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Competitive policies in the Nordic Energy Research and Innovation Area eNERGIA

Part 3: Special reports

Antje Klitkou, Trond Einar Pedersen, Lisa Scordato and Åge Mariussen

NIFU STEP

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Part 3: Special reports

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Preface

This report outlines the energy research and innovation policy in the Nordic and Baltic countries – Denmark, Finland, Iceland, Norway, Sweden, Estonia, Latvia and Lithuania.

The report is the result of the research project Competitive policies in the Nordic Energy Research and Innovation Area (eNERGIA). The project was co-funded by Nordic Energy Research and NIFU STEP. The objective of the project was to determine possible policy interventions targeted at the development and commercial promotion of promising renewable energy production technologies in the Nordic countries.

The report is based on an analysis of the framework conditions for the sector innovation systems for energy production, with a focus on research and innovation policy in the Nordic and Baltic countries. We identified the key actors and institutions in all the eight countries studied. In addition, we conducted a performance assessment based on the quantitative indicators of publishing and patenting, international collaboration and funding data. Using these indicators as a basis, we conducted an analysis of the strengths, weaknesses, opportunities and threats (SWOT analysis) of the Nordic sector innovation systems for energy production. This analysis identified common or diverging characteristics, challenges, framework conditions, energy-technology specialisation and, most important of all, cases of good practice in key technologies.

The project included two workshops, and the results of these are also reported here. The outcomes of the workshops have been used in several parts of the project:

- A Nordic workshop on the environmental consequences of deployment at scale of these technologies to replace existing energy systems, with a focus on wind energy and photovoltaic energy, carbon dioxide capture and storage, and second-generation bioenergy.
- A Nordic workshop on policy implications for Nordic Energy Research.

The report comprises three parts:

Part 1: Country reports
Part 2: Technology reports
Part 3: Special reports

The results are summarised in the *Synthesis report.*

The authors of these reports are Antje Klitkou, Trond Einar Pedersen, Lisa Scordato and Åge Mariussen. We want to thank Nordic Energy Research for funding this project and our colleagues from NIFU STEP for their comments on the project. In addition, we would like to thank the participants at our workshops and the interview partners in our case studies for their valuable contributions.

Oslo, 1 July 2008

Per Hetland
Director

Liv Langfeldt
Head of Research in Research and Innovation Policy

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List of Acronyms and Abbreviations

€	Euro
AAU	Aalborg University
ACER	Advisory Committee on Energy Research (DK)
ÅSC	Ångström Solar Center
Asea	Allmänna Svenska Elektriska AB, now ABB Asea Brown Boveri
AT	Austria
AU	Australia
b	billion
BAFF	BioAlcohol Fuel Foundation (SE)
BALTREL	Baltic Ring Electricity Co-operation Committee
BE	Belgium
BG	Bulgaria
BI	Burundi
BIA	User-directed innovation arena (NO)
Bio-DME	Bio-dimethyl ether
BR	Brazil
BSR	Baltic Sea Region
BTK	Biofuel Technology Centre
BTL	Biomass to liquids
CA	Canada
CBEM	Common Baltic Electricity Market
CCP	CO_2 Capture Project
CCS	Carbon capture and storage
CEE	Central and Eastern Europe
CEEF	Commercializing Energy Efficiency Finance (Latvia)
CET	Centre for Energy Technologies at TKK
CFD	Computational Fluid Dynamics
CH	Switzerland
CHP	Combined heat and power
CHPP	Combined heat and power plant
CIM	Continuous Improvement Management
CMR	Christian Michelsen Centre for Industrial Measurement Science and Technology (NO)
CN	China
CO_2	Carbon dioxide
COST	European Cooperation in the field of scientific and technical research
CSLF	Carbon Sequestration Leadership Forum
CY	Cyprus
CZ	Czech Republic
DAWE	Danish Academy of Wind Energy
DBT	Danish Board of Technology
DCB	Danish Centre for Biofuels
DE	Germany
DEA	Danish Energy Authority
DH	District heating
DHI	Danish Hydraulic Institute
DK	Denmark
DKK	Danish Kroner
DRE	Decentralised rural electrification
DTU	Denmark's Technical University
EBA	Estonian Biomass Association
EBIT	Earnings before interest and taxes
EC	European Commission

ECT	The Energy Charter Treaty
EE	Estonia
EEA	European Economic Area
EEF	Energy Efficiency Fund (Latvia)
EEK	Estonian Kroner
EFP	Energy Research Programme (DK)
EG	Egypt
EK	Confederation of Finnish Industries
ELF	Estonian Fund for Nature
ELFORSK	Energy Efficiency Programme (DK)
EMA	Electricity Market Act (EE)
EnMi	Energy & Environment Programme Commission (DK)
EPC	Engineering, procurement and construction
EPO	European Patent Organisation
ERA	European Research Area
ERA-NET	European Research Area Network
ERDF	European Regional Development Fund
EREC	European Renewable Energy Council
ES	Spain
EstSF	Estonian Science Foundation
EU	European Union
EUDP	Energy Technology Development and Demonstration Programme (DK)
EWEA	European Wind Energy Association
FAEE	Fatty acid ethyl esters
FAME	Fatty acid methyl esters
FDI	Foreign direct investment
FEED	Front end engineering and design
FI	Finland
FMR LLC	Fidelity Investments, one of the World's largest mutual fund firms
ForskEL	Clean Electricity Production Programme (DK)
FP5	Fifth European Framework Programme
FP6	Sixth European Framework Programme
FR	France
FT	Fischer-Tropsch
GC	Grid code (EE)
GDP	Gross domestic product
GE	General Electrics
GEUS	Geological Survey of Denmark and Greenland
GHG	Greenhouse gas
GR	Greece
Gt	Gigatonne
GW	Gigawatt
GWh	Gigawatt-hour
GWh/year	Gigawatt-hour per year
GWp	Gigawatt at peak
HPP	Hydropower plant
HRM	Human resource management
HTU-Diesel	HydroThermalUpgrading diesel
HU	Hungary
HY-CO	Hydrogen and Fuel Cell Coordination Network
HyFC	Hydrogen and Fuel Cell Academy
IBERP	Inter-Baltic Energy Research Programme
ICT	Information and communication technology
IE	Ireland
IEA	International Energy Agency
IFE	Institute for Energy Technology (NO)

IGG	Institute of Geology & Geography (Lithuania)
IL	Israel
IN	India
IPE LAS	Institute of Physical Energetics, Latvian Academy of Sciences
IPR	Intellectual property rights
IRIS	International Research Institute of Stavanger (NO)
IS	Iceland
ISI	Institute for Scientific Information
ISO	International Organization for Standardization
ÍSOR	Iceland GeoSurvey
IT	Italy
ITER	International Thermonuclear Experimental Reactor
IWC	Latvian State Institute of Wood Chemistry
JTI	Swedish Institute for Agricultural and Technical Engineering
KTH	Royal Institute of Technology (SE)
Ktoe	Thousand tonnes of oil equivalent
KTU	Kaunas University of Technology (LT)
KVL	Royal Veterinary and Agricultural University (DK)
kW	Kilowatt
kWh	Kilowatt-hour
LAEC	Latvian Association of Energy Construction
Latbio	Latvian Bioenergy Association
LCA	Life-cycle assessment
LCCI	Latvian Chamber of Commerce and Industry
LEA	Latvian Environment Agency
LEGMA	Latvian Environment, Geology & Meteorology Agency
LEI	Lithuanian Energy Institute
LEIF	Latvian Environmental Investment Fund
LNG	Liquefied natural gas
LT	Lithuania
LU	Luxembourg
LV	Latvia
LVAF	Latvian Environmental Protection Administration Fund
m/s	Metre per second
M€	Million Euro
MA	Morocco
MEEC	Finnish Ministry of Employment and the Economy
Mkr	Million kroner
Mm^3	Million cubic metres
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
MW/year	Megawatt per year
MWh	Megawatt-hour
MWp	Megawatt at peak
MY	Malaysia
N/A	Not available
NCS	Norwegian Continental Shelf
NEFCO	Nordic Environmental Finance Corporation
NER	Nordic Energy Research
NGO	Non-governmental organisation
NGU	Geological Survey of Norway
NIB	Nordic Investment Bank
NILE	New Improvements for Ligno-cellulosic Ethanol
NL	The Netherlands
NO	Norway
NOK	Norwegian Kroner

NPD	Norwegian Petroleum Directorate
NPP	Nuclear power plant
NTNF	Royal Norwegian Council for Scientific and Industrial Research
NTNU	Norwegian University of Science and Technology
NVE	Norwegian Water Resources and Energy Directorate
O&M	Operations and maintenance
OES	Ocean Energy Systems
OHSAS	Occupational Health and Safety Advisory Service
OPET	Organisations for the promotion of energy technologies
Orkustofnun	National Energy Authority of Iceland
OSKE	Finnish Centres of Expertise Programmes
P&C	People and culture
PCT	Patent Cooperation Treaty
PFI	Paper and Fibre Research Institute (NO)
PHARE	Poland and Hungary: Assistance for Restructuring their Economies Programme
PL	Poland
PPO	Pure plant oil
PSO	Public service obligations
PT	Portugal
PV	Photovoltaic
QSE	Qualified scheduling entity
R&D	Research and development
RALA	Agricultural University of Iceland (IC)
RCHPP	Rīga combined heat and power plant
RCN	Research Council of Norway
RD&D	Research, development and demonstration
REC	Renewable Energy Corporation AS
REFU	Advisory Committee on Energy Research (DK)
RES	Renewable energy sources
RES-E	Electricity from renewable energy sources
RES-H	Production of heat and cold from renewable energy sources
RME	Rapeseed methyl esters
RO	Romania
RPS	International consultancy providing advice on the development of natural resources, land and property, the management of the environment, and the health and safety of people
RTD	Research, technology and development
RTU	Riga Technical University
RU	Russia
SACS	Saline Aquifer CO_2 Storage, demonstration and monitoring project at the Sleipner field
SE	Sweden
SE21	Sustainable Estonia 21
SEK	Swedish Kroner
SGS	State Geological Survey (Latvia)
SI	Slovenia
SITRA	The Finnish Innovation Fund (FI)
SK	Slovakia
SLU	Swedish University of Agricultural Sciences
SME	Small and medium-sized enterprise
SNG	Synthetic natural gas
SOFC	Solid oxide fuel cells
SSG	Seawave Slot-Cone generator
SVC	Swedish Centre for Hydropower
SWOT	Strengths, Weaknesses, Opportunities and Threats [analysis]
TCM	International Test centre Mongstad (NO)
TEKEL	Finnish Science Park Association
Tekes	National Technology Development Agency (FI)

TGC	Tradable Green Certificates
TJ	Terajoule
TKK	Helsinki University of Technology
TN	Tunisia
toe	Tonnes of oil equivalent
TOI	Institute of Transport Economics Norwegian Centre for Transport Research (NO)
TPWind	Wind Energy Technology Platform
TR	Turkey
TSO	Transmission system operator
TWh	Terawatt-hour
TWh/year	Terawatt-hour per year
UA	Ukraine
UK	United Kingdom
UMB	University for Environment and Bioscience
US	USA
US-DOE	US Department of Energy
USPTO	US Patent and Trademark Office
VC	Venture capital
VTT	Technical Research Centre of Finland
W/m^2	Watt per square meter
WEC	World Energy Council
WNRI	Western Norway Research Institute
WTO	World Trade Organization
ZA	South Africa

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Introduction

This report (Part 3: Special reports) is the third in a series of four reporting the results of the eNERGIA project. The first report presents the eight countries examined in the project – Denmark, Finland, Iceland, Norway, Sweden, Estonia, Latvia and Lithuania. The second report deals mainly with selected renewable energy technologies, which are discussed from different perspectives. The fourth report provides a summary of the whole project.

The present report summarises the SWOT analyses of the Nordic countries and the eNERGIA workshops, and presents case studies of good practice.

1 SWOT analysis of Nordic countries' performance in selected renewable energy technologies

In this section we present a SWOT analysis of the Nordic countries. The aim of the SWOT analysis is described in the eNERGIA project description:

> The SWOT analysis will conclude in an assessment of important focus areas in the different countries in the energy sector and will help to identify cases of good practice for the second phase of the project.

Hence, the aim of the SWOT analysis is relatively limited, being to substantiate arguments for identifying firms for case studies within specific technology areas in the different countries. However, the process of doing the SWOT analysis and the results obtained there from have actually contributed to the documentation of the Nordic countries' conditions for the development of renewable energy technologies.

A SWOT analysis is a business tool that has the objective of generating strategic alternatives by identifying the studied object's Strengths, Weaknesses, Opportunities and Threats. The SWOT analysis is basically a marketing tool, and thus is mostly used in business entrepreneurship, market research and business management, where business ideas, products or services are analysed in terms of their business potential. Some areas of the social sciences have adopted the SWOT analysis and this has resulted in a broadening of methodology, in the sense that non-quantifiable variables are used. A broad SWOT can contribute to the assessment, interpretation and comparison of socially shaped phenomena. However, the downside of applying non-quantifiable variables is, of course, that the accuracy of the information obtained is debatable.

SWOT analysis has deficiencies even when only quantitative variables and measures are used. For example, the individual factors being examined are often described briefly and very generally (Yuksel and Dagdeviren 2007). The eNERGIA team is aware of the weaknesses of SWOT analysis as an evaluation tool, and we have therefore used it only for the restricted objectives of helping us to identify case studies, and to assess and compare the Nordic countries' conditions for renewable energy technology development in certain fields.

Method used for the SWOT analysis

A SWOT analysis may be undertaken in many different ways. Here, we did not use the SWOT analysis to compare business ventures, but rather to compare much more complex phenomena: technologies, policies and national innovation systems. In so doing, we applied an important restriction – the input to the analysis was restricted to the data on renewable energy technologies and the national R&D policies gathered and reported in the rest of the eNERGIA project.

These data enable us to make a comparison between the four Nordic countries' performance in selected renewable energy technologies (wind, solar photovoltaic,

second-generation biofuels, carbon dioxide capture and storage). Iceland was excluded from the analysis, as it has no significant activity in these selected energy technologies.[1]

Further to the restriction imposed on the input data used, comparisons were made primarily *between* the Nordic countries, and with not to the rest of the world. However, as a follow-up to the present analysis, it would have been relevant to identify world-class performers, which is the usual approach in business analysis. The validity of making comparisons between the Nordic countries is supported by the fact that, while the individual countries are different, they have comparable similarities and thus can learn from each other. If one Nordic country is exceptionally better in terms of an industrial performance than the others, it is reasonable to ask why this is so, and then start to look for the answer. One of the findings, documented below, is that the Nordic countries are specialising in different directions. This point is elaborated on further in our synthesis report.

We have tried to identify the strengths in each technology area of the four Nordic countries. Where a country performs particularly well in one or more technologies, it is defined as having "good practice" in that particular technology field compared with the other Nordic countries. The identification of a case of good practice helped us to begin looking for the reasons why a particular country has good practice. In the following analysis we refer to "leaders". It is our claim that there is a race going on, and that the laggards must look to the leader and try to learn from them. This view can, however, be contrasted with another position: the Nordic countries are specialising in different directions, and the mechanisms of path dependency in any given country may be appropriate. This is a perfectly legitimate assumption. There is nothing wrong with specialisation, especially when one takes into consideration the limited resources available in each Nordic country.

Table 1: Categories used in the SWOT analysis

Energy policy and strategy	Existence of a long-term and comprehensive energy policy strategy
Policy support mechanisms	Technology-specific R&D instruments and incentives
RD&D, funding development over time	RD&D funding normalised per capita
Performance assessment	Patents and scientific articles from 1998 to 2006
R&D interaction	Scientific collaboration at Nordic level, in EU FP and participation in ERA-NETs
Industry	Energy production normalised per capita, number of R&D intensive firms in the particular energy technology field, total R&D intensive firms
Environmental impact	Environmental impact assessment and dealing with risks

[1] There has been little or no attention to other new renewable energy technologies in Iceland because of the presence of abundant renewable energy sources in the form of geothermal energy and hydropower.

However, if media reports about oil shortage, rising oil prices and global climate change are not just a media whim, but carry some serious substance, there is no reason why business entrepreneurs and governments in the Nordic countries should not form policies to promote their green industries. In this respect, an inter-Nordic comparison is useful, as it could at least give rise to ideas about how we may learn from each other to achieve more competitive Nordic economies in the future. In our analysis we have looked at various categories that indicate the activity levels in the countries studied, such as: energy policy and strategy; policy support mechanisms; research, development and demonstration (RD&D), funding development over time; performance assessment in patents and publishing; research and development (R&D) interaction at national, Nordic and European Union (EU) level; the industry sector; and environmental impact. Specific details of each category used in the SWOT analysis are described in Table 1.

Wind energy

Strengths and weaknesses

Denmark is the leader, long-term policies and feed-in tariffs are key instruments

The Danish success story in this technology is due to a clear, long-term policy focus, where the wind energy industry in Denmark has enjoyed forceful policy support and good institutional frameworks. In Denmark, feed-in tariffs have contributed to the success in wind energy production. Feed-in tariffs and other institutional frameworks that enable a growth in production are likely to stimulate industrial capacity and increase attention from corporate actors.

Danish strengths in scientific publishing and patenting

Denmark provides the case of good practice in wind energy, with the highest levels of public funding, articles (243),[2] patents (107), electricity production (20 % of national electric demand in 2007) and export-intensive firms. Two Denmark-based companies, Siemens Wind Power and Vestas Wind Systems, had an approximately 30 % share of the world market in 2007.

When looking at all four Nordic countries, these variables are closely correlated, with the exception of articles, where Sweden has a strong position (202), despite its overall low level in terms of patents (13) and energy production from wind (1 %). Norway (8 patents and 99 articles) and Finland (5 patents and 59 articles) are at a substantially lower level than Denmark on all other variables. For comparison, the USA ranks highest in terms of scientific publishing, with 2625 articles, followed by England (602) and Germany (514).

[2] The total number of scientific articles published between 1998 and 2006.

The Danish strategic planning approach has proved to be successful

The strategic planning process has proved to be a successful tool compared with the one-by-one approach (i.e. individual interactions between individual actors in a development project). A suitable legislative and planning framework has been important to support local initiatives.

Export-intensive wind power industry

Export of the wind power industry is considerable in both Denmark and Norway. The Danish wind turbine industry served 30 % of the world market in 2007. In 2007, around two-thirds of the Danish export of energy technology were from the wind power industries, compared with 30 % in 1998. The value of this export of energy technology was DKK 32.5 billion (approximately €4.340 billion) in 2004 and increased to DKK 51.8 billion (€6.906 billion) in 2007. In comparison, in 2004 Norway exported NOK 400 million (approximately €49.6 million) in wind power technology

Sophisticated knowledge base in wind energy technology

Several strong Swedish, Finnish and Norwegian corporate actors have sophisticated knowledge bases in the general technology fields that are applied in wind energy production. Because of this, it is possible that these countries my catch up on the Danish industrial in this area.

