages that could open up new and bigger markets for Shecco technology. According to the Japanese newspaper Nikkan Kogyo Shimbun⁵², 70,000 units were sold in 2003.

Meanwhile, OSO Hotwater⁵³ is continuing its test and development work, and new laboratory tests at SINTEF indicate that a significant potential lies in Shecco technology for heating forced air, something which could also be installed in existing buildings at less cost than for waterborne heating (Nekså 2004). There are obviously immense environmental gains to be made here in the long term, but more tests and a pilot system must first be implemented. According to information received by ProSus, SINTEF/NTNU are currently seeking cooperation partners. However, ENOVA or other public bodies have not as yet been brought into the picture.

7.3 Refrigerators and refrigerated counters - commercial

As far as the information received by ProSus goes, developments are primarily being made on two fronts within this segment: 1) Danfoss in Denmark, manufacturers of refrigerating cabinets/counters for grocery

⁵² Translated and referred to on Shecco's home page: <http://www.shecco.com/artikler/co2technologyinjapan.htm> and <http://www.shecco.com/artikler/newspapernikkansangyoshimbun.htm>. The newspaper is otherwise available in Japanese only at: <http://www.nikkan.co.jp/> (All three sites accessed on 11th May 2004).

⁵³ More on OSO is available at: <http://www.oso.no/>. (Accessed on 10th June 2003).

retailers, and 2) a new and exciting development within soft drinks vending machines, in which Coca Cola among others seem to be active.

1) Danfoss develops components for the refrigeration industry and are among others at the forefront of compressor technology. The company has also designed systems that yield better energy efficiency than rival cooling media. According to the company, the compressor can be used in both refrigerating cabinets/counters and the production of hot water⁵⁴.

2) In 2000 Coca Cola announced that, after the Olympic Games in Athens in 2004⁵⁵, it would not purchase new refrigerating cabinets/counters run on HFC if cost-effective alternatives existed. The company has invested considerable resources in the research and development of new refrigerating cabinets/counters. So far three alternative technologies have been investigated: CO₂, hydrocarbons and the Stirling engine (helium). It is reasonable to assume that other companies in the industry are undergoing similar processes. Interestingly enough, Coca Cola has collaborated with Danfoss in developing a new compressor for such applications⁵⁶. Coca Cola has an estimated 9 million refrigerators, soft drinks vending machines and dispensers carrying its trademark, so there is a significant market potential here for Shecco technology⁵⁷.

7.4 Conclusion - lessons to be learned for Norway?

According to Marstrander, the effects of using industrial financing, in an insufficiently budgeted state system, are enormous. Further, industrial financing may be instrumental in setting the guidelines for how the limited resources available are actually distributed⁵⁸. An understanding of the game rules for national and European research politics is a prerequisite. In this connection Norsk Hydro gained valuable, though negative, experience through the RACE collaboration of how car manufacturers excluded relevant technology suppliers who had powerful resources in the shape of granted patents for CO₂ technology.

The reorganisation of the Research Council that took place in 2004 could provide new opportunities here, even though the general available resources offered in the public budgets are increasingly linked to self-financing. New initiatives linked to so-called KMB projects (Competence Projects with User Participation) could provide new opportunities for national state funding, for example in the development of tap water heat pumps. It is important to remember here that ENOVA's mandate as of now, rules out providing any support for technology development. ENOVA focuses more on introduction to the market and commercialisation of

⁵⁴ See press release from Danfoss dated 17th September 2003. Accessed on 11th May 2004 at: <http://www.danfoss.com/News/archive.asp?mm=24>.

⁵⁵ See for example pp. 18 and 19 in Coca Cola's environmental report for 2002. Accessed on 11th May 2004 at: http://www2.coca-cola.com/citizenship/environmental_report.pdf.

⁵⁶ For more information see press release from Danfoss dated 27th January 2004. Accessed on 11th May at: <http://danfoss.com/News/showoldnews.asp?id=235>.