Opportunities and threats

Research collaboration

Collaboration on wind energy research is taking place at the Nordic level. In recent years, projects on wind system integration have been managed by Nordic Energy Research. Sweden and Denmark are participating in International Energy Agency (IEA) wind projects. At EU level, Risø National Laboratory-Denmark's Technical University (DTU) is coordinating a large wind project – Upwind – under the EU Sixth European Framework Programme (FP6), with partners from Finland (VTT) and Sweden (Luleå University of Technology).

Large potential for further installation of wind power in the Nordic region

Some of the strongest winds occur in Northern Europe (see Figure 2 in part 2, chapter on wind energy). Mapping of wind sources indicates that all four Nordic countries have a large potential for further installing wind power. Winds are particularly strong along the entire coastline and large parts of the inland of Norway. The Swedish south-western coastline has particularly good wind conditions, and Finland has excellent wind sources.

New efforts to increase wind power are taking place in all Nordic countries

New wind parks are being planned in Sweden in the coming years. For the period 2007–2008 the Swedish government is allocating SEK 60 million to the planning of new wind power plants. In Finland, the government has recently discussed increasing wind power substantially, and large energy companies such as Fortum have declared that they are planning for large-scale wind power generation in the years to come. However, policy instruments will be needed in Finland if, in particular, offshore wind power generation is going to be competitive. In Norway, StatoilHydro has decided to build the world's first full-scale offshore floating wind turbines. The company is investing NOK 400 million in building and developing the pilot phase, and in the R&D of the wind turbine concept.

But lack of support mechanism is a threat

The technology for and potential of wind energy has not received the same level of attention by energy policy-makers in other Nordic countries as in Denmark. In particular, without feed-in tariffs or electricity certificate systems, production is not likely to start. The capacity of the other Nordic countries to reach the Danish level of wind energy production depends on improvements in funding and support mechanisms. Without this investment the existing industrial and scientific potential to catch up with the Danish position is likely to remain unexploited.

Photovoltaic energy

Strengths and weaknesses

Norwegian mineral technology

Norway is the leading Nordic country in this photovoltaic (PV) energy technology, with the greatest production of exported solar cell panels. The Norwegian lead is also manifested in a superior score in terms of the number of patent applications and the number of firms involved. This situation did not come about as part of a dedicated energy policy, but is due to an early initiative to exploit silicon resources commercially. The strong Norwegian solar cell industry could benefit from the long-standing experience in mineral processing in Norway. Compared to, for instance, Denmark, public R&D support levels in Norway have been much lower. The solar cell industry in Sweden has grown rapidly in recent years and is partly linked to the Norwegian industry.

Strong Swedish position in scientific publishing

PV is a broad scientific field. Within this field, Norway has the largest number of patent applications (18), followed by Sweden (4) and Finland (3).[3] The activities in Norway are concentrated on silicon-based solar cells, while the patenting in Sweden is specialised in second-generation PV cells, i.e. thin-film solar cells.

[3] European Patent Organisation (EPO) patent applications 1998-2005.

Among the Nordic countries, Sweden has the highest performance in scientific publishing, with 582 articles published between 1998 and 2006, followed by Finland (251) and Denmark (148). In this respect Norway significantly lags behind all other Nordic countries, with only 105 published articles. This reflects the industrial and manufacturing profile of the Norwegian position. For comparison, the USA ranks the highest in terms of scientific publishing, with 6813 articles, followed by Japan (3880) and Germany (3336).

Danish challenge

Unlike Norway, Denmark stands out as a case where policy initiatives to develop the technology have been strong, and initiated and supported at a high level. On the face of it, this may be seen as an attempt by Denmark to take their success in wind energy into another technology. So far, however, this high-level support for PV energy has not paid off the same way as for wind energy. Despite its lead in terms of R&D support, Denmark does not have any patents, and clearly fewer articles have been published than by Finland or Sweden. This must be seen in the context of a weak industrial base in this field, with just few firms being involved. However, it is important to stress that Denmark is choosing a different path from Norway and Sweden, with its primary focus being on so-called third-generation solar cells, a technology that has not yet reached the commercial stage.

Weak domestic market

With some minor exceptions, there is no large-scale production of solar energy in the Nordic countries. The solar energy is generally produced off the national grid, for example in private dwellings, and the actual energy production is therefore not measurable. As primary production of PV energy is not going to be a growth industry in the Nordic countries, industrial development cannot rely on the home market, as is partly the case for wind energy. This limits domestic feed-in tariffs as a tool to boost the industry. In Sweden, green certificates and investment support for solar cell systems in public buildings are contributing to the increased installation of PV energy systems, and an increasing number of industrial players are entering the market.

Opportunities and threats

International cooperation

The interaction of the Nordic countries in terms of the R&D of PV energy is taking place at different levels. At Nordic level, the Nordic Centre of Excellence in Photovoltaics – coordinated by the Institute for Energy Technology from Norway – is aiming to improve Nordic collaboration in this research field. Sweden and Denmark are participating in the PV ERA-NET, while Sweden, Denmark and Norway are participating in the International Energy Agency's Photovoltaics Power System Programme.

Rapid global market growth

Globally there is a strong market growth for solar cell equipment. This might indicate potential for Denmark, Sweden and Finland to catch up and join in with Norway's success in this area. The solar cell industry in Sweden has grown rapidly in recent years. Swedish business activity is mainly in the manufacturing of modules from imported solar cells, but companies are also being established to develop the commercialisation of thin-film technologies.

Fierce technological and scientific competition

That part of the industry which is involved in exploiting existing PV cell technologies is characterised by a fierce competition to increase productivity and develop existing technologies, to achieve more efficient and price competitive technologies compared to the carbon-based alternatives.

Globally, the cutting edge of the PV industry is in the USA, in Silicon Valley. However, in terms of the science of this technology, Norway's strength is its ability to combine material technology, energy, minerals and chemistry, and to scale up the technology and to generate high levels of productivity.

The future will show whether the Danish efforts to penetrate this market will succeed. Sweden and Finland do have a science base in this PV technology, with a high level of publications and even some patents. There are great opportunities for major Swedish and Finnish actors to increase their presence on the world market.

Technological and scientific challenges

There are several technological and scientific challenges facing the PV energy industry. The technology is in an early phase of its development, and there are several competing radical technological alternatives. In addition, there is a fairly direct interaction between developments in the basic science of PV energy production and new applications. In this early stage of the technological race, existing technologies may rapidly be made obsolete by new, radical scientific discoveries and technology-driven innovations such as ink (paint) based silicon or other solutions. Norway seems to be specialising in the raw-material end of the race, i.e. the purification of silicon. Globally, the rapid growth of the market for these products has caught a lot of attention from investors.

Several industrial actors and venture capitalist funds are now investing heavily in PV energy technology. This means that the race to become highly productive has also increased in pace. This race relies on a combination of dynamic, fast-moving industrial actors and good basic R&D. These dynamics may render this industry a difficult one to enter for newcomers, despite the strong market growth. Catching up in this industry is likely to depend on the capacity to reach deep into the science knowledge base and at the same time rapidly become extremely productive in industrially. This last factor, in addition to timing, was the backbone of the Norwegian success story (see case study on the solar cell industry in Norway).

Second generation biofuels

Strengths and weaknesses

Sweden and Denmark are leading

In this sector, Denmark and Sweden are clearly in the lead, with clear policy priorities and market incentives. Industrial performance is also at a relatively high level. Denmark is a world leader in the prospect of using enzymes for second-generation ethanol production, and Sweden is developing cellulose-based ethanol. Testing plants for second-generation biofuels based on cellulose ethanol are being established in Sweden, Finland and Norway. In Sweden, the ethanol company SEKAB has great potential to be an important world producer of second-generation bio-ethanol in the coming 5–8 years. Sweden is also the leading Nordic country in using public incentive mechanisms (tax incentives and subsidies) to foster the development and implementation of a functioning biofuel market. This represents a clear advantage for, and might facilitate the introduction of, second-generation biofuels in the coming years.

Swedish and Danish strengths in scientific publishing and patenting

R&D in second-generation biofuels has a high priority in Swedish and Danish national R&D programmes. Substantial financial resources have been earmarked for the development of second-generation technologies in the coming years. Norway lacks R&D policies that specifically target second-generation biofuels. Denmark has the largest number of patent applications (52), followed by Sweden (14), Finland (12) and Norway (7).[4] Patenting in second-generation biofuels is an important domain for Danish companies, which is in line with the Danish traditions of a strong competence in biotechnology and a strong food sector. Denmark has both strong industrial actors and strong small and medium-sized enterprises (SMEs) that are specialists in this field. Patenting in Finland and Sweden is a clear continuation of the strong focus on bioenergy in general in these countries, while Norway remains in more of a starting position in this respect.

Sweden has shown a steady increase in the number of scientific publications from 1998 to 2006, with Denmark catching up in 2006. Sweden ranks highest among the Nordic countries, with 171 articles, followed closely by Denmark (134). Finland (78) and especially Norway (25) are at a lower level. For comparison, the USA ranks the highest in terms of scientific publishing, with 985 articles, followed by Spain (441) and Japan (329).

[4] EPO patent applications 1998-2005

Opportunities and threats

International R&D collaboration

The interaction between the Nordic countries in terms of R&D activity in second-generation bioenergy is taking place at different levels. At the Nordic level, the Nordic Bioenergy Project is investigating the opportunities and consequences of an expanding bioenergy market in the Nordic countries. Sweden and Finland are partners in the EU FP6 project NILE (New Improvements for Ligno-cellulosic Ethanol), which was the only bio-ethanol project to be approved FP6.

Lack of second-generation plant builders and venture capital

This is a new technological area within a broader field where Sweden, Norway, Finland and Denmark have clear strengths, both in terms of the science base and industrial activity. However, too few demonstration plants based on second-generation technologies are being built or planned, and it is unclear how the scale-up of the existing plant can be funded. The challenge, therefore, is to identify possible funding sources. Venture capital investments have not reached this field in any considerable way. Existing plants and funding might not be sufficient to meet future demand for biofuels.

Lack of adequate policy instruments

Of the Nordic countries, Denmark and Sweden have the most sophisticated policy measures in place to support domestic consumption of biofuels. This is an area where other Nordic countries could improve their performance. As is the case for wind energy, the Danish and Swedish leading position is due to a combination of technological strengths and properly directed policy measures stimulating domestic consumption. This creates a good circle of growing domestic consumption feeding industrial innovation and learning, and providing consumers with better and more accessible products. For a variety of reasons, these policy instruments are not in place in the other Nordic countries, and if this situation prevails, catching up with the Danish and Swedish performance could be hard.

Opportunities and risks with first-generation bio-ethanol

In Norway the production of first-generation biodiesel, mainly from imported plant oils, is increasing. This focus on high production of first-generation biofuels could threaten the future large-scale production of, second-generation bioenergy. With first-generation technology it is important to consider the risk of external factors, which include negative impacts on the environment and society. Recently there has been much debate about the negative impact of first-generation biofuels on food prices, and the actual contribution of biofuel use to reducing greenhouse gas (GHG) emissions. Certification of the full production chain is therefore deemed to be urgently necessary. However, the current situation can also be seen as an opportunity, as it builds up market mechanisms and could be a driver for the technologies necessary for second-generation bioenergy. Sweden is a big importer of sugarcane-based ethanol, mainly from Brazil. From a life-cycle analysis

perspective, ethanol from sugarcane is the most sustainable biofuel presently available on a large scale, as compared with corn from the USA and European rapeseed. Swedish industry, with SEKAB in the lead, has developed agreements with its Brazilian industrial partners based on sustainability criteria. In the future, bagasse from sugarcane could be an important biomass feedstock for second-generation biofuels (see Section 4: Case study of good practice: promotion and production of biofuels in Sweden – Biofuel Region and SEKAB).

Challenges in scaling up demonstration projects: high risk, high costs

Many efficiency and cost-effectiveness improvements will be needed over the 5–10 years. The main challenges in reaching full-scale commercial plants for cellulose-based ethanol production are related to the high risk and high costs. Current estimates indicate that a single ethanol plant would require up to SEK 1 billion to scale up production to a commercially viable quantity. There are also many uncertainties associated with the success and economic returns of the first commercially viable plants.

Carbon capture and storage

Strengths and weaknesses

Norway is the leader in carbon capture and storage (CCS)

Norway has a high production of oil and natural gas and, because of the introduction of the carbon dioxide tax in 1991, oil companies have been actively exploring and developing CCS technologies. There are several important industrial actors in CCS technology in Norway. The Sleipner project, initiated by the Norwegian company Statoil, has become an international, full-scale demonstration plant for CO_2 storage in aquifers. The technology companies Aker Clean Carbon and Aker Solutions work actively with commercial applications of CO_2 capturing technologies, both for gas- and coal-based emissions. The industry actors have a high level of R&D activities, and they collaborate with the most active Norwegian R&D organisations in this field, the Norwegian University of Science and Technology (NTNU) and Sintef.

There have not been many patent applications in CCS. Of the Nordic countries, Norway has the largest number of patent applications (8), followed by Denmark (3) and Finland (1).[5] In terms of the number of scientific publications, Norway has shown a steady increase from 1998 to 2006, with Sweden catching up. Norway had a total of 71 articles and Sweden had 62 articles published in that period. Denmark (22) and Finland (13) are at a lower level. For comparison, the USA ranks the highest in terms of scientific publishing, with 864 articles, followed by Canada (199) and Japan (166).

[5] EPO patent applications 1998-2005

Policy instruments – the carbon tax is an important driver

In the early 1990s the Nordic countries implemented CO_2 taxes (or carbon taxes'), but these work slightly differently in each country. The introduction of a carbon tax for petroleum-related activities on the continental shelf was a driver for oil and gas companies operating in Norway to engage in CCS-related R&D. The Norwegian authorities have implemented several policy instruments to strengthen the focus on CCS, such as research programmes and Gassnova, the governmental centre of CCS expertise.

Swedish and Danish industries are important actors …

For various reasons CCS-related R&D is of minor importance in both Finland and in Sweden. Sweden is nevertheless participating in EU-funded projects on CCS, wherein Vattenfall is one of the most actively participating companies. CO_2 demonstration plants are being developed in southern Sweden by EON and Alstom, and Vattenfall is building a full-scale demonstration project in Denmark. Danish firms have been active in the CASTOR EU FP6 project. In Finland there are no important industrial actors in CCS technologies.

… but so far little attention from policy-makers

Despite the use of coal in combined heat and power (CHP) stations and oil and gas production in Denmark, policy-makers have not directed enough attention to the development of CCS technologies, which is also reflected in the low level of funding and government support for R&D for CCS technologies in Denmark. Similarly, we found no evidence of significant research programmes or public funding for CCS in Sweden. However, there are important R&D environments in Sweden active in the CCS field, such as Chalmers University of Technology and Lund University. In Finland CCS-related R&D is of minor importance.

Opportunities and threats

Mongstad represents a good opportunity for inter-Nordic and international collaboration

The Test Centre Mongstad (TCM) is being developed by Norwegian (StatoilHydro), Danish (DONG), Swedish (Vattenfall) and Dutch (Shell) companies. This project represents an opportunity for the three Nordic countries to reach a world-leading position in CCS technologies. The TCM is an international project to develop and test technology pathways for CCS, and will provide valuable recommendations for further RD&D policy. Close inter-Nordic country collaboration, such as in this case, is an important opportunity to have a greater influence on EU RD&D policy and potentially leading to the setting up of ERA-NETs. At the same time, other CO_2 capture units are being prepared. Aker Clean Carbon (ACC) is conducting a front end engineering and design (FEED) study for the CCS facility at Kårstø, and ACC is participating in an international consortium in the UK government's competition to develop the first commercial-scale CCS project for a coal-fired power plant. As a part of the EU FP6 project CASTOR, in 2006 the Danish company Elsam launched the world's largest pilot plant for capturing CO_2 from the flue

gases of a coal-fired power station at Esbjerg. The pilot unit is capable of treating 1-2 tonnes of CO_2 per hour.

Major challenges remain for carbon storage

There are technological and scientific challenges in the CCS area, such as developing CCS systems. The high costs associated with capture and storage can hinder the development of large scale versions of such technologies. The USA and Japan are leaders in commercially available absorption technologies, and the USA is undertaking robust R&D efforts to develop membrane technologies. A low public acceptance and technological barriers (e.g. leakage of CO_2 from storage sites or transportation) could be a threat to, or even preclude, the future large-scale deployment of CCS technology. The environmental aspects of carbon storage have to be investigated further, and storage sites need to be monitored over a long time frame. In addition, international regulations for CO_2 storage must be developed.

Main conclusions

Denmark has clearly strengths in wind power technologies, in terms of both energy production and the scientific and industrial base. Perceived weaknesses in this sector in Denmark are a lack of human resources in the technology area, which is a problem for the industry when recruitment needs cannot be met. In PV energy technologies, Norway has a clear technological and industrial advantage compared with the other three Nordic countries. As with the case for wind energy in Denmark, the Norwegian PV industry needs more science and technology graduates. A considerable problem in Norway is the lack of support mechanisms, such as feed-in tariffs and certificate systems, that could help foster the development of, in particular, wind power and bioenergy. Finland has chosen to invest further in nuclear power, which might slow down or divert attention away from renewable energy technologies. This trend is further confirmed by the four new nuclear power stations being considered in Finland. Sweden has significant industrial and research activities in the four selected technology areas. In the coming 5 years Sweden has great potential to become an important producer of second-generation biofuels. However, the timing and availability of funding for scaling up demonstration projects are major challenges.

Although venture capital investors have increased activities in alternative energy during the last couple of years, their level of investment in the Nordic countries remains relatively small. Norway represents an exception in this context, especially if CCS is considered. Norway has some of the world's leading companies in CCS technologies, and CCS ranks high on the Norwegian political agenda.

The rapidly growing global competitiveness and rapid market growth in renewable energy technologies represent both a challenge and an opportunity for the Nordic countries. In this context, a strong science base combined with high industrial productivity, backed by strong political commitment, are crucial factors for becoming successful global players in the renewable energy field. The results of our analysis indicate that the Nordic countries, within their different fields of specialisation, have

great potential to become such players in the renewable energy technologies examined in this study.

SWOT analysis, by country, of selected renewable energy technologies

The tables presented below describe the Strengths, Weaknesses, Opportunities and Threats in the four energy technology fields for the four Nordic countries. The most salient characteristics of the energy technologies in the four countries are described.

Table 2: SWOT analysis for Denmark

Renewable energy technology	**Second-generation bioenergy**	**Wind energy**	**PV energy**	**CCS**
Strengths	Patents, Publishing, Enzyme industry, Generous public funding	Long-term policy focus, Public funding, Articles, Patents, Firms, Electricity production, Export of wind technology, Feed-in tariffs, Close science–industry links, Strong demand	Development of third-generation solar cells	CASTOR pilot: world's largest pilot study for CCS for coal PP, Industrial actors (Elsam, DONG), CO_2 emission tax, Patents, Publishing
Weaknesses	Lack of venture capital, Lack of plant builders	Lack of human resources, Slowdown of activity on home market	Venture capital, Policy instruments	Too little European collaboration
Opportunities	Clear policy priority, R&D, existing Infrastructure for further development, Scaling up of demonstration project	Export Offshore Onshore, repowering	Relatively strong public R&D support level, Rapid global market growth, R&D focus on third-generation solar cells	Nordic R&D collaboration (Test Centre Mongstad)
Threats	Slow transition phase from first- to second-generation	Strong global competition	Technological and scientific challenges, Strong global competition	Public opinion for storage

Table 3: SWOT analysis for Sweden

Renewable energy technology	Second-generation bioenergy	Wind energy	PV energy	CCS
Strengths	Publishing, Industrial attention, Strong R&D interaction, World-leading industry (SEKAB)	Scientific publishing, Firms, R&D activities and international collaboration, Incentive programmes	R&D focus on second-generation solar cells, Manufacturing of solar cells, Ångström Solar Center	Publishing, Strong industrial actors (Vattenfall), CO_2 emission tax
Weaknesses	Insufficient funding, Lack of plant builders	Low level of patents	Venture capital	No patents Few R&D environments
Opportunities	Pilot plant for cellulose-based ethanol, Abundant bioenergy resources, Scaling up of demonstration projects	Green certificates, Sophisticated knowledge base, Natural conditions, Industrial potential, Long-term planning of national targets Many new investors are entering the market, Good hydro- and wind power compatibility, Planning of new wind-power plants	Green certificates, Investment support, Rapidly growing solar cell industry, Rapid global market growth, Strong science base	Nordic collaboration, Participation in EU-funded research, R&D environments
Threats	Slow transition phase from first- to second-generation	Strong global competition	Technological and scientific challenges, Strong global competition	Strong R&D efforts in the USA, Public opinion for storage

Table 4: SWOT analysis for Finland

Renewable energy technology	Second-generation bioenergy	Wind energy	PV energy	CCS
Strengths	Europe's largest R&D institution in bioenergy (VTT), building of advanced gasification test equipment, Industry–science collaboration	R&D capacity, EU/Nordic R&D collaboration	Strong science base	Presence of R&D environments for CCS, Nordic and EU project collaboration
Weaknesses	Insufficient funding, Too few demonstration plants, Lack of plant builders	Low production level, Slow progress in increasing wind power, Low industrial activity, Low incentive mechanism	Lack of industry, Little Nordic and European collaboration	Low investment in CCS
Opportunities	Strong RD&D activities, Strong pulp and paper industry, Scaling up of demonstration projects	Some patents, Publications, Sophisticated knowledge base, Good natural conditions	Rapid global market growth	R&D activities, Research collaboration
Threats	Global challenge, Domination of first-generation biofuels, High production costs, Production capacity under construction, Slow transition phase from first- to second-generation	Low political commitment, Increase in use of nuclear power, Global competition	Technological and scientific challenges, Strong global competition	Low political priority

Table 5: SWOT analysis for Norway

Renewable energy technology	Second-generation bioenergy	Wind energy	PV energy	CCS
Strengths	Pilot projects at industry level, Developed process industry	Firms, R&D collaboration, Production of large turbines, Export of turbine blades and services within wind mapping	Strong national metallurgical silicon industry, Combination of material technology, minerals, chemistry and ability to scale up technology and generate high production levels, Global industrial actor, High competence	At the core attention of national energy policy, Long R&D traditions in CCS, Policy instruments, Public funding, Patenting, Publishing, Sleipner CCS, Industry–public science collaboration, Strong industry actors (Statoil-Hydro, Aker)
Weaknesses	Low public R&D support level, Lack of plant builders	Low production level	Low public R&D support level, Lack of qualified workforce	Low attention to storage safety
Opportunities	Abundant bioenergy resources, Investment support, Scaling up of demonstration projects	Industrial potential, Sophisticated knowledge base, Growing industry, Strong knowledge in oil and skip industry for offshore installations, Good hydro- and wind power compatibility, Excellent natural conditions	Rapid global market growth	Strong R&D environments, Policy instruments, StatoilHydro participation in EU FP, European Test Centre Mongstad, Aker Clean Carbon as global actor
Threats	Slow transition phase from first- to second-generation, Lack of support mechanisms	Negative public opinion on onshore installations, Strong global competition, Lack of support mechanisms	Global competition, Scientific and technological challenges	High costs, Strong R&D efforts in the USA, Public opinion on storage

2 Summary of the eNERGIA Workshop on Environmental Consequences of Deployment at Scales of Alternative Renewable Energy Technologies

Global warming, security of supply, and the economic impact of high energy prices and climate change represent the background for the increased focus on policy on renewable energy. The answers to how the share of renewable energy production can be increased are not clear cut. At the global level there is room for all kinds of renewable energy, while at the regional and national levels different renewable energy technologies compete.

New solutions that may seem well intentioned, such as biofuels for cars, may have unexpected implications, such as increased death by starvation in poor countries. Some countries are fast movers and have come a long way. Other countries find themselves dependent on paths of their existing energy sources, which are well protected by institutional arrangements. An important obstacle to development is everything we do not know. There are many areas that have not yet been addressed by research. This ignorance due to lack of research diverges into confusion, uncertainty and an inability to act. Another hindering factor is the established institutional arrangement and 'systemic' mechanisms that maintain path dependency of energy sources. A third challenge is the step from the knowledge base on new solutions to investment in new energy systems in practice.

The Workshop was held on 24 –25 April 2008 at NIFU STEP and brought together experts on the environmental consequences of renewable energy technologies. The Workshop focused on four selected technology areas: wind energy, carbon capture and storage (CCS), photovoltaic (PV) energy (including silicon), and second-generation bioenergy.

The structure of this summary corresponds to the structure of the Workshop as it was organised. There were four sessions, each of which consisted of one or two presentations followed by a discussion.

Session 1 Sustainable development and renewable energy

The Workshop started with a cross-cutting theme, *Sustainable Development and Promotion of New Renewable Energy Technologies.* In his presentation, Audun Ruud, from Prosus, University of Oslo, pointed out the basic problem of path dependency of dominant energy systems, and the corresponding dynamics in renewable energy policy governance in Norway. If the political objective of sustainable development, and consequently the promotion of renewable energy, is to be achieved, it is evident that the degree of policy coordination across issues (and ministries) with strong sector interests is too low. How is renewable energy to gather political attention and resources when at least three ministries, often with diverging interests (the examples given in the presentation were the Ministry of the Environment, the Ministry of Petroleum and Energy, and the Finance Ministry), are to compromise. At an aggregate level, how can we foresee a

solution or a problem-solving process that can contribute positively? According to Ruud this is a tripartite issue:

1. Is this a question of *greening of energy policies*?
2. Is it a question of *integrating energy into environmental policies*?
3. Or is the issue to strengthen the *interaction of environmental and energy policies*?

If one of these three options is contributing to improved attention and resource allocation to sustainable development and renewable energy, what if the Ministry of Finance at the end of the day obstructs a corresponding financial flow? This is a fundamental topic, and there is more information about this in a report from the OECD Monit project, in the chapter about energy and innovation.[6] According to Ruud, the basic rhetorical questions are: Is there sufficient political concern for sustainable development across sectors? Is there political and bureaucratic will for sustainable development to be a fundamental concern? The answer is probably 'No', Ruud argued.

If 'No' is the answer, how can the concern for sustainable development be brought up on the agenda? Improving transparency is an issue to start with. Bureaucratic attention and dedication were also basic points addressed by Ruud. He referred to the example of when ministers or bureaucrats leave meetings after their presentations, without listening to other contributors or taking the time to discuss, as an indication of lack of attention and dedication. There are clear structural problems in Norway compared to other countries. With this in mind, do we have good practice in the Nordic countries to look to? The Nordic countries organise their energy policies, environmental policies, etc., in different ways. It seems that we lack more systematic information about this. The message from Ruud is that there is no quick fix, and he refers to a forthcoming book on Edward Elgar in September 2008.[7]

The discussion that followed Ruud's presentation was broadly focused on how to deal with path dependency and related obstacles. What kinds of innovation are needed? One suggestion from the participants was to take the message of global aspects communicated by Jeffrey Sachs into consideration. We have an opportunity to solve all problems. Can we learn from what is going on in the global arena? The answer is 'Yes', according to Sachs. We can learn from the use of partnerships, getting to understand what partnership is, how it can be implemented, and what it implies.

A repeated question in the discussion was: What is the problem? Considering the need for change, what is the chicken and what is the egg in this situation? Is it investments and market changes, or is it structural changes that are to lead the way? Is it basically a political structural problem, as Ruud argues? Is it the lack of central authority and the corresponding strong and diverging interests of the ministries? According to some of the participants in the Workshop it is a question of whether there is sufficient political mandate and bureaucratic will to promote renewable energy sources. If you look at what is going on, there seems to be both a lack of political will and no incentives to invest in Norway. Both the political and the financial risks of investing in renewable energy

[6] OECD, Governance of Innovation Systems, Vols 1-3

[7] Lafferty W. and A. Ruud (eds.) (2008) Promoting Sustainable Electricity In Europe, Edward Elgar (forthcoming in September)

sources in Norway are very high. There is a need to look to and learn from other countries, such as Denmark, where the momentum of the application and industrial development of wind energy has been established and maintained by strong systemic features. This implies that all types of actors have been gathered around one vision of making wind energy technology a success.

The discussion indicated that the Norwegian policy promotion of sustainable development and renewable energy seems to be challenged by a strong path dependency in the dominant energy systems. There financial and political interests in relation to the energy systems are strong. How can the variables that maintain the strong degree of inertia against changes in the dominant energy and production systems be influenced so that new paths can be created? According to several of the participants in the workshop there is need for reinforcement of the variables that influence the development and diffusion of renewable energy technologies. There is need for reinforcement of the variables that influence the competition in markets for different renewable energy solutions. And there is need for reinforcement of the variables that influence the integration of renewable energy technologies in local energy systems.

The discussion confirmed the point made by Ruud in his presentation. Interactions between actors are very important. There is not a 'one size fits all' solution to the institutional setting, but the structure is important, as is the political will to set a vision and goal. This is lacking in Norway! Sweden has done better, with former Prime Minister Göran Persson's ambitious targets to make Sweden an Oil free society by 2020.

According to the discussion the questions are, however: Is there really any environmental concerns in the energy policy? Perhaps the policy concern rather is influenced by concerns for security of supplies, concerns for research and development, concerns for economic growth, and concerns for regional development. And are these energy-policy concerns competing with or complementary to environmental concerns? To what extent is there a concern for sustainable development? If there is a concern for climate change and renewable energy sources, to what extent is there a *political mandate* and *bureaucratic will* to promote sustainable development?

Session 2 Solar Photovoltaic technology

The session on solar photovoltaic technology (PV) was introduced by Mariska de Wild-Scholten, from the Energy Research Centre of the Netherlands (ECN), Unit Solar Energy, with a specialisation in studies of the environmental impact of PV using the methodology of life-cycle assessment (LCA).[8] LCA is a comprehensive methodology with two main steps. The first step is to describe which emissions will occur and which raw materials will be used during the life of a product. This is usually referred to as the inventory step. The second step, referred to as the impact assessment, is the assessment of what the impacts of these emissions and raw material depletions are. In the presentation, this final step was an impact assessment within the damage categories of human health, ecosystem quality, climate change and resources.

[8] LCA models the complex interaction between a product and the environment from raw materials to disposal.

Going through the LCA of PV energy, the presentation addressed a number of concrete measures and a number of policy issues for discussion. As exploitation of PV technology depends on the sun, many of the measures depend on local, geographical parameters. Among the overall policy issues addressed is the need for updated data that can be fed into the life-cycle inventory. Another issue is as central as it is neglected. There is a need to establish waste management and recycling systems. It is clearly better to do this at the supra-national level. There are recently established initiatives of waste management and recycling systems in the European Union (EU).

An important consideration addressed in the presentation, and this is an issue potentially for policy and regulation, is the issue of energy use/consumption in the PV energy value chain. This issue is directly linked to the energy payback time for PV technology, which is roughly 1.5 years in the south and 3-4 years in the north of Europe[9]. According to the ECN researcher, there has been an evolution of the energy payback time in recent years, reflecting the many options for improvement that exist in technological innovation. These include replacements for scarce and toxic materials, reductions in material and energy consumption, reductions in waste and emissions, and an increase in the performance (efficiency) of the solar panels.

Summing up the main message from the presentation and discussion concerning the environmental consequences of PV technologies, waste management and recycling systems are crucial to save existing resources. There is a need for more research into replacements for scarce metals. In terms of the currently most common environmental impact, greenhouse gas emissions, PV technology has the same level of emissions as other renewable energy production types. Finally, there is urgent need to improve the quality of data quality, thus enabling improved LCA.

After the main presentation in the PV energy session, the industrial success story of PV technology in Norway was presented by researcher Åge Mariussen (NIFU STEP). A fortunate coincidence of a range of circumstances and factors, such as a competent entrepreneur's will to spin-off and innovate, localised industrial competence and raw materials, and risk capital from regional policy instruments, enabled the start of the Norwegian solar cell adventure. Later, a perfectly timed investment in a US raw material supplier solved problems of forthcoming raw material scarcity and increasing prices, and shaped the basis for value creation on the stock market. The story of the Norwegian PV industry is one that does not include research and development in the way that one likes to believe industrial development occurs. The presentation did not address explicitly the environmental impact of PV technology, but together with the main presentation it did raise issues for discussion.

A general remark in the following discussion about the environmental impact of PV technology concerns the advantages of PV compared with other renewables. The flexible solutions that PV technology offers means that in certain situations it can leapfrog other energy-supply solutions, e.g. in geographical areas where large-scale infrastructure is lacking, or where there are mobility issues. This is of course more relevant in developing

[9] The energy payback time is defined by the energy input during the module life cycle (which includes the energy requirement for manufacturing, installation, energy use during operation, and energy needed for decommissioning) and the annual energy savings due to electricity generated by the PV module.

areas of the world. In developed countries, where PV energy is supposed to complement energy supplied by the existing grid, the issue of infrastructure investment is more related to the need for a more flexible transformation capacity.

Session 3 Biofuels

Second-generation biofuels are made from lignocellulosic biomass feedstock using advanced technical processes. Lignocellulose sources include woody, carbonaceous materials that do not compete with food production, such as leaves, tree bark, straw or woodchips. In addition, new bioenergy technologies, including solutions based on gene technology, enzymes, algaes and so on, are emerging that possibly have great potential.

This section draws on input from different sources in addition to the Workshop organised by NIFU STEP in the eNERGIA project. Studying energy policy strategies and policy systems, and the energy technology and energy production status in the Nordic and Baltic countries, has given the NIFU STEP research team valuable information. The session within the eNERGIA Environmental Impact Workshop was to focus mainly on second-generation biofuels, but this turned out to be problematic, partly because it is impossible to discuss the environmental impact of second-generation biofuels without also referring to issues associated with first-generation biofuels. The main difference between first- and second-generation biofuels is that the former are produced from only parts of the raw material, while the latter are produced from the whole biomass source. The environmental aspects of second-generation biofuels are therefore more positive than those of first-generation biofuels.

Having studied biofuels from the technology and policy perspective, it seems evident that when discussing the environmental impact of biofuels, it is necessary to consider the raw material. Biofuels derived from different raw materials have different impacts on the environment in terms of greenhouse gas emissions (GHG). Life-cycle assessment (LCA) is the method by which the environmental accounts of different types of biofuel are estimated. There is a need to improve the systematic LCA within this domain. For example, corn-based ethanol from the USA performs worse than sugar cane from Brazil. Moreover, forest wood from Scandinavia performs better than sugar cane based ethanol from Brazil, and European rapeseed is not competitive with Brazilian ethanol from sugar cane.

The recent media headlines about biofuel production compromising food production in the global context show that this theme is highly relevant and problematic. There has in fact been a growing uncertainty about how large emission reductions could be. Biofuel production may also have a negative impact on biodiversity.

The main Workshop presentation on biofuels focused on an example of biofuel from Norwegian wood combined with carbon capture and storage (CCS) solutions, presented by Tom Bøckmann from Tel-tek. The example case is in the phase of research, development and demonstration. While there were positive comments about this biofuel/CCS energy alternative, questions were raised about the economic viability of the process. The discussion addressed basic issues of bioenergy production and consumption. Numerous difficulties are encountered when determining the environmental impact of

bioenergy. Is it the right choice to use forest wood for biofuels? Is the impact of first-generation biofuels only negative and that of second-generation ones only positive? It was emphasised that there are not abundant resources for bioenergy. In fact, on the contrary, the resources are scarce. This might be the case in many countries, but the overall situation is complex.

Going through energy policy strategies in the different Nordic and Baltic countries it is the NIFU STEP research team's reflection that different countries adopt different strategies and place different emphases and priorities when considering bioenergy in general and biofuels in particular. Some countries adopt a 'wait and see' approach, while others have already come a long way in investment and production. Finland and Sweden belong to the latter group of countries. Even though Norway has not prioritised bioenergy as heavily as Finland and Sweden, the Nordic region is definitely a rich region in this context. Second-generation biofuels from boreal forest represent a natural solution by which the region may achieve a significant reduction in the impact of transportation. Exports of biofuels may even contribute significantly to a reduction in transport emissions in the rest of Europe.

According to the participants in the workshop some experts only support second-generation biofuels because of the issue of food production. Other observers argue that there is a need to support an expansion of first-generation biofuels, and thereby support the investment in the necessary infrastructure, so that the demand and the value chains for bioenergy are built up. This of course triggers the question of whether we should instead use biomass for combined heat and power purposes, which is more energy efficient. The workshop discussion revealed different and partly opposing opinions on this topic.

A comment from the participants of the workshop focused on the fact that liquid coal resources can be a serious competitor force of biofuels. However, now coal prices are increasing, and this price growth will trigger different mechanisms of allocation to different technologies and energy carriers.

Session 4 Carbon capture and storage

The main presentation on carbon capture and storage (CCS) was given by Peter M. Haugan, of the Geophysical Institute, University of Bergen, Norway. Having worked on CCS for decades, Haugan pointed out that it was remarkable that this was the first time he had been invited to speak about the environmental consequences of CCS.