⁵⁷ For more on this market see for example: <http://www.refrigerantsnaturally.com/>, and speech made by Coca Cola representative Jeff Seabright given at a conference in Brussels on 22nd June 2004, available at: [http://www.refrigerantsnaturally.com/speeches/The per cent20Coca-Cola per cent20Company per cent20speech.pdf](http://www.refrigerantsnaturally.com/speeches/The%20per%20cent20Coca-Cola%20per%20Company%20speech.pdf). (Both accessed on June 28th 2004).

⁵⁸ This point was also brought up by Bjørn Arne Sund at a meeting on May 2nd 2003 (in connection with hydrogen). He added that linking the project to the environment or sustainable development would lend it even more credibility.

already developed products. Given this situation, it remains unclear how and to what degree ENOVA can play any role in technology development, and in realising Shecco's potential in Norway.

As far as we have been able to verify, no contact concerning Shecco existed between Berntsen/the Ministry of the Environment and relevant contacts at the Ministry of Trade and Industry. However, it is important to stress that Norsk Hydro did not attempt to establish such a connection because it was considered that such contacts would complicate the situation. Also, in Norsk Hydro's opinion, there was no indication that they would receive support. It appears that US environmental and industrial policy administrative bodies coordinate their strategies to a greater degree than is the case between the Norwegian Ministries of the Environment and Trade and Industry.

All the same, speaking now as an observer, Marstrander's assessment today is that due to the change in strategic orientation, Norsk Hydro lacks the clout due to limited internal support to develop its own products. Breaking into a new market and developing a new product requires a certain amount of effort being applied. One must create a wheel that, once set in motion, continues to roll forward by virtue of its own weight. But since Norsk Hydro did not wish to produce own products, it chose not to follow this route. Instead it chose to establish alliances based on its licenses, alliances that could create a bigger wheel that would roll faster and faster. Stenstadvoid is doubtful as to whether HAEX represents sufficient weight. Nonetheless, only time will tell whether the license strategy will give the returns anticipated.

Even though Norsk Hydro's patenting rights for the Shecco technology probably will expire before MAC with CO₂ as working fluid is introduced in the market, the contribution to a more sustainable car industry will perhaps be maintained. It is clear that the "threat" posed by the CO₂-technology and other alternative cooling media has resulted in HFC technology being considerably improved in purely ecological terms. Just the same, the modifications remain technically limited, and these modifications, which are encouraged in the USA among others, could effectively hinder more radical reorganisation towards an increased eco-efficient solution that would be in line with the technology represented by Shecco.

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9. WEB BASED RESOURCES

Commercial/Corporate:

- Danfoss: <http://www.danfoss.dk/>
- Denso (Japansk site): <http://www.denso.co.jp/en/>
- Denso (Global site): <http://www.globaldenso.com/en/>
- Modine: <http://www.modine.com/english/index.php>
- Norsk Hydro: <http://www.hydro.com/en/>
- Obrist Engineering: <http://www.obrist.at/>
- Shecco Technologies: <http://www.shecco.com/>
- Tokyo Electric Power Company (Tepco): <http://www.tepco.co.jp/en/index-e.html>

R & D:

- ACRC ved University of Illinois: <http://acrc.mie.uiuc.edu/>
- Sintef: <http://www.sintef.no/> (Søk på Energiforskning)

EU

- "EU Consultation Paper. How to Considerably Reduce Greenhouse Gas Emissions Due to Mobile Air Conditioners" 4. Feb 2003:
http://europa.eu.int/comm/environment/air/mac2003/pdf/consultation_paper.pdf
- Background information concerning the F-gas directive:
http://www.europa.eu.int/prelex/detail_dossier_real.cfm?CL=en&DosId=184911
- F-gass Direktive as pr. 28. september 2004: <http://www.environmentdaily.com/docs/41007a.pdf>
- EU Strategy on CO2 emissions from passenger cars:
http://europa.eu.int/comm/environment/co2/co2_home.htm

MAC-conferences:

- MAC Summit
 - 2003 (10.-11. feb i Brüssel; Arrangør EU):
http://europa.eu.int/comm/environment/air/mac2003/programme_presentations.htm
 - 2004 (14.-15. april i Washington DC; Arrangør US EPA):
<http://www.epa.gov/cppd/2004MACSummit.pdf> (klikk på foredragene i pdf-dokumentet)
- VDA Alternative Refrigerant Winter Meetings
 - 2002: <http://www.vda-wintermeeting.de/2002/index2.htm>
 - 2003: <http://www.vda-wintermeeting.de/2003/index2.php>
 - 2004: <http://www.vda-wintermeeting.de/2004/index2.php>
- SAE Automotive Alternate Refrigerant Systems Symposium, Scottsdale Arizona:
 - 2002: <http://www.sae.org/events/aars/2002/presentations.htm>
 - 2003: <http://www.sae.org/altrefrigerant/presentations/>
 - 2004: <http://www.sae.org/events/aars/presentations/2004.htm>

APPENDIX

The CondEcol Research Protocol

1. What are the most important characteristics of a more eco-efficient alternative to existing products or processes?
2. How can the company characterise the product in relation to the first seven spokes in the Eco-design Wheel?
3. What were the main reasons for the company's decision to develop and market the product as a more eco-efficient alternative?
4. Which key actors have influenced the product development so far?
 - a) Technology and manufacture
 - b) The market
 - c) Financing
 - d) Regulatory bodies
 - e) Cultural and social organisation
5. What have been the central decisions and critical moments in the development of the product so far?
6. What have been the significant factors, both positive and negative, that have affected the innovation journey so far?
 - a) Input factors – specific manufacturer constellations
 - b) Technology and manufacture
 - c) Internal actors
 - d) Financing: internal/external
 - e) Market characteristics
 - f) External infrastructure
 - g) Legal/political framework
 - h) Culture and society
 - i) Other
7. What are the current plans for future production and marketing?

Greenhouse gasses and warming potential

Source: Statistics Norway (SSB): http://www.ssb.no/emner/01/klima_luft/boks1.html.

The three most important greenhouse gasses are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Man-made emissions of CO₂ are primarily linked to the combustion of fossil fuel, but are also created by different chemical processes in industry. Methane is created in particular during the decomposition of biological waste on waste dumps and from livestock production in farming. Farmyard manure and the use and production of artificial fertilisers cause most of the N₂O emissions in this country.

Hydrofluorocarbons is the group of greenhouse gasses that are most relevant in terms of SHECCO. HFC-134a is used in mobile air conditioning (MAC) systems. In stationary applications different mixtures of hydrofluorocarbons are used.

The GWP (Global Warming Potential) of a gas is defined by the accumulated impact on greenhouse effects caused by one tonne of emission of the gas compared to one tonne of emission of CO₂ over a specific amount of time. With the help of the GWP values, the GHG emissions are weighed together with CO₂ equivalents. The GWP values for the greenhouse gasses included in the Kyoto Protocol are shown below, with a time frame of 100 years.

Components:	GWP value:
Carbon dioxide (CO ₂):	1
Methane (CH ₄):	21
Nitrous oxide (N ₂ O):	310
Hydrofluorocarbons (HFC):	
HFC--23	11 700
HFC--32	650
HFC--125	2 800
HFC—134a	1 300
HFC-143a	3 800
HFC--152a	140
Perfluorocarbons (PFC)	
CF ₄ (PFC-14)	6 500
C ₂ F ₆ (PFC--116)	9 200
C ₃ F ₈ (PFC--218)	7 000
Sulphurhexafluoride (SF ₆)	23 900

The Kyoto Protocol lays down mandatory goals for GHG emissions from the industrial countries. In addition to CO₂, CH₄ and N₂O, the Protocol also includes the greenhouse gasses sulphurhexafluoride (SF₆), hydrofluorocarbon (HFC) and perfluorocarbon (PFC).