According to reflections in the presentation and the following discussion, at a general level, the key to CCS is the oil industry, which is well equipped in terms of financial resources, technology and competence. Experts seem to agree that CCS is necessary in a transition phase towards a carbon-neutral society. A possible problem with CCS is that, even though it cannot be considered a renewable energy technology, resources for technological development within renewable energy and CCS are scarce and seem to be competing. According to the discussion, this is at least how it looks in the Norwegian case. As coal-based energy is still being a part of the economy, there is need to retrofit (i.e. clean) old power plants because they are already there. The main global sources of coal are in the USA, China, India and Australia, and thus it is in these areas that the main

effort must be made. Compared to current technology, there is need for improvement in the energy efficiency of the CCS operations themselves.

According to Haugan's presentation the main issues of CCS and its environmental consequences include:

- a lack of knowledge about storage, and
- the size and magnitude of CCS operations (i.e. the importance of scaling up).

These two main issues are linked to a range of technical, economic, social and political issues that were addressed and discussed in this session.

Lack of knowledge about storage

The discussion about the lack of knowledge about storage started by addressing the following issues:

- CO_2 is less dense than water in the sub-sea sediments and thus it can escape. There is huge uncertainty in monitoring this phenomenon, and this fact is under communicated.
- CO_2 leakage may have an impact on flora and fauna.
- There are risks of subsurface fluid flow and fluid–rock interactions on time scales of hundreds to thousands of years.
- There is a lack of knowledge about CO_2 storage in abandoned wells and well borders.
- The risks of migration into groundwater and lakes need to be studied further.

The following policy issues were discussed:

- The OSLO–PARIS (OSPAR) and EU directive appendix shows ignorance and immaturity in its policy reflections. The concept "indefinite" is used by the EU, which illustrates the naive attitude present.
- The EU policy banning deep ocean storage – this transfers responsibility to national governments.
- Science and politics have been decoupled. Politicians are taking irrational decisions. Deep ocean storage is banned, but not for scientific reasons.

Going more into details, the discussion revealed that the main risks of storage are related to the leakage of CO_2 and the impact of this leakage. A main impact of CO_2 leakage is reduced biodiversity. Injection of CO_2 requires high permeability of the receiving material, and overpressuring can compromise the rod cap, with the result that CO_2 leaks into gas reservoirs. Other impacts include groundwater salinification, mobilisation of methane, acidification and limnic eruptions (local) (on land, not in the ocean). Storage may induce small seismic events. Of major importance is the difficulty of estimating the amount of CO_2 in situ. There is currently no technology for monitoring CO_2 at sea level, just for seismic monitoring. There are huge areas of CCS science that are not understood properly, and this is indicated by the fact that there are few peer-reviewed publications on the subject (Socolow 2002).

One issue addressed in the presentation and the discussion is that despite the huge uncertainties in the technology, we can still look back on more than 25 years of experience with CO_2 storage in Norway. CO_2 has been stored for more than 10 years in the Utsira formation, an area composed mainly of. The so called Troll formation near Mongstad is more variable in composition, and can compromise gas production. There is currently new activity on Svalbard, where the overall (and in fact realistic) objective is a carbon-neutral society not too far in the future.

The discussion emphasized that even though the CO_2 storage is considered problematic in EU policy formulations, there has been no problem with public opinion of this technology in Norway. The reason for this may lie in the public's consciousness of a strong seismic knowledge generated because of oil/gas extraction.

Size and magnitude of CCS, the importance of scaling up

In the presentation and the following discussion it was emphasized that when it comes to basic environmental impact, emissions from capturing processes are similar to those of standard power plants. CCS was introduced because there was need for it, and it has been used in industry since 1981. The technology is therefore mature and established, but it has never been implemented for purely environmental purposes, which require *scaling up.* This is doable, but not easy. To use CCS for environmental purposes it is necessary to scale up the existing technology 10 fold, and this may involve major problems. This was a recurring theme in the discussion. Currently, the EU is projecting 12–15 full-scale development sites to test CCS. From 2020, in the EU CCS will be mandatory in coal plants. Globally there is need for 3500 storage places. Is it possible to build this fast enough? China is building as many coal plants every 7 months as the UK is currently operating. Just in order to keep up with the growth in fossil fuelled plants, there is need for 750 sites similar to Sleipner each year.

A question that came up in the discussion addressed whether the Norwegian Government is "on the ball" with regard to CCS? The answer was yes, or at least more so than other governments. The EU and Norway are working together, and have established good processes. Germany has the same national policy as Norway, and top level government is involved, but there is a question of whether the bureaucracy is sufficiently involved to make the system work effectively.

The discussion of the presentation raised a range of problematic issues and challenges. It is a challenge that the debate is about either technical issues or costs. Where is the debate about the policy dimensions, coordination, and global industrial/political agreements? There are uncertainties related to CCS yes, but we should be more optimistic and willing to run CCS at a lower target efficiency (e.g. not aim at 99 % efficiency, but at 95 %), which would reduce costs radically. We are too pessimistic about costs and too optimistic about time.

Another question in the debate was, is CCS a means to an end or a goal in itself? Path dependency on CCS can lead to lack of attention/emphasis to renewable energy. This is linked to the debate of industrial development as an intrinsic part of CCS efforts. Even at the fastest possible rate of investment in CCS is it possible to make a difference when we know there is need to clean most/all facilities globally?

The debate revealed that the precautionary principle is central, but it seems to be used differently in different countries and in the EU depending on topic/knowledge/consciousness. The precautionary principle is used against storage in the sea, but there is in fact no technical problem with storing carbon deep in the sea bed, as it will never come to the surface. The precautionary principle is also used in Norway against investment in onshore wind energy generation. The precautionary principle is used differently in different contexts.

Session 5 Wind energy

The main presentation in the wind energy session was given by Charlotte Boesen from DONG Energy, Denmark. Dong has wind energy operations in northern Europe: Denmark, The Netherlands, Poland, the UK and France. Boesen has experience in the strategic planning and assessment of offshore wind farms in Denmark.

Boesen gave an overview of the environmental issues related to wind power. It indicates the broad areas of impact that wind turbines may have.

- Socio-economic effects/human:
  - Visual effects,
  - Landscape,
  - Use of the area – leisure, tourism, agriculture,
  - Shipping, military, etc.,
  - Archaeology and culture.
- Noise emission – under and above water.
- Animal and plants:
  - Plants and habitats,
  - Fish and benthic fauna,
  - Birds,
  - Reindeer,
  - Other mammals.

The main emphasis in the presentation was on the advantage of the strategic planning approach as compared to the one-by-one approach. According to Boesen the issue of one-by-one or strategic planning is of crucial importance from a policy perspective. The strategic planning approach is a top-down controlled approach, which is essential to avoid the “not in my backyard” (NIMBY) effect. The strategic planning approach is a comprehensive strategic process that has been used with success in Denmark. The one-by-one approach by and large implies interactions between power companies and individual developers and private investor/landowners and the authorities in a development project.

Boesen emphasized that the strategic planning approach, which has been used in offshore wind energy generation in Denmark, includes governmental/regional authorities and stakeholders. The approach has been used in planning the Danish offshore wind farm projects Horns Rev and Nysted. It includes strategic screening of grid connections, and

assessment of issues such as wind resources, protected areas, and access roads, migration routes/bottlenecks.

In the presentation it was argued that strategic planning is more effective but is time consuming. It contributes to a reduction in political risks. The Danish government wants the regional authorities to do the planning. Currently planning is underway to replace old small turbines with new larger ones. The authorities in Denmark, Norway and Sweden are quite pragmatic about monitoring, while in the UK, Germany and Poland the authorities are quite restrictive and not very flexible.

The history of Danish wind energy is special because of the initial development of small turbines and their ownership by farmers. Boesen presented this story. Technological developments have led to larger and more efficient windmills, but the restructuring processes (exchanging many small wind turbines with fewer larger ones) in Denmark have become difficult due to local public opinion. The debate and resistance encountered is in fact similar to strong public opinion against wind energy in Norway. Boesen has experience from Norwegian wind energy initiatives as well.

The presentation gave insight into the environmental impact assessment that has been done in Denmark. After screening follows scoping, which is an early, critical step in environmental impact assessment. Scoping needs to be focused and balanced. Poor scoping can lead to a situation where investigations are repeated, relevant mitigating measures are not identified, and requests for further information lead to delays and more work. Generally, the message from Boesen is that there is need to allocate resources to monitoring procedures and there is need to monitor research. Moreover, there is need for competence, and reflection focusing on what kind of information is needed (or of importance) in different contexts.

The most important variables that have been focused on in the projects in Denmark include visual effects, leisure, noise (under and above water) and birds (collision). Boesen presented results from EU research. According to 31 studies in the EU, the average number of bird collision is 9 birds/year per turbine, but this varies greatly from area to area. In addition, the impact on harbour porpoises has been investigated. Generally there is a need for knowledge sharing and knowledge use across borders.

The level of monitoring is the same in all the Nordic countries, but the focus of the monitoring is not good enough. The message from Boesen in DONG to policy-makers and bureaucrats is that monitoring should be more focused.

The wind energy session also included two presentations by Ask Rådgivning, a Norwegian consultancy that specialises in the energy sector. These presentations focused on the environmental assessment of forthcoming Norwegian wind farms, including specific attention to wind farms and reindeer husbandry. Almost all wind farms in Norway are located in wilderness areas, where tourism, national heritage and wildlife are significant factors. In Norway the connection of wind turbine to the central grid often implies very long power lines.

Ask Rådgivning emphasized that disturbance is always an issue when wind energy is the topic in Norway. Both primary effects and secondary effects are of great importance. Bird life is very sensitive to disturbance. The birth rate of some birds is endangered and

this represents a serious hindrance to wind energy projects. Work and research on the impact of wind turbines on migratory birds is sorely lacking.

The last presentation focused on wind farms and reindeer husbandry, which raises natural and anthropological challenges in relation to wind farms. There is need for before and after studies on reindeer husbandry and wind farms, but such studies require control areas in order to isolate the effects of the wind farms. Reindeer husbandry requires large territories, and large movements are one of the more central issues that imply conflict. Reindeer are sensitive to the seasons, in particular the insect season, when they need to be high up in the mountains.

According to the presentation wind turbines do not seem to have impact on reindeers. Rather it is the human aspects related to the (5000–8000) herdsmen that are the biggest challenge. There are indications of increased individual/social tensions, and the problem is that reindeer herdsmen often do not know how to resolve the issues. People seem to be fleeing windmill areas.

There may be a difference between the 30,000 wild and 200,000 semi-domesticated reindeer. In the discussion questions were raised about political issues and protests against wind farms. Who is it that is actually protesting? There seems to be need for research on this topic as well.

The message from Ask Rådgivning is that there is need for dialogue when it comes to wind turbines and reindeer husbandry. A cooperative approach, with early involvement, information and dialogue, is very important, and is a problem-solving process in itself. The process may include all stakeholders, local people, herdsmen, Sametinget, and so on. Coordinating the scoping and the effects is essential. An organised coordination and decision/planning process involving the different stakeholders results in more consensus-based decisions and increases the possibility of success.

Among the issues raised in the discussion was the question of how big is the reindeer problem in terms of the need for research and an improved knowledge base. How can knowledge be better shared? The message from the experts is that one should focus on strategic planning in Norway. There is a need for coordination of procedures. In relation to research needs and knowledge sharing, the need for cross-national coordinated funding may be a issue for Nordic policy.

Table 6: List of participants in the eNERGIA Workshop on Environmental Impacts and Consequences of Deployment at Scale of Alternative Renewable Energy Technologies, 24–25 April 2008, Oslo

Name	Institution
Jonathan Colman	Ask Rådgivning
Torgeir Isdahl	Ask Rådgivning
Bjørn Utgård	Bellona
Charlotte Boesen	Dong Energy
Mariska J. de Wild-Scholten	Energy research Centre of the Netherlands ECN, Unit Solar Energy
Antje Klitkou	NIFU STEP
Aris Kaloudis	NIFU STEP
Lisa Scordato	NIFU STEP

Trond Einar Pedersen	NIFU STEP
Åge Mariussen	NIFU STEP
Amund Vik	Nordic Energy Research
Andreas Bratland	Norsk bioenergiforening
Audun Ruud	Prosus, University of Oslo
Laure Delmas	SFFE
Tom Bøckmann	Tel-tek
Peter M. Haugan	University of Bergen
Audun Rødningsby	Zero

3 Summary of the eNERGIA Policy Workshop

Introduction

The Policy Workshop was held on the 18 June 2008 in collaboration with the Research Council of Norway and Nordic Energy Research. The objective of the Workshop was to study and learn from selected good Nordic policy practices and results. After a brief welcome by the host, Per Koch from the Research Council of Norway, the Workshop began with a presentation on the eNERGIA project by Antje Klitkou, NIFU STEP, who focused on the project results and the issues relevant for policy. The Workshop addressed three good-practice cases: Swedish bioenergy, Danish wind energy and Norwegian carbon capture and storage. An introduction by Birte Holst Jørgensen, Director of Nordic Energy Research, followed. The introduction covered the framework within which Nordic Energy Research works, and the activities of the institution.

The sessions were organised with a main presentation of each country by invited experts (Lars Guldbrand, Director of R&D Strategy, Swedish Energy Agency; Hanne Thomassen, Energy Technology Development and Demonstration Programme, Danish Energy Authority; and Trygve U. Riis, Natural Gas Power (CLIMIT), Research Council of Norway). As a response to the relatively broad overviews that were given by the experts, the eNERGIA research team presented case studies of good industrial practice, which were followed by question and answer sessions. The last session was a panel debate, with the invited experts as participants.

Due to scarce resources, the eNERGIA project team was forced to limit the Policy Workshop to a discussion of the cases in Sweden, Denmark and Norway only.

The main focus of the Workshop was what the Nordic countries can learn from these good practice achievements. How can the Nordic countries develop policies in order to support the development of renewable energy?

In the introductory presentation on the eNERGIA project and policy issues, Antje Klitkou emphasised that the background to different development paths being established in the different Nordic countries lay in their energy policies after the oil crisis in the 1970s. Thus the situations in Denmark, Sweden and Norway today are basically the result of a course that was chosen about 30 years ago. The visions and related strategies, and priorities and strategic plans of each country were vitally important. These factors led to the establishment of policy systems, with actors and policy instruments, and with mechanisms for involving civil society and the coordination of policy on different levels. The political decisions that were taken were not just for renewable energy production, but also for storage, transport and distribution. This implied allocation of resources to research, and industrial policy initiatives. These allocations and initiatives were to shape the basis for the economic and industrial specialisations that we see in these countries today.

The preliminary analysis in the eNERGIA project identified certain characteristics in the development path of each country.

For Sweden the following development lines were identified:

- Public funded (bio)energy research was begun after the oil crisis.
- Strong forest industry precondition for focus on bioenergy.
- Energy was previously under the Ministry of Sustainable Development, but is now under the Ministry of Enterprise, Energy and Communication.
- Traditionally dominated by nuclear power and hydropower, the 1980s saw growing pressure to phase out nuclear power production.
- 1997: Parliament –voted to phase out nuclear power; long-term energy policy programme (1998–2004) proposed.
- Alignment of policy instruments, industry and civil society.
- 2005: commission on oil independence appointed.
- Current government: "Climate Billion" (2008–2010).

For Denmark the following development lines were identified:

- Governmental focus on renewable energy resources, environment and sustainability – energy was part of environmental policy, now the Ministry of Climate and Energy.
- Goals set for high shares of renewable energy – increased funding of RD&D in renewable energy technologies, energy efficiency and saving.
- A strong machine building industry precondition for the development of wind technology; a strong agriculture and food industry – precondition for bioenergy.
- Alignment of policy instruments, industry and civil society.
- Tradition of strategic planning.
- Advisory Energy Research Committee – important policy driver for energy research: strategy for energy RD&D (2006).
- Political agreement between government and other political parties on Danish energy policy 2008–2011 (February 2008).

For Norway the following development lines were identified:

- Policy context: hydropower and oil and gas, under the Ministry of Petroleum and Energy.
- Traditionally, environmental concerns about more hydropower, and oil and gas production, but less focus on new renewable energy.
- Lack of efficient policy instruments for implementing new renewable energy projects.
- Strong specialisation in mining, shipbuilding industry and maritime traditions – focus on offshore oil and gas, potential for offshore wind power.
- Political agreement on Norwegian climate policy.
- R&D Strategy Energi 21 for the Ministry of Petroleum and Energy.
- Policy strategy – will to emphasise renewable energy; however, actual priorities are oil/gas, CCS and hydropower related.
- Misalignment of industry, policy instruments and civil society.
- Path dependency, sufficient industrial/bureaucratic resources for new renewable energy?

What type of policy decisions seem to be necessary in order to make an impact? In Antje Klitkou's presentation the following factors were emphasised:

1. Long-term:
   - Planning of funding of RD&D,
   - Incentives for industrial RD&D,
   - Incentives for realising desired projects.
2. Mapping of geographical, economic, financial, environmental and social possibilities for and barriers to implementing action plans.
3. Education of workforce to provide relevant skills and competences.
4. Long-term monitoring of implemented projects.
5. Path dependency of technology development – carbon lock-in.
6. Specialisation versus a broad range of technologies.

These factors have relevance to different sectors in society (education, research, manufacturing industries, service industries). Long-term planning and coordination is therefore crucial.

The core question for Nordic policy-makers, which after all is the main focus of this project, is what role and function Nordic policy can play in the context where national and European policy-making actors are dominant. The bullet points below give an overview.

- Role of Nordic collaboration for national policy:
  - Collaboration versus specialisation,
  - Regional collaboration.
- Broad range of policy arenas important for RD&D:
  - Strategic bilateral and multilateral collaboration agreements,
  - Collaboration under the Nordic Council of Ministers,
  - Nordic Energy Research,
  - European Framework Programmes,
  - ERA-NETs and technology platforms,
  - International Energy Agency.
- Coordination of infrastructure, Nordic electricity market.

Sweden and biofuel good practice

The presentation by Lars Gulbrand (Swedish Energy Agency) on Swedish biofuel outlined a range of policy instruments that have been directed at increasing the share of renewable energy in Sweden.

- Carbon dioxide taxation since 1991,
- Emissions trading,
- Electricity (so-called “green”) certificates,
- Wind power policies,
- Tax reduction on biofuels for transport,
- Information and education,
- Innovation and RD&D,
- Phase-out of specific subsidies.

The policies, measures and regulations specifically for biofuels and cars in Sweden include:

- Tax strategy for alternative fuels,
- Obligation for filling stations to provide biofuels,
- Bonus for buying an eco-friendly car,
- Environmental policy for government vehicles,
- Reduction of benefit attributed to eco-friendly cars for tax purposes,
- RD&D.

Lars Gulbrand's presentation focused on the fact that the policy initiative for renewable energy sources in general and biofuels in particular is reinforced. A Parliament decision based on the Government Bill 2005/06:127 Research and New Technology for the Energy System of the Future provides, according to Gulbrand, clear objectives, higher long-term budgets, higher ambitions for commercialisation, and an increased focus and concentration of efforts. The initiative emphasises the long-term nature of energy RD&D. A system of goals with targets, criteria and indicators is operated. The Swedish Energy Agency is responsible for the whole programme.
The overall objectives of the measures concerning RD&D and commercialisation are:

- To build scientific and technical knowledge and expertise, within universities, colleges, other higher education institutions, government agencies and the business sector, necessary to enable a transition to a long-term sustainable energy system in Sweden through the application of new technology and new services, and
- To develop technology and services that, through the Swedish business sector, can be commercialised and thereby contribute to the transition and development of the energy system in Sweden and other markets.

Energy RD&D is organised in six thematic areas:

- The building as an energy system,
- The transport sector,
- Fuel-based energy systems,
- Energy-intensive industry,
- Power systems,
- Energy systems studies.

Complementing the issues addressed by Lars Gulbrand, Lisa Scordato from NIFU STEP presented the case study of good practice of the Biofuel Region and the ethanol pilot project in Örnsköldsvik. The region has a long industrial tradition of and extensive experience in ethanol production (since the 1930s). Scordato summarised the case by emphasising important factors.

- Early systemic features and interactions seem to have been essential,
- Swedish long-term energy policy focus on bioenergy,
- National natural conditions,
- Industry specialisation – forest industry, processing,
- Available biomass,
- Persistent political will,
- International (Nordic and EU) collaboration essential.

Denmark and wind energy good practice

The presentation by Hanne Thomassen (Danish Energy Authority) on the Danish wind energy emphasised key policy instruments that have been aimed at promoting renewable energy in Denmark.

- Public support to the RD&D of renewable energy technologies,
- Investment grants for standardised renewable energy equipment, e.g. windmills and biomass boilers,
- Favourable prices for electricity fed into the public grid,
- A suitable taxation structure reflecting the external costs of fossil fuels,
- A suitable legislative and planning framework to support the local initiative,
- Agreements between the Government and the utility companies, e.g. large-scale wind power programmes and the biomass agreement.

The Danish policy is active. Development of offshore wind parks is one of the current challenges. Confidence-building measures for investors in offshore parks, and a legal right to access to the energy grid wind energy producers are two examples of the existing proactive policy-making. Denmark has (like Sweden) recently reinforced its energy policy. A new political agreement came into force in February 2008. The main objective is to reduce dependency on coal, oil and gas. It includes new targets for renewable energy in general, but wind energy is an important element of the agreement. The subsidies for wind-generated electricity are increased, municipalities are to identify locations for new wind-energy generating sites (150 MW) on land, and close neighbours to new wind turbines are to receive economic compensation. Finally, there is agreement about a new tender for two 200 MW wind energy parks offshore, and a master plan is to be drawn up for the location of new offshore parks.
Two other important issues in Danish wind energy policy were emphasised.

Megawind is a new initiative that aims to strengthen public–private cooperation (between the state, businesses, knowledge institutions and venture capital) in order to accelerate innovation in wind technology. The partners include many of the most significant actors in the Danish wind energy domain: Vestas Wind Systems A/S, Siemens Wind Power A/S, DONG Energy A/S, Vattenfall A/S, The Technical University of Denmark (DTU), Risoe National Laboratory (DTU), Aalborg University, Energinet.dk, and The Danish Energy Authority.

The Danish Energy Research Programmes, in particular the Energy Technology Development and Demonstration Program (EUDP), has an envisaged budget increase from DKK184 million in 2007 to DKK 404 million in 2010. The EUDP includes two main initiatives: Development and Demonstration – energy, preferably public–private projects with commercial potential; and the EUDP secretariat, which is to form an independent entity within the Danish Energy Agency.

The aims of the EUDP are:

- To support energy policy objectives:
  - Security of supply,
  - Combating climate change,
  - Economic growth.

- To develop further the existing strong industrial positions in energy technology, and to realise the potential to increase exports of energy technology and experience.
- To establish internationally competitive projects.

The EUDP has some technology priorities:
- Hydrogen and fuel cells,
- Second-generation biofuels for transport,
- Wind power,
- Energy efficiency in buildings,
- Renewable energy sources in general,
- Energy efficiency in general,
- Energy systems/integration/energy cities,
- Carbon capture and storage (CCS),
- Enhanced oil recovery (EOR).

Complementing the issues addressed by Hanne Thomassen, Trond Einar Pedersen from NIFU STEP presented the case study of good practice of Vestas Wind Systems A/S. As in the Swedish case, industrial competence achieved many decades before the first wind turbines were produced in 1979 shaped the basis for the success story. The case study describes Vestas' success with reference to the company's strong focus on technology and innovation, business skills, technical excellence and determination.

The role of policy and policy instruments in Vestas' success was described in three main points:
1. Stability and cultural acceptability is needed in the rules-of-the-game –regulations and subsidies, policy at large and policy instruments.
2. Feed-in tariffs are preferred to tradeable certificate systems.
3. Large R&D programmes need to be accompanied by modern intellectual property rights (IPR) regulations.

The same early systemic features in the wind-energy domain seem to have been present in Denmark as was the case in Sweden. These features were political will, public policy actors, education and R&D, industrial entrepreneurship and excellence, and above all, in the beginning, a vital market pull force from Danish farmers and individuals.

Norway and carbon capture and storage good practice

The presentation by Trygve U. Riis (Research Council of Norway) on the Norwegian CCS case described the Norwegian CCS policy. It has four components:
1. It is necessary to develop sustainable energy systems. CCS is a solution – in addition to other measures such as energy efficiency and increased use of renewable energy sources
2. All new gas-fired power plants shall, as a rule, be based on technology for CO_2 capture
3. The Norwegian government intends to:
   - cooperate with the industry,

- provide public funding.

4. Make widespread use of CCS a reality.

The Norwegian CCS case is a story of early investment in R&D. More than 15 years of RD&D is currently in the phase of commercialisation. The effort has been tremendous, and 160 engineers are now working on CCS in the Aker system. The current challenge in terms of CO_2 capture is to reduce costs, in terms of CO_2 transport to ensure safety and in terms of CO_2 storage to make storage reliably and safe.

Central to the maintenance of the strong Norwegian science base in CCS is the participation of the biggest Norwegian research institutes and universities in EU framework programmes and the EU Technology Platform Zero Emission Fossil Fuels Power Plants (ZEP). Important R&D environments for CCS are the NTNU, the Sintef Group, the University of Bergen and the Institute for Energy Technology. Researchers from the NTNU began publishing papers on CCS before 1987.

Complementing the issues addressed by Trygve U. Riis, Antje Klitkou from NIFU STEP presented the CCS good practice case study of Aker Clean Carbon.

The main points illustrated by the Aker Clean Carbon case can be used to reflect on the role and significance of public policy in CCS RD&D and commercialisation.

1. An orientation towards the global market has contributed to a greater focus on flexible and standardised solutions that are applicable to both the gas and the coal power market.
2. Collaboration with strong R&D organisations is a driver for technology development.
3. A combination of new technology systems in a systemic approach – bioenergy and CO_2 capturing – can contribute greatly to the main aim of further technology development, reduced costs and increased CO_2 capturing capacity.

Policy instruments and policy measures

The Norwegian authorities have implemented several policy instruments and measures for strengthening the focus on CCS. The introduction of CO_2 emission taxes for petroleum-related activities on the continental shelf in 1990 (in force since 1991) was a driver for oil and gas companies to engage in CCS R&D. Funding of CCS RD&D is a high priority in Norway (Tjernshaugen 2008). Globally, Norway has the highest share of funding for CCS per million GDP. In 2008 the Norwegian government has allocated NOK 1.125 billion to CCS RD&D.

The Norwegian Commission on Low Greenhouse Gas Emissions was appointed by the Norwegian government in 2005 (NOU, 2006). The conclusions in the final report implied that CCS is a political priority. Gas- and coal-fired power plants must implement CCS, as should process industries with large pulse emissions.

Several Norwegian R&D programmes and activities have ensured the maintenance of the CCS science base. The KLIMATEK programme, which looks at technology for the reduction of greenhouse gases, had a budget of about NOK 612 million (1997–2001). After 2001 the EMBa Programme took over the relevant projects – Energi, miljø, bygg og anlegg at the Research Council of Norway. EMBa ended in 2004 and RENERGI took over (2004–2005) the task of supporting CCS-related R&D. The CLIMIT programme

was launched in 2005, and is now the national programme for CCS for gas power technologies. The role of this programme is to promote the RD&D of CCS technologies. Annually the Norwegian government allocates more than euro16 million to CLIMIT. Together with the funding from the energy industry itself, the total R&D expenditure amounts to more than €50 million per year. Main areas of activity are:

- power generation and CO_2 capture to reduce the costs of carbon dioxide capture,
- transport and storage of CO_2 to create public acceptance for geological storage.

Gassnova SF is a governmental centre of CCS expertise. It was established in 2005 as a Government Centre for Gas Power Technology, and in 2007 became a state-owned enterprise. Gasnova will be an adviser to the government on the development of CCS support technology (capture, transport, injection and storage of CO_2) and is responsible for the management of several strategic projects on CCS, such as the European CCS Test Center Mongstad, the full-scale carbon capture plant at Mongstad, the full-scale carbon capture plant at Kårstø, and transport and storage of CO_2 (Riis 2008). Funding is available for a broad range of activities, from R&D projects to the building of full-scale plant. Gassnova receives revenue from the gas technology fund, which was established in 2004 and has about € 250 million, of which and Gassnova receives about euro10 million per year.

The Norwegian oil and gas company StatoilHydro (formerly two separate companies, Statoil and Norsk Hydro) is the main industrial actor in the field of CCS. The company has been, or still is, involved in following thirteen EU-funded projects. Moreover, StatoilHydro is involved in four large-scale commercial projects on CCS at different levels of maturity:

- The Sleipner field in the North Sea, where there has been storage of CO_2 since 1996.
- Liquefied natural gas production at the Snøhvit gas field and CO_2 storage in an aquifer in Northern Norway since 2007.
- In Salah in Algeria.
- The carbon capture facility at the Mongstad refinery, west Norwegian cost.

Conclusions

What can we learn from the Swedish success in biofuel, the Danish success in wind energy and the Norwegian success in CCS? A common feature of all three cases is the presence of political vision and objectives with a long-term view. Policy strategies and related objectives have been supported by relevant targets that have worked as a concrete motivation for decisions and action (funding and investments). Another feature is the establishment of pragmatic laws, regulations and policy measures, including appropriate subsidies, investment grants, feed-in tariffs, and generous public support for R&D.

Table 7: List of participants in the eNERGIA Policy Workshop, 18 June 2008

Name	Affiliation
Bjørn Utgård	Bellona
Hanne Thomassen	Danish Energy Authority

Liv Lunde	Institutt for energiteknikk IFE
Jan Carsten Gjerløw	Kunnskapsbyen Lillestrøm/OREEC
Andreas Holm Bakke	Kunnskapsdepartementet
Ragnhild Børke	Miljøverndepartementet
Åge Mariussen	NIFU STEP
Antje Klitkou	NIFU STEP
Aris Kaloudis	NIFU STEP
Hans Skoie	NIFU STEP
Lisa Scordato	NIFU STEP
Trond E. Pedersen	NIFU STEP
Amund Vik	Nordic Energy Research
Birte Holst Jørgensen	Nordic Energy Research
Lise Jørstad	Nordic Energy Research
Vida Rozite	Nordic Energy Research
Sigridur Thormodsdottir	Nordisk InnovationsCenter
Andreas Bratland	Norsk Bioenergiforening
Indra Øverland	NUPI, Energiprogrammet
Hans Otto Haaland	Research Council of Norway
Per Koch	Research Council of Norway
Trygve U. Riis	Research Council of Norway
Lilia Vázquez Holm	Statkraft, New Energy, IPR Manager
Lars Guldbrand	Swedish Energy Agency
David Pointing	UNEP Risø Centre for Energy, Climate & Sustainable Development

4 Case study of good practice: promotion and production of biofuels in Sweden – Biofuel Region and SEKAB

This section describes BioFuel Region, a regional cooperation initiative with the role of promoting alternative fuels in the region, and SEKAB, one of the main industrial partners in the region which is developing a pilot plant for the large-scale production of cellulose ethanol.

4.1 Biofuel Region

4.1.1 Overview and background information

The BioFuel Region (BFR) is a platform of actors operating in two Swedish counties, Västernorrland and Västerbotten. The platform has, since it was started in 2003, been actively promoting the development and introduction of biofuels by mobilising, committing and activating the people in the region. The vision of BFR is to become "a world-leading region in sustainable transport based on biofuels and bioproducts from renewable raw materials". The initiative has attracted wide international attention and is seen as a good example of how successfully to mobilise a region to creating a sustainable transportation system.[10]

The establishment of a formalised network around alternative fuels in the region has its roots in a long industrial tradition of and experience in ethanol production. Ethanol producing industries have been active in the Örnsköldsvik (Ö-vik) area since the 1930s. Svensk Ethanolkemi AB (SEKAB) was founded in the mid-1980s, and the company is now a leading ethanol supplier in Europe. The BioAlcohol Fuel Foundation (BAFF) has its headquarters in Ö-vik and has for the last three decades actively worked to develop knowledge about ethanol production and use in the transportation sector. The existence of a solid forest industry in the region has been important in the process.[11]

The BFR focuses on being at the forefront of societal change, and industrial and regional development, and on increasing the availability of renewable raw materials. The present stakeholders represent 16 municipalities, two county councils, county administrations and 11 private enterprises. Schools are actively involved, and many activities are focused on raising awareness among students. The activities are carried out in independent groups that are connected to the different areas of the biofuel development chain: raw materials, production and distribution, vehicles, laws and regulations and consumer information. The working groups are: Adult Education and Commitment, School, Research and Development, the Public Sector, Development of Filling Stations, Raw Material Issues, Industrial Development, and Long-term Financing.

[10] www.biofuelregion.se

[11] VINNOVA, ISA and NUTEK (2005), "Formation for Collective Action – The development of BioFuel Region"

The municipalities play a central role in implementing the strategy. Each participating municipality makes a committed declaration to reach a certain number of targets. These targets can include a commitment to implement green transport procurement, free or subsidised parking for ethanol-fuelled cars, inventory of the raw materials present in the municipality, or education of staff and other awareness raising activities.

An important source of funding comes from the BEST project (Bioethanol for Sustainable Transport) under the Sixth EU Framework Programme (FP6). Together with eight other sites in Europe, the BFR is engaged in preparing a market for ethanol-fuelled vehicles and bioethanol in Europe. The aim of the project, which started in 2006 and will continue until late 2009, is to put into operation more than 10,000 cars and 160 buses.

Since the start of the project, the target has been to prioritise ethanol and Fischer Tropsch diesel (FT diesel) derived from forest based raw materials. In the first years of the project, the mission was to become self-sufficient in biofuels by 2020 and become a world-leading model for making a regional transportation system sustainable through regional and local cooperation. This has, however, changed recently, and the mission is now o become a world-leading region in renewable raw materials. The recent debate on the increase in food prices and its link to the production of ethanol from food crops has created some scepticism among the BFR members with regard to the promotion of ethanol.

4.2 SEKAB

4.2.1 Company details

Year of establishment: 1985
Address: Örnsköldsviks Office, Box 286, SE-891 26 Örnsköldsvik, Sweden
Website: www.SEKAB.com
Main sector(s) of activity (Description & NACE Rev. 1, 2-digit code): Industry code: 20140, manufacture of other organic basic chemicals
Respondent: Jan Lindstedt, SEKAB
Interviewer/data: Lisa Scordato, NIFU STEP. 23 May 2008

4.2.2 Company structure and operations

SEKAB (previously Svensk Ethanolkemi AB) has been active in the development of cellulose ethanol since the end of the 1980s. Today, SEKAB is one of the leading ethanol suppliers in Europe. The company was founded in 1985 by Berol (50%) and MoDo (50%), based on their ethanol production operations, which started at the beginning of the World War II. In 2006, the new SEKAB Group was formed. Etek and Svensk Etanolkemi AB were re-named as SEKAB E-Technology and SEKAB BioFuels & Chemicals, and become part of the SEKAB Group, together with two new companies SEKAB Industrial Development and SEKAB International. SEKAB is today owned by a regional consortium consisting of Ö-vik Energi, Umeå Energi, Skellefteå Kraft, Länsförsäkringar i Västerbotten, OK Ekonomisk förening and EcoDevelopment.

SEKAB has expanded in recent years, and has doubled its number of employees in the last two years. It now has 170 employees, of which 140 are full-time, permanent staff, and of these 35 are involved in the development of the cellulose plant. SEKAB also runs activities in Tanzania, where large investments are being made in the production of sugarcane-based ethanol. The total turnover of the company in 2006 was SEK 1.8 billion.

4.2.3 The Ethanol Pilot Project

SEKAB E-Technology is developing the cellulose-based ethanol technology. The mission is to create an international centre of expertise for the development of cellulose-based bioethanol plants. The holding companies at Umeå and Luleå universities are the official owners of the plant. However, all the technology and the patent rights belong to SEKAB.

The pilot project is a long-term industrial initiative in cellulose-based ethanol and the development of production facilities on an international scale. In 1995, the company applied to the Swedish Energy Agency to build a small demonstration plant. The proposal was, however turned down. In 2000 a new proposal was made and this received approval. The plant was officially opened in May 2004 by the former Prime Minister Göran Persson. The first ethanol was produced in March 2005.

The plant is located next to SEKAB's plant on the Domsjö industrial site. The current raw material used in the development process is wood chips from softwood trees (usually spruce). The company's resources include R&D engineers, whose principal task is to develop and evaluate the operational processes of the pilot plant, and15 operators, who work in shifts and are responsible for the plant's operation. The plant is considered to be unique because of its continuous operation in shifts, which allows for careful monitoring of any clogging and stoppage.[12] According to SEKAB's estimates, the pilot plant could currently produce 150m^3 ethanol per year. Operational and developmental costs amount to approximately SEK 30 million annually, and are covered by funding from industry and public funds (the Swedish Energy Agency, MISTRA, the EU's Framework Programme and EU structural funds). The project is receiving SEK 34 million from the energy agency for the next 2 years.

Preliminary studies have been started with the aim of launching the next stage of the project. This stage involves scaling up the current plant to an industrial production unit with a potential capacity of 6000 m^3/year. The cost of scaling up the plant is round SEK 1 billion. SEKAB estimates that a commercial plant can be operational in 2014–2015, although further technological improvements are still required to scale up the plant. The operation is dependent on external funding.

[12] Information based on the description from SEKAB's webpage.

Table 8: Sources of funding for the ethanol pilot project (Source: SEKAB)

Source	Million SEK
Swedish Energy Agency	112
Industry	11
European Regional Development Fund – Södra skogslänen – Northern Norrland	 15 10
Total	148

4.2.4 Development phases

The second stage of the cellulose ethanol project started in 2007, with the planning of the scale up to a new industrial development unit (IDU). The planned facility is approximately 40 times larger than the current pilot plant. The IDU will be constructed on the same site as the pilot plant, which is located at the existing sulphite ethanol plant at Domsjö Factories, where SEKAB produces chemicals from bioethanol. Technological changes have been made during this development phase. Enzymes pre-treated in a one-step acid hydrolysis, instead of a two-step dilute acid hydrolysis, are now used. The IDU will be designed to use forest residues from softwood as the feedstock, but it will be possible to test bagasse from sugar cane as well.

According to SEKAB's current timetable for the industrial development of cellulose ethanol, a full-scale commercial facility will be in operation in 2014–2015, with a total production capacity of 60,000–100,000 m^3/year.

4.2.5 Research collaboration

R&D work is conducted in collaboration with a comprehensive network of national and international R&D groups and technology and consulting companies. The Swedish Energy Agency has appointed a technical council of experienced researchers from both academia and industry to assist with the project.[13]

The research team is spread throughout the country, but is composed mostly of researchers from the University of Lund, Chalmers and KTH. Their ideas to create a better Nordic collaboration for cellulose ethanol is considered important, and SEKAB is already engaged in common research projects with institutions in Sweden's neighbouring countries (e.g. with the Paper and Fibre Institute in Norway and VTT in Finland).

An important platform of which SEKAB is a member is the Processum Technology Park. Processum is considered to be a good example of an industry-driven innovation cluster working around the biorefinery concept. The participating companies have the competence to develop the biorefinery of the future, based on forest resources, and

[13] www.SEKAB.com

operate within manufacturing, consultancy, R&D in the pulp and paper industries, and chemical and energy industries.

NILE stands for New Improvements for Ligno-cellulosic Ethanol and is an EU-funded research project in which SEKAB is one of the work package leaders. The overall aims of the project are to develop cost-effective, environmentally sound methods for the mass production of ethanol as a vehicle fuel. The initiative is one of a number of efforts to reach the goal of reducing the use of fossil fuels in the transport system by 5.75 % by 2010, as outlined in an EU directive. NILE was the only bioethanol project to be approved in the EU FP6. The Seventh Framework Programme (FP7) includes a much larger investment in biofuels.[14]

The NILE project has identified three priorities:

1. To develop new enzymes for the break down of cellulose in plant material (especially for softwoods and farm waste products such as wheat straw) into sugar.
2. To develop a number of new types of yeast that can convert the various sugars found in biomass into ethanol.
3. To improve process integration in order to reduce energy consumption.

4.2.6 Framework conditions: drivers and barriers

Sweden has a long history of extracting cellulose raw materials from forestry products, and has world-class expertise and world-leading companies in this field. After the oil crisis in the 1970s, Sweden made considerable investments in initial R&D activities in ethanol production technologies. Later, however, as the price of oil stabilised to lower levels and the urgent need to invest in alternative fuels receded, the ambitious ethanol projects were halted.

In Sweden there is strong political will to support technology and the market introduction of biofuels. There are several policies and measures for biofuels:

- RD&D,
- an obligation for filling stations to provide biofuels,
- a bonus for buying an eco-friendly car,
- a tax strategy for alternative fuels.

The share of biofuel use in transportation has risen considerably since the end of 1990.

The challenges in the development of pilot plants of this type are closely linked to the high risks and high costs involved. Estimates indicate that the first commercial-scale plants will require investment costs of the order of billions of SEK.

Another barrier perceived barrier is the lack of coordination between funding agencies (mainly Vinnova and the Swedish Energy Agency). Hence recent action has been taken by the biofuel industry in Sweden, including SEKAB and the BioAlcohol Fuel Foundation (BAFF), to propose a long-term funding plan (SEK 1 billion for 8 years) to support of second-generation biofuel technology.

[14] www.SEKAB.com, see also http://www.nile-bioethanol.org/

Many large cellulose ethanol plants are being developed, both in Sweden and internationally. Significant efforts are being made by the USA, Canada, Japan and China. Rather than being seen as competitors, these initiatives are considered necessary to satisfy the future need and growing demand for cellulose-based ethanol at a European and global level. Several hundred ethanol plants are needed in Europe alone if the EU target of 10% biofuels is to be met by 2020.

4.3 Key conclusions

Key message 1

BFR represents a case of good practice on how regional stakeholders can collectively take action to prepare the market for alternative fuels. The initiative could be transferred to other regions in Nordic and European countries. Good planning and cooperation between stakeholders during the initial phase of a project is essential for its success.

Key message 2

The main challenges that business and policy-makers face are to overcome the high risks and high costs associated with producing cellulose ethanol at a commercially viable level.

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5 Case study of good practice: Vestas Wind Systems A/S[15]

5.1 Company details

Year of establishment: dates back to late 19th century, with several reorganisations. In 1979, Vestas started to produce wind turbines
Address: Vestas Wind Systems A/S, Alsvej 21, 8900 Randers, Denmark
Website: www.vestas.com
Main sector of activity: Wind turbines, NACE 29.11 manufacture of engines and turbines, excluding aircraft, vehicle and motorcycle engines
Interviewer: Sven Faugert, Technopolis
Data and editing: Trond Einar Pedersen, NIFU STEP

5.2 Why is this company an innovation leader?

Following the first oil crisis in the 1970s, Denmark began systematically to decrease its high dependence on imported fossil fuels. A stable Danish energy policy was established, and in the following decades both continued improvements in energy efficiency and the development of renewable energy sources were pursued. Vestas reacted quickly to this new energy policy and market trend – a trend that was also occurring in other countries due to the international nature of the oil crisis. Vestas started producing wind turbines as early as 1979.

Of key importance for Vestas success has been stability of regulations and subsidies over a fairly long time period. This is a general requirement for fostering innovations that will contribute effectively to long-term societal objectives and accompanying long-term growth of new sustainable industries. This applies to policy in general as well as to detailed policy instruments. One example of such a policy element is the EU-wide and legally binding objective for a certain proportion of the electricity generated to come from renewable sources. This policy will be of vital importance to the long-term growth of the European renewable energy industries. For a company that is operating on a global scale, there is the added condition that different instruments applied to implement such policies need to be culturally acceptable in each national setting. For example, state subsidies may be perfectly legitimate and accepted in one national market, whereas common standards are the preferred instruments in others. The key concern for the industry is that there is stability through a long-term commitment, in the countries

[15] This case study integrates information from different sources. The main information source is an interview with the representative Lise Backer from Vestas Government Relations. The interview was done by Sven Faugert in Technopolis (http://www.technopolis-group.com/index.html) in the context of the Innovation Watch/Systematic project, which is part of the so-called Europe Innova initiative; see the Europe Innova portal (http://www.europe-innova.org/index.jsp). Technopolis and NIFU STEP were partners in the Innovation Watch/Systematic project consortium.
As a supplement to the interview the internet is the second main source of information. There is extensive and partly relatively detailed information about Vestas' activities and engagement on the internet, in particular on Vestas own internet site www.vestas.com.

concerned, to the policy instruments applied. Stop and go policies are not helpful in the process of creating a new sustainable industry. The 'best' policy instrument in this perspective is one that is accepted in the country and therefore stays in place.

Early on Vestas demonstrated the business skills, technical excellence and determination, which characterise many market and technology leaders. Vestas has always had a strong focus on technology. Thus from the beginning innovative wind turbines were developed in close and innovative interaction with leading Danish academics (e.g. Risoe/DTU). In addition, Vestas was in close dialogue with the national agencies associated with the policy for developing a domestic market for wind power. This attempt to influence the development of this market was also supported by other stakeholders in Danish wind power. Together, these stakeholders managed to ensure that wind power technologies and the domestic wind power market successfully developed together over time.

While in the beginning the Danish market was of key importance to Vestas, emerging wind power markets in other countries quite quickly began to be important to the company. Vestas is today a truly global company – an identity that was rapidly due to the global character of the wind turbine market.

As stated previously, Vestas is a technology-driven company, and this is reflected in the name of its R&D business unit (Vestas Technology R&D). At Vestas there has been a continued focus on reducing the weight and cost of wind turbines, Vestas turbines are relatively light, highly sophisticated and competitive. Over the years, Vestas has continually introduced innovative products ahead of its competitors, and today it is the technology and market leader in the global wind energy industry.

Vestas Technology R&D is, like the company's sales and production units, international, with operations in Denmark (headquarters), the UK, Germany, Singapore and India. A new R&D centre will be opened in the USA in 2009. A number of Vestas Technology R&D offices are located near to or at universities that have strong wind power research competences. A department for dealing with intellectual property rights (IPR) has been established and the company's IPR policy has been tightened in recent years in response to increasing international competition in the wind power industry. Recruitment has also been adapted to the competitive market situation. For example, in order to recruit the best students in wind power from universities around the world, Vestas Technology R&D offers scholarships to do their MSc or PhD at Vestas. As a contribution to publicly funded research programmes, Vestas participates in common work on technology platforms within both the EU and Denmark.

5.3 Key performance indicators

The following key performance indicators highlight the development of Vestas during the last few years.

Indicator	**2002**	**2006***
Number of employees	5,794	11,334 [(3)]
Total turnover, in million euro	€ 1,395 million	€ 3,854 million
Profits: earnings before interest and	€ 74 million	€ 201 million

taxes (EBIT)		
R&D personnel (researchers and engineers, technicians, etc), % of total employees	n.a.	626 (5% of total staff)
Net sales, in euro	n.a.	n.a.
Exports, % of net sales	n.a.	n.a. (1)
R&D expenditures, % of net sales	n.a.	n.a. (2)
Patents granted (by the European Patent Office (EPO), the US Patent and Trademark Office (USPTO), others by 2006 incl.	n.a.	337 (4)

(1) Vestas' home market is relatively small in sales terms. Exports, taken as sales to customers outside Denmark, are estimated to be over 90% of total sales.
(2) No published figures. Based on employment, an estimate is 5%.
(3) Expected to increase to 14,000 by the end of 2007.
(4) A substantial increase in patent applications filed was reported between 2005 and 2006. The figure refers to number of publications by Vestas as per February 2008.

5.4 Company structure and operations

History

Vestas has a long history as a manufacturing company, going back to the late 19th century, when a blacksmith is said to have started what was later to become Vestas. Agricultural trailers, mud pumps, ploughshares and hydraulic cranes for lorries are some of the products it has produced over the decades. Its interest in wind power started in 1978, in the wake of the first oil crisis, with some experiments on vertical axis wind turbines of the Darrieus type. This design was soon abandoned, and the first commercial, three-bladed wind turbine was delivered by Vestas in 1979. Only 6 years later, Vestas employed 800 people.

Decades of growth, mergers and acquisitions and dramatic market changes have followed Vestas' entry into the wind energy business. Some milestones are:

- **1980**: Decision to start serial production of wind turbines.
- **1981**: First large order from the USA, Vestas starts production of glass fibre components for wind turbines.
- **1985**: Vestas was the first company to deliver pitch-regulated turbines, and since then they have become well known under the name *OptiTip*.
- **1986**: The expiry of favourable tax legislation in California threw Vestas into a crisis, and the following year the company was restructured, with the formation of a new company concentrating exclusively on wind energy. A new management team was installed.
- **1989**: Merger with Danish Wind Technology.

- **1990**: Vestas achieved a technological breakthrough with far-reaching consequences when it succeeded in reducing the weight of a wind turbine blade by 70%.
- **1991**: Economic breakthrough – turnover rises by 35%, and Vestas becomes the first wind turbine manufacturer to become ISO 9002 certified.
- **1992–1994**: Expansion in the USA, Germany, Sweden and Spain.
- **1995**: A new factory was established in Denmark. Vestas was the first to introduce individual pitch regulation on all three turbine blades, and an offshore wind farm was erected in collaboration with a Danish power company.
- **1998**: Vestas had 22% of the global market and was a dominant force in the industry; Vestas was floated on the Copenhagen Stock Exchange.
- **1999**: A new blade factory was established in Denmark. A further development of Vestas wind turbine technology for low wind speed areas, called *OptiSlip,* was introduced. Vestas took over a supplier of software and components for control systems. Vestas shares showed a record increase on the stock market.
- **2000–2002**: Record years for Vestas, as new markets opened up, and employees were offered shares for the second time. The global market share exceeded 25%, and new production facilities were set up in the UK and Germany. At the end of 2002, negative developments in the US market obliged Vestas to lay off almost 500 employees. However, there was still a net staff gain of 759 in 2002.
- **2003**: Vestas launched three new turbine types: V90-1.8MW, V90-2.0MW and V90-3.0MW.
- **2004**: Vestas merged with Danish NEG Micon, another leading wind power manufacturer, and even bigger turbines were introduced. The decision was taken to locate a new blade factory in Australia. Vestas market share increased.
- **2005:** Ditlev Engel became the new CEO and published a strategy for 2005–2008, entitled "The Will to Win", which included a vision summarised as Wind, Oil and Gas, emphasising that wind energy is ready to compete on equal terms with oil and gas as an energy source. The new strategy focused on profitability and it contained a number of challenging targets for Vestas' economic performance. A decision was made to build a new factory in China.
- **2006-7**: The implementation of the will to win strategy progressed, moving Vestas to a level were the company could rightly claim to be the number one in modern energy.

Activities

Today Vestas is a large company with around 15,000 employees spread over several continents. It has a market share of 23% of wind turbines sold, and more than 33,500 of its turbines are installed over five continents. The company is presently organised into 12 business units:

- 5 business units for its ***geographical markets*** (the Americas, Asia-Pacific, Central Europe, Mediterranean, Northern Europe),
- 1 business unit for the growing ***offshore market,***
- 6 ***functional business units*** (People and Culture, Technology R&D, Blades, Control Systems, Nacelles, Towers).

Vestas Technology R&D presently employs one new Vestas engineer every day, and the total number of employees in this unit is expected to increase to approximately 800 by the end of 2008. Traditionally, Technology R&D was organised into units according to the components or technical subsystems of wind turbines. However, these units were recently reorganised according to the technology development chain. According to this new principle, there is now one department for Global Research, one for Engineering and one for Operations. The objective is to achieve efficient feedback from Operations to Engineering, and from these back to Research, and vice versa.

From 2008, the headquarters of Vestas Technology R&D will be located in Aarhus, Denmark. This will be the world's largest wind power research centre. A major new test centre will be part of the Vestas R&D headquarters.

Ownership

On 31 December 2007, Vestas had 77,124 shareholders registered by name, representing 89.9 % of the company's share capital. The distribution of the shareholders in terms of capital is shown in the Figure 1 below.

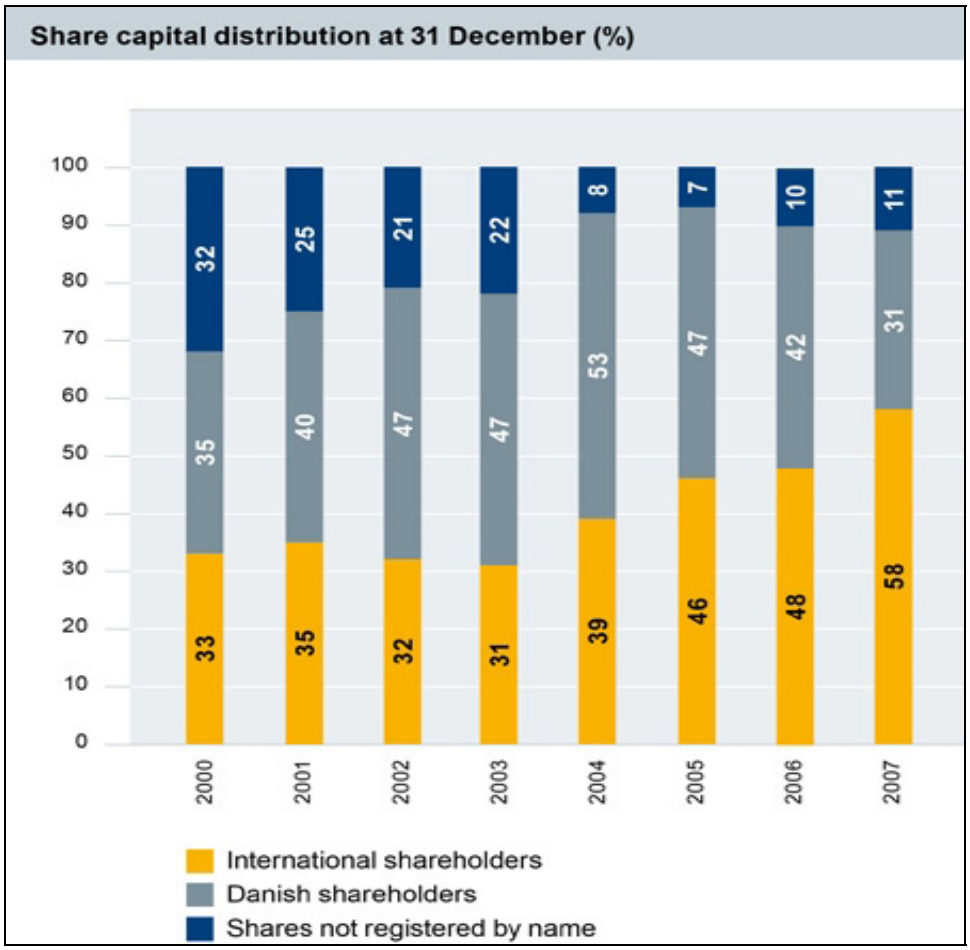

Figure 1: Vestas' share capital distribution at 31 December 2007. (Source: www.vestas.com)

Major shareholder

In accordance with the Danish Public Companies Act, Section 28 (a and b), the following shareholder has informed the company that they own more than 5 % of the share capital: FMR LLC (Fidelity), USA (5.04 % at 15 May 2008).

Suppliers and customers

In Vestas there is a conscious managerial strategy to maintain professional relationships with and treatment of suppliers and customers. For this reason Vestas promotes collaboration with suppliers, and involves them in common development processes. The idea is that this will improve the efficiency and quality of procedures, and generate common benefits by prioritising the optimisation of costs, the quality of supplies, delivery dates as per agreements, and the technical characteristics required.

Vestas considers its suppliers of equipment, materials, and services to be a basic element of the company's production procedures. In concrete terms Vestas has made a supplier qualification system, wherein all suppliers are evaluated for their information and knowledge, and capacity and limitations.

Vestas' activity in the Nordic countries

In 2003 Vestas merged with the Norwegian Windcast Group (Kristiansand). This Norwegian casting specialist had supplied different components to windmill manufacturers for many years. In 2003 the company became an exclusive supplier to Vestas' windmills. In Sweden the activity of Vestas increased substantially early in 2008 when the company relocated its North European headquarters from its native Denmark to Malmö in Sweden, a move that created around 90–150 jobs in Sweden's third largest city. Malmö was chosen because of its proximity to Copenhagen international airport and because Vestas expects strong growth in wind turbine sales in the Swedish and Norwegian markets.

To promote professional relationships with its customers, Vestas carries out annual customer satisfaction surveys. The results are used as input to dialogue with individual customers. These processes are expected to increase customer satisfaction. At the same time the surveys are a driver of innovation, because they are a channel for customers to communicate their needs.

Competitors[16]

The main competitors of Vestas Wind Systems include US-based GE Energy, Gamesa in Spain and Nordex in Germany.

GE Energy is a descendant of Edison's light bulb and a global leader in the design, manufacture, installation and maintenance of gas-, nuclear, wind- and steam-driven power generation plants. One of General Electric's largest divisions, GE Energy's

[16] The information about Vestas' main competitors is taken from http://www.hoovers.com.

customers are utility companies, industry and governments throughout the world. It supplies products such as compressors, turbines, generators and nuclear reactors. It also provides equipment that supports oil and gas distribution, and services ranging from consulting and field engineering to environmental monitoring and product lifecycle management.

Gamesa Corporación Tecnológica makes wind turbines and operates wind farms. It has also created Gamesa Solar, which manufactures photovoltaic solar cells and solar thermal power systems at a plant in Seville. In 2003 Gamesa acquired MADE, the Spain-based wind turbine maker, from Endesa for €120 million. The company has sold many of its wind farms in Europe to Electrabel (a part of the Tractebel group). More than half of Gamesa's sales in to Europe, although sales to the USA are growing rapidly.

Nordex makes wind-powered turbines used for generating electricity. Its subsidiaries Nordex Energy and Südwind Energy handle the company's manufacturing and engineering operations, while its NPV Planung & Vertrieb subsidiary acts as the sales and planning arm for the Nordex group of companies. Nordex also designs wind farms and offers maintenance services. Its products include both onshore and offshore turbines; the latter take advantage of stronger wind conditions but are more expensive to operate. Nordex has installed more than 3,000 wind turbines around the world.

Participation in research collaboration on the European scene

Vestas' activity on the European renewable energy research and development scene reflects its significance as a global actor in the wind energy field. Vestas works within the objective of being visible and active at conferences, exhibitions and in associations, as well as in R&D projects.

Vestas is an obvious industrial cooperation partner and a qualified research partner in European research projects. The company is an active member of the European Wind Energy Research Community and the European Wind Energy Association (EWEA). EWEA includes manufacturers covering 98% of the world wind power market, component suppliers, research institutes, national wind and renewable energy associations, developers, electricity providers, finance and insurance companies and consultants. This combined strength makes EWEA the world's largest renewable energy association. The EWEA Secretariat is located in Brussels at Renewable Energy House. The Secretariat coordinates international policy, communications, research and analysis. It manages various European projects, hosts events and supports the needs of its members. EWEA is a founding member of the European Renewable Energy Council (EREC), which brings the six key renewable energy industries and research associations together under one roof.

As Vestas has the largest R&D department in the whole wind power industry worldwide, researchers from Vestas are active not only in the European research area but also in the global research arena.

Intellectual property rights (IPR)

Government R&D programmes can also work as a positive stimulus to innovation and the further development of cooperation between industry and academic researchers, provided that the IPR regulations are modern enough to allow companies to safeguard the intellectual property produced when working with university researchers. It seems that governments' readiness to embrace globalisation, whereby more money is put into creating a knowledge-based society, with the purpose of contributing to maintaining the technological leadership of western companies and sustaining highly skilled jobs in the west, are counteracted by old IPR regulations. Companies are, as opposed to universities, the ones that can commercialise new inventions at the necessary pace in the global economy. Thus, old IPR regulations need to be redesigned and these problems overcome if governments are to succeed fully achieving their goals in relation to globalisation.

5.5 Managing innovation – internal barriers and drivers

The three most important company-specific drivers for innovation in the company in the last 5 years are:
1. In-house R&D and technological capacities
2. Specialist knowledge and skills
3. Strategic planning and prioritisation of innovation

The three most important company-specific drivers for innovation in the company for in the next 5-10 years are:
1. In-house R&D and technological capacities
2. Specialist knowledge and skills
3: Strategic planning and prioritisation of innovation

The three most important company-specific barriers to innovation in the company for the next 5-10 years are:
1. Human resource development and motivation polices/practices
2 & 3. Intellectual property management

Source: Company response to self-assessment survey

Ever since Vestas entered the wind power business in 1979, continuous innovation and improvement have comprised the main element of its strategy. In 2005 a change of leadership at this large company triggered the strategy "The Will to Win, 2005–2008", which laid out a number of quantifiable economic targets and an even more marked emphasis on R&D and product improvement to preserve Vestas' position as the technology leader in the industry and to maintain its image with customers. Its vision − Oil, Gas and Wind Power − pretty well encapsulates the challenge that Vestas has taken on, i.e. for wind power to be seen as a modern energy source on equal terms with fossil fuels.

Vestas has the largest R&D department in the whole wind power industry. By end of 2008, Vestas Technology R&D will employ around 800 people over several continents.

The new organisation principle that was recently applied at Vestas Technology R&D (following the logical order of Research and Development delivering innovative concepts and technical solutions to Engineering, which in turn hands completed products to the care of Operations, with feedback loops integrated in the organisation) codifies the basic role of innovation in the operations of the company. Innovation makes it possible to reduce the cost of wind energy, including through reductions in maintenance and repair costs, production and shipping and installation costs, and not least through better exploiting the wind power potential at different locations.

Innovations are produced by people working together, and this is facilitated by the organisational principles mentioned. Of central importance to driving these processes is the recruitment of high calibre staff. Throughout the world Vestas Technology R&D currently recruits one new employee per day. The fact that there is a designated People and Culture (P&C) department within Technology R&D illustrates the strong need to recruit highly skilled experts into this business unit. It is a conscious P&C policy to be visible at academic wind power conferences and universities, in order to nurture the image of Vestas as the world's leading wind power technology and thus to attract the best R&D talents from different parts of the world. It is also a conscious policy to recruit broadly, by attracting people from different ethnic backgrounds, because this is believed to be a source of creativity and innovative ideas for product improvement.

This recruitment policy is also necessary because of increasing competition as markets grow and attract new competitors into the field. In parallel, the ability to meet the requirements of increasingly demanding and professional customers becomes an increasingly important condition for growth. In such a context it is of vital importance to be able to protect the technical solutions and intellectual property created by keeping it within the walls of the company, i.e. to recruit the specialists and creative people you need instead of relying on outside sources. From this follows the need to protect the intellectual property produced by applying for patents. The last few years have seen a marked increase in the number of patent applications filed, and the number of IPR staff in Technology R&D has also increased.

The necessary focus on IPR in the innovation race in the wind industry can ironically act as a barrier to the pace in innovation, because this necessary focus on IPR means, for example, that it becomes more cumbersome to acquire knowledge by exchange with external sources. This barrier is overcome in Vestas by expanding the IPR department to enable the building of external links and cooperation, despite the IPR challenges. Today Vestas is cooperating with universities worldwide, and the necessary IPR staff have been recruited to assist in this. The necessary focus on IPR again underlines the need to recruit highly skilled and expert people to produce innovations in house. However, the steady stream of new employees requires a very large Human Resource Management (HRM) effort within the P&C department so that new employees are rapidly integrated into the organisation.

Quality and environmental considerations also act as drivers for innovation. Vestas has a Qualified Scheduling Entity (QSE) organisation that works to optimise the quality of its products over the entire process. To achieve this end, the QSE department collaborates closely with the Continuous Improvement Management (CIM) organisation within Vestas Technology R&D.

Vestas focuses a lot of attention on environmental and occupational health matters, and aims to certify all its activities according to ISO 14001 and OHSAS 18001. This systematic work will also gradually improve its products, as well as its production process, and should also be regarded as an important source of incremental innovations.

5.6 Innovation activity

The Vestas product line consists of wind turbines, ranging from under 850 kW to over 3 MW:

- V 52 has a capacity of 850 kW. It is a flexible turbine specially designed for remote sites where there is an occasionally weak electrical grid. The *Optispeed* system makes it possible to adapt the turbine to the noise levels appropriate in densely populated areas.
- V 80 has a capacity of 2 MW. It is designed for high efficiency at sites where there are relatively low wind speeds and a low tolerance for noise produced during operation. *OptiSpeed* is a key feature.
- V 90 has a capacity of 2-3 MW. It is designed for a range of wind speeds. The hew materials used in its construction make the tower both stronger and lighter. The output from the high lift blade profiles and the high efficiency generators are optimised for each specific site.

The common driving forces behind these innovative products are the continuing need to lower the costs of energy production and to increase generator efficiency, the need to adapt to the requirements of different markets and wind power plant locations, and also the need to minimise operation and maintenance costs in order to maintain customer satisfaction with this new power source. Core innovative technologies are integrated in all these Vestas products and are well protected by patents. Significant technological improvements are in the following key areas:

- *Lightweight components*. Keeping the weight of components down is a high priority in wind turbine design, regardless of the market, because weight drives the cost of production, of materials, of transport and of installation. Weight reductions are achieved by using new materials, such as lightweight carbon fibre in blades, strengthening the tower with high strength steels, and using magnets that reduce the overall amount of steel required. These design concepts have been implemented in the most modern 2–3 MW turbines.
- Mapping wind currents with the aid of *computational fluid dynamics* (CFD) is another speciality where a combination of theory and software helps Vestas' specialists to evaluate the best layout for the wind turbines based on local airflows. This minimises the wear and tear costs and maximises energy production. CFD is also used to optimise blade orientation and to minimise the amount of noise produced. The CFD programme does this through the creation of a virtual wind tunnel that simulates the air flow around the blades.
- Optimisation of blade positioning through the *OptiTip* control technology. This is a microprocessor-controlled pitch regulation system that constantly adjusts the angle of the turbine blades to ensure optimal positioning in relation to prevailing winds. The *OptiTip* technology is used in most turbines in the Vestas product portfolio.

- Optimum adaptation to changing wind speeds through advanced *OptiSpeed* technology. This technology allows the rotational speed of the rotor to vary from the nominal speed and the synchronous speed in order to maximise power production in changing wind conditions. It also minimises unwanted fluctuations in the electricity grid and the load on vital parts of the structure, such as the gearbox, tower and blades. The technology ensures exploitation of the energy in strong wind gusts and reduces the noise level from the turbines, and is used throughout the Vestas product range.

In addition Vestas utilises sophisticated monitoring and control systems. Wind power plants and subsystems can be monitored in real time over the internet.

Of central importance to most of these technologies, ever since Vestas started making wind turbines, is Vestas' world-leading competence in loads, controls and aerodynamics. This expertise is being continually developed through Vestas' long-standing collaboration with major research institutes such as the Risø National Laboratory in Denmark.

5.7 External barriers and drivers of innovation – sectoral issues

The three most important external drivers for innovation in the company in the last 5 years are:
1. Access to top-level human resources
2. Relationships with affiliates and subsidiaries of the company (corporation)
3. Cooperation with research and technology organisations

The three most important external drivers for innovation in the company in the next 5–10 years are:
1. Access to top-level human resources
2. Relationships with affiliates and subsidiaries of the company (corporation)
3. Cooperation with research and technology organisations

The three most important external barriers to innovation in the company in the next 5–10 years are:
1-3. Access to top-level human resources

Source: Company response to self-assessment survey

As for internal drivers and barriers, highly skilled people may act as both external drivers and external barriers to innovation. Increasing competition from increasingly competent competitors has made it necessary to develop special policies regarding the company's cooperation with higher education institutions and recruitment from these same institutions. So far, the universities have been able to produce the well-educated people that Vestas needs. However, Technology R&D is internationalising and must be able to continue recruiting the highly skilled people this business unit needs. Technology R&D's ability to recruit and retain talented people from universities and research institutes

worldwide, and put their creativity to work has certainly been – and will continue to be – one of its success factors.

Vestas also has a tradition of participating in public–private R&D cooperative projects to accelerate the innovation process, and is the leading company in the recently established partnership *Megawind*, which includes several companies, universities and the Danish Energy Authority. A recent report from Megawind, chaired by Technology R&D, has proposed a strategy for wind power R&D in Denmark. Education, validation, testing, demonstration and research are cornerstones of the strategy. The innovative reliability strategy in this report includes components and turbine parts, wind turbines and wind farms, and wind power plants in the energy system.

Apart from reliability, life cycle aspects and occupational health have recently come into focus. Vestas thus works systematically and successfully to reduce work-related injuries, and to reduce the use of energy and materials in their production processes. For example, key indicators on these issues (the number of occupational injuries, the consumption of metals and other raw materials and energy, the percentage of energy consumption covered by renewable energy, the volume of waste produced, emissions, and environmental accidents) are reported in Vestas' annual.

Other drivers of innovation are a closer collaboration with suppliers in order to share efforts to minimise maintenance and repair costs, and for guarantees. These aspects are becoming increasingly important as the market matures, clients become more professional and experienced, and competition gets tougher.

Among the external drivers of and barriers to innovation, we should mention the regulations and subsidies that exist in various countries, as well as government R&D programmes that can assist in knowledge development and serve as a training ground for key innovative people.

Incentive systems

The feed-in system (premiums), which accounted for 83 % of the installed wind power capacity in Europe in 2006, has been proven by long experience to be a highly efficient and fast working incentive system – provided the tariff level is appropriate. It is also a scheme that can be flexible in terms of support level, because it offers the possibility of adjusting the tariff and/or introducing a ceiling for maximum tariff support, according to world energy prices. A price guarantee, overall, acts to reduce important parts of the uncertainty for those who are willing to invest in the alternative energy sector, on both the demand and supply side. This is something that is probably common to all or most renewable energy.

Tradable certificate systems, on the other hand, have so far had only a limited effect on driving the European wind power markets. The markets that today show some activity are only doing so with a significantly higher certificate price than the equivalent support paid out by a feed-in tariff. Although there has not been extensive experience with certificate systems, it is known from the market that these systems need to reach a certain critical mass in order to be effective, and are thus not suitable for small national markets. Another serious concern is that volatility in certificate system pricing mechanisms could

discourage investors from investing in renewable energies and wind power technology. Therefore, more experience is needed before final conclusions can be drawn about the effectiveness of tradable certificate systems.

Environmental impact

Vestas is fully aware of the need to consider the environmental impact of wind energy technology. The installation of a wind farm is begun only if the environmental impact assessment and life cycle conclude that the farm has an acceptable impact on the environment.

Future plans

Vestas' plan for the future is to follow up and maintain the successful growth and impact that the company has made globally. According to Vestas, the process of innovation in wind energy does not stop and should not stop. In Denmark, Vestas has reached a 20 % penetration in the wind energy market (2007), and it is now aiming to achieve a target of 50 % market penetration. If wind energy is to become one of the key answers to the threat of global climate change, there is a need to continue to innovate in wind energy worldwide. It is Vestas' objective to be central in these processes.

The following quote illustrates this vision of being central in wind energy innovation globally:

> "A global company such as Vestas will be able over time to create a growing number of new modern high skilled jobs in those markets where Governments adopt, implement and keep in place ambitious wind energy policies and regulation". (Lise Backer in Vestas Governmental Relations, at the Workshop on environmental innovation and global markets Berlin, 20-12 September 2007)

5.8 Key conclusions

Key message 1: Stability and cultural acceptability are necessary

Of key importance for Vestas success has been stability of regulations and subsidies over a fairly long time period. This is a general requirement for fostering innovations that will contribute effectively to long-term societal objectives and accompanying long-term growth of new sustainable industries.

Key message 2: Feed-in tariffs are preferred to tradable certificate systems

In Vestas feed-in tariffs are preferred to tradable certificate systems. The feed-in systems in Europe have been proven by long experience to be highly efficient and fast working incentive systems – provided the tariff level is appropriate. A price guarantee acts to reduce important parts of the uncertainty for those who are willing to invest in the alternative energy sector, on both the demand and supply side.

Key message 3: Large R&D programmes need to be accompanied by modern IPR regulations

Government R&D programmes can also work as a positive stimulus to innovation, provided that the IPR regulations are modern enough to allow companies to safeguard the intellectual property produced when working with university researchers. Old IPR regulations need to be redesigned if governments are to succeed fully achieving their goals in relation to globalisation.

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Lise Backer in Vestas Governmental Relations, speech on the Workshop on environmental innovation and global markets Berlin, 20-12 September 2007

Vestas Wind Systems A/S www.vestas.com

http://www.hoovers.com

6 Case study of good practice: Aker Clean Carbon AS

6.1 Company details

Year of establishment: 2007
Address: Aker Clean Carbon AS, Snarøyveien 30, NO-1360 Fornebu, Norway
Main sector(s) of activity: development of technology for CO_2 capture
Respondent: Oscar Fr. Graff, Chief Technical Officer (CTO) at Aker Clean Carbon AS, Tel.: +47-24 13 00 00, E-mail: og@akercleancarbon.com
Interviewer/Data: Antje Klitkou, NIFU STEP, 20 May 2008

6.2 Why is this company an innovation leader?

Aker Clean Carbon is a Norwegian technology company, which focuses on developing commercial technologies for carbon capture facilities for a worldwide market. The company can build on more than 15 years of experience in various carbon capture technologies from Aker Solutions (Graff 2008d). Currently at Aker, about 160 engineers are working on carbon capture and storage (CCS) technology and projects. An 8-year research and development (R&D) programme (approximately €40 million) has been established together with Sintef/NTNU and strategic partners. An advanced mobile test unit will start operation in September 2008 and will be used to verify and demonstrate innovative solutions. The Just Catch™ and the Just Catch Bio™ technologies that Aker has developed since 2004 are now ready for commercial production.

6.3 Key performance indicators

Number of employees:	19
R&D personnel, % of total employees:	80%
Patent applications under PCT by 2007:	7

6.4 Company structure and operations

Management

- Jan Roger Bjerkestrand, Chief Executive Officer (CEO)
- Lasse B. Kjelsås, Chief Financial Officer (CFO)
- Oscar Fr. Graff, Chief Technical Officer (CTO)
- Tore Killingland, Communication Manager

History

Aker Clean Carbon AS is a young company, but it can build on the knowledge and competencies developed in the Aker group of companies over many years. Aker Kværner is one part of Aker, and has developed the Just Catch™ and Just Catch Bio™ technologies. The company has invested NOK 110 million and received an additional NOK 15 million from Gassnova for the development of this technology (Graff 2008d). Aker Clean Carbon AS was established in 2007 as a subsidiary of Aker, but in 2008 Aker Kværner decided to concentrate the CO_2 capture activities in a separate company, and transferred its technology for CO_2 capture to Aker Clean Carbon (Lindbæk and Torkildsen 2008). Aker Solutions (previously Aker Kværner) and Aker are the two owners of Aker Clean Carbon AS.

Aker has developed carbon capturing technology over many years (Graff 2008c, d):

- Since 1980 16 amine based plants for removal of $CO_2$from natural gas delivered
- 1991 Post-combustion technology (membrane-Gore)
- 1995 Carbon black/hydrogen plant (Canada)
- 1996 Sleipner CO_2 Platform – 1 Mt/year, MDEA absorbent, EPC contract
- 1997 Oxyfuel combustion (HiOx)
- 1998 Green FPSO (Shell)
  Kårstø CO_2 pilot plant (partner Statoil)
- 2000 Fuel cells (ZESOFC), ONS Award
- 2003 Zero Flare (ADCO, Emirates), HSE Award
  Compact steam reforming (Shell)
  CO_2 hydrates (IEA)
- 2004 CO_2 capture. Just Catch™ start
- 2005 Extended oil recovery, Haltenbanken (Shell & Statoil)
- 2006 Full-scale capture plant at Kårstø (NVE)
- 2007 CO_2 capture, Just Catch Bio™ start (FEED)
  Test Centre Mongstad, FEED
  Advanced mobile test unit, FEED
- 2008 Advanced mobile test unit, EPC Contract
  Demonstration plant at Kårstø, EPC Contract (6 months)
  Full-scale plant at Kårstø, FEED
  SOLVit R&D programme
  UK competition, CO_2 capture from coal-fired power plant

Ownership

Aker Clean Carbon is now owned by Aker Solutions (formerly Aker Kvaerner) (30 % of shares) and Aker ASA (70 % of shares). The Norwegian state has part ownership in Aker Holding, and thereby also in Aker Solutions.

Activities

Aker Clean Carbon has several ongoing activities (Graff, 2008c, d):

- Developing Just Catch™ & Just Catch Bio™
- Mobile test unit (in operation from September 2008)
- FEED study for full-scale CO_2 capture facility at Kårstø (contract worth NOK 16 million)
- Future full-scale plant at Kårstø (competition with three other companies)
- Competition for a demonstration plant at Mongstad Test Centre
- SOLVit (R&D Programme)
- UK government competition to develop the first commercial-scale CCS project for a coal-fired power plant (participation in an international consortium led by Scottish Power)

Suppliers/partners

The Aker group has been supplier and contractor for several commercial projects, including include CCS, e.g. the Statoil's Sleipner CO_2 project and liquefied natural gas (LNG) Snøhvit.

Aker Clean Carbon is collaborating with Aker Kværner, now Aker Solutions. Aker Solutions is the exclusive supplier of front-end engineering and design (FEED) and engineering, procurement and construction (EPC). As Graff has pointed out, Aker Solutions is one of the few global contractors with the relevant competence in the complete CCS value chain (Graff, 2008b).

Aker Clean Carbon is also collaborating with international industry actors. For the purpose of the UK government's competition to develop the first commercial-scale CCS project for a coal-fired power plant, Aker Clean carbon is part of an international consortium led by Scottish Power, a part of the Iberdrola Group. Other members of the consortium are Aker Solutions and the American enterprise Marathon Oil Corporation.

Aker Clean Carbon is collaborating in important R&D technology projects in Trondheim:

- Test rigs at SINTEF (Trondheim),
- Strategic R&D programme SOLVit (Sintef& NTNU), including industrial partners.

Competitors

There is an ongoing competition for the contract to develop the technical FEED pre-studies for a full-scale CO_2 capturing plant at Kårstø. Aker Clean Carbon is competing with the following companies for a contract to build the full-scale utility at Kårstø: Fluor Daniel Construction Company, from England/the USA; and Mitsubishi Heavy Industries, Ltd, from Japan. Two other competitors, HTC Purenergy Inc. and Bechtel Overseas Corporation from Canada/the USA, were involved in an early stage of the competition, but were rejected. The final investment decision will be made by Gassnova SF. Gassnova has is collaborating with the German company Fichtner GmbH & Co. KG, as a technical

adviser, and Norsk Energi, who will conduct the impact study (communication from Gassnova SF, 5 March 2008).

According to Løken (2008) Aker Clean Carbon has competitors at several stages on the value chain. With regard to the development of post-combustion CO_2 capturing technology she listed ECO2 (UK), BASF (Germany) and HTC Pure energy/Bechtel (Canada, USA). In addition, she mentioned competition from post-combustion process plant entrepreneurs, such as Linde (Germany), Mitsubishi Heavy Industries (Japan) and Fluor (USA).

6.2 Innovative products and practices

Innovative products

As long as the global price quotas for CO_2 are as low as they are today it is difficult to make CO_2 capturing technology commercially viable. Therefore, Aker Clean Carbon has a focus on reducing costs, and is addressing this issue in several ways.

Important aspects in this cost reduction are the need for improved absorbents and increased energy efficiency of the entire process. The Just Catch™ technology is based on low-energy amines. With a view to developing improved absorbents, Aker Clean Carbon has launched a strategic R&D programme in collaboration with Sintef and the NTNU. One solvent, JC1, is ready for commercialisation and others are being tested.

Another approach to cost reduction is the development of a standardised design. The development of the *mobile test unit*, which will be ready in September 2008, will contribute significantly to this end. With this test unit it will be possible to test the Just Catch™ technology using real flue gas from any plant in the world. The unit will allow for very sophisticated monitoring of the capturing process. The unit can be transported by land or ship in two containers, and is therefore very flexible and can be used by every possible client in the world.

Graff has pointed out the following features for the mobile test unit (Graff, 2008b):

- Safe operation
- Easy transport and h-up
- Standard container
- Lorry or ship transport
- Industrial flue gases
- Amine flexibility
- Just Catch™™ design features
- Verified design data
- Verified solvent
- Long-term testing
- Easy modifications
- Capacities:
  - flue gas: 1000 Am^3/h
  - CO_2 capture:
    - coal power: 180 kg/h
    - gas power: 60 kg/h

The further development of the Just Catch™ technology into the Just Catch Bio™ technology has provided a substantial contribution to addressing the needs for a sustainable technology pathway. The CO_2 capturing technology is still very energy intensive, and therefore there is a need to combine the Just Catch™ technology with a bioenergy plant in order to reduce CO_2 emissions from the process as a whole. The bioenergy plant will provide the energy for the capturing process, and the CO_2 emitted from the bioenergy plant itself will be captured. According to Graff, the proposed biofuel demonstration plant at Kårstø will have a capturing capacity of 100 000 tones CO_2 per year and will achieve a capture rate of 116 % (Graff 2008b). It will therefore contribute to the realisation of the so-called "carbon negative" concept, which has been argued for by non-governmental organisations (NGOs) such as Bellona and others (Birkeland et al. 2008).

6.2 Managing innovation: internal drivers and barriers

Intellectual property management

Aker Clean Carbon is pursuing an active intellectual property rights (IPR) strategy. The Just Catch™ technology has been protected by seven applications under the umbrella of the Patent Cooperation Treaty (PCT) (see e.g. Woodhouse 2006).

This process was started at the end of 2006, when the predecessor company made national patent applications. These applications were extended to global protection at the end of 2007. Some of the applications have now been published at the World International Property Organization.

Capacity for building relationships with external partners

Aker Clean Carbon has a strong focus on the further development of the knowledge base of CCS in Norway, and has therefore collaborated closely with the main Norwegian R&D organisations in this field, NTNU and Sintef.

Aker Clean Carbon, Sintef and the NTNU have started the Strategic R&D programme SOLVit. This programme deals with the selection of optimum solvents for the next generation of post-combustion CO_2 capture systems (Graff, 2008c, d). It is a €40 million programme over 8 years (2008–2016). The programme has applied for co-funding from the Research Council of Norway. The programme will also invite other industrial players, such as energy companies, to participate.

According to Graff (2008c) the programme has the following main goals:

- Develop, test and select improved solvents.
- Low energy requirement:
    - minimum environmental impact,
    - low corrosion,
    - low degradation.
- Advanced simulation model.

- World class laboratory and testing facilities (upgraded infrastructure at Gløshaugen, full-height rig)
- Mobile test unit (container size); Aker Clean Carbon is responsible for this and the unit will be ready in September 2008
- Education programme (International Master, PhD and post-doctoral programme in CCS)

Strategic planning and prioritisation of innovation

As Graff has pointed out, current European projects are heavily subsidised, and Aker Clean Carbon is therefore pursuing a tight time schedule in its participation in various competitions to be involved in subsidised projects. The aim of this high activity level is to obtain the advantage of being a first mover (Graff, 2008b).

The planned development of projects over the period 2007–2014 focuses on the further improvement of absorbents to achieve second-generation absorbents, and thereafter third-generation absorbents. This is a key activity for the company.

After the contract for the FEED study for the full-scale facility at Kårstø (July 2008, Norwegian projects will become the centre of the company's attention: the competition to building the full-scale facility and the competition for the demonstration plant at Mongstad.

An important issue is to develop the Just Catch^{TM} technology to be used with coal-fired power plants, as this is the main global market for this technology. Central to this development is the company's participation in the UK government competition.

Operational and process management of innovation

Specialist knowledge and skills

Aker Clean Carbon has 19 employees, 80% of whom are R&D personnel. Within Aker as a whole, about 160 engineers are currently working on CCS technology.

Forecasting technology and markets

Aker Clean Carbon estimates that there are 4000 large CO_2 sources–(power plants and industry) worldwide, which together produce about 40% of global CO_2 emissions (Graff 2008a). At present, there are more than 2000 power plants with emissions of at least one million tonnes CO_2 per year. Within Europe, CO_2 emissions are especially high in the UK and Germany.

6.3 External drivers of and barriers to innovation: sectoral issues

External drivers

The focus of the European Union (EU) on climate-change challenges put pressure on national governments to develop at least pilot or demonstration plants for CCS. National governments in Norway and the UK, for example, are focusing on such projects. For Aker Clean Carbon the participation in the competitions for these projects is an excellent driver for the further development of their innovative technology.

Det Norske Veritas (DNV) has qualified the Just Catch™ technology in accordance with DNV RP-A203 Qualification Procedures for New Technology, and it will also be involved in qualifying Just Catch Bio™.

An important goal for Aker Clean Carbon is to develop and test the Just Catch™ technology not just for CCS at gas-fired power plants but also at coal-fired power plants. Therefore Aker Clean Carbon is very active in the European market, in particular through its involvement in the competition for installing CCS in a UK coal-fired power plant.

Access to appropriate financing

Aker has provided Aker Clean Carbon with a lot of capital investment, and Aker Clean Carbon is able to invest a significant amount of this high risk capital in accelerating technological development. According to Graff, Aker Clean Carbon has invested about NOK 100 million in various projects and the mobile test unit, and is planning to invest another NOK 100 million in the SoLVit R&D programme.

Access to top-level human resources

The technology director of Aker Clean Carbon has emphasised that the company has a very good access to highly skilled specialists in the CCS field. In addition, the company is also very active in broadening the supply of newly educated specialists. This includes an education programme that is integrated in the Strategic R&D programme SOLVit. The education programme includes programmes for International Masters, PhD and post-doctoral qualifications in CCS.

Favourable policies and programmes supporting innovation

There are two Norwegian policy instruments that should be mentioned:

- Gassnova SF: this government centre of CCS expertise was started in 2007 and receives revenue from the Gas Technology Fund (NOK 80 million, about €10 million/year) of NOK 2 billion/year. Gassnova manages and supports the development of CCS technology. Funding is available for a broad range of activities, from R&D projects to full-scale installations.

- CLIMIT programme: this was launched in 2005 as the national R&D programme for gas power technologies with CCS. The programme is administered by Gassnova SF and the RCN.

In addition, it should be mentioned that Norway is a member of the Carbon Sequestration Leadership Forum (CSLF), and Norwegian R&D organisations have actively participated in most of the R&D projects under the EU Framework Programmes that have addressed CCS.

External barriers

The high cost of CO_2 capture is one of the main barriers to taking the technology to a commercial level. As long as CO_2 quotas are at the low level hey are today, it is difficult to achieve commercial viability of CCS without public subsidy.

The success of the projects planned by Aker Clean Carbon depends on factors that are not always under the company's control. An example of such an external barrier is the fate of the envisioned demonstration plant at Kårstø. Here Aker Clean Carbon was dependent on access to the flue gas to be able to capture the emitted CO_2. This could not be accomplished, and therefore the plans for a self-financed demonstration plant have been cancelled (see Dagens Næringsliv, 1 July 2008).

6.3 Key conclusions

Key message 1: Global orientation fosters standardised solutions

An orientation towards the global market has contributed to a greater focus on flexible and standardised solutions that are applicable to both the gas and the coal power market.

Key message 2: Collaboration with strong R&D organisations

Collaboration with strong R&D organisations is a driver of technological development.

Key message 3: Combining CCS with bioenergy

A combination of new technology systems within a systemic approach – bioenergy and CO_2 capture – will make a greater contribution to the main aims of further technological development, reducing costs and increasing CO_2 capturing capacity.

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7 Case study of good practice: Renewable Energy Corporation (REC)

7.1 Overview and background information

The solar cell industry is based on an innovation made in Bell Laboratories in 1954. The first breakthrough was the application on the Vanguard 1 satellite launched in 1958. Whereas batteries in satellites lasted for only 20 days in space, the solar cell panels of Vanguard 1 lasted for 7 years, until 1964.[17] This success initiated the "space age" of the solar industry. On Earth, solar cell technology is still not efficient enough to be able to compete with other technology sources.[18] The market relies on policy measures. The industry boomed in the 1970s, when the oil crises forced countries such as the USA, Japan, Sweden and Denmark to apply *supply-side* policies, and fund photovoltaic (PV) cell research to achieve national energy security. Later, this objective was combined with "sola visions", based on the need to develop alternatives to carbon-based energy sources. As Norway had oil, there was no need to apply these policies. This is why Norwegian R&D investment in PV cell research is still small from a Nordic perspective.

In the 1990s, several European countries and Japan began to apply *demand-side* incentives, such as feed-in tariffs, to promote solar cell panels (Jakobsson et al. 2002, Ruud et al. 2005). In the USA, tax relief and subsidies were introduced, and this led to a rapid growth in the market (25 % in 1995). At the same time, due to large, long-term R&D investments, sophisticated solar cell *technology* was available on the market in Germany and elsewhere. This German technology could be *bought* by the entrepreneurs who had started to develop Scan-Wafer, which was later to become the core of Renewable Energy Corporation AS (REC) in Glomfjord in 1994. The successful start-up of REC was based on German R&D policies, creating a global market for PV technology. Another enabling condition at the time was German, Italian and Japanese demand-side policies to promote the use of PV technology. The Norwegian contribution to the PV industry, through cooperation with the German technology supplier ADL, was to transform the small-scale, craft-based production technology, which was the German, world-class standard in 1996, to a large-scale, automated, efficient process industry, which is used by REC today.

7.2 Company details

By setting a new global standard for productivity, REC achieved global visibility through the rapid growth and remarkable stock performance after IPO in 2006. In 2007, REC's growth in income was 53%. Income has been used to grow the company through investments in Norway and the USA, and recently through a NOK 13 billion investment in a solar industry plant in Singapore. In 2007, total REC stocks were valued at NOK

[17] www.engadget.com/2008/03/14
[18] With the exception of China (Bai 2008)

136,431 million (Renewable Energy Company, 2008); the total turnover in 2007 was NOK 6642 million.

Year of establishment: December 1996 **Address**: main office in Oslo, Norway **Main sector of activity**: REC integrates a value chain, which includes mineral processing and energy technology production **Website**: www.recgroup.com **Data**: Åge Mariussen, NIFU STEP

7.3 Why is this company an innovation leader?

The cooperation between Scanwafer/REC and ADL was initiated in 1998 to develop a new large-scale furnace technology. ADL got a share ownership of Scanwafer, and in return Scanwafer got exclusive rights for 10 years for the new large-scale technology. A partnership with a Norwegian mechanical company, Trondrud Engineering provided a highly automated production line. In this way, REC achieved a world-leading productivity level, which it is now exploiting through rapid growth.
Later, REC made a series of successful acquisitions of raw material suppliers in the USA.

7.4 Key performance indicators

The Earnings Before Interest, Tax, Depreciation and Amortization (EBITDA) were NOK 3172 million (net profit before financial transactions and taxes). This reflects a rate of annual profit (before financial costs and taxes) of 47%. This figure may be compared with the *ReneSola Ltd* of China, with an operating margin of 17.4% in 2007, and ersol *Solar Energy* of Germany, with an operating margin of 22.6% in 2007. Differences like this may be seen as reflecting several factors. However, it is quite obvious that REC is doing very well indeed.

REC is recognised as the world largest producer of solar cell *wafers*. A wafer is the *mineral core* of a cell. Through acquisitions in the USA, REC also has a strong position in silicon purification.

7.5 Company structure and operations

General

REC integrates a value chain, which is explained on the company's homepage (www.recgroup.com) as:

> *The presence in all parts of the value chain of the photovoltaic industry is one of REC's key strengths. It provides in-depth industry insight at a point in time when the industry is still immature, which makes REC well-positioned to analyze and execute on strategic opportunities. It also enables REC to carry out joint technology*

development and further strengthen its leading technological position throughout the chain. Efficient collaboration across segments makes it possible to exploit operational synergies and apply consistent application of manufacturing principles. It also provides flexibility to grow where opportunity is greatest at any time, in a coordinated manner. Own production of polysilicon secures the growth potential of all REC businesses. This enhances other strengths, notably efficient and scalable operations with lean manufacturing and mass production concepts implemented throughout the group.

REC has three divisions (www.recgroup.com):

REC Silicon
REC Silicon produces silane and polysilicon for the PV and electronics industries at two facilities in the USA. REC Silicon is the world's largest dedicated producer of silicon materials for the PV cell industry.

REC Wafer
REC Wafer produces multicrystalline wafers for the solar cell industry at two production facilities in Norway, as well as specialised monocrystalline wafers at a separate plant in Norway. REC Wafer is the world's largest producer of multicrystalline wafers.

REC Solar
REC Solar produces solar cells at its plant in Norway and solar modules at its facilities in Sweden. It also operates a small systems installation company, Solar Vision, in South Africa.

Ownership

The main owners (May 2008) of REC are: Elkem (23.45%), the German Q-Cells AG (17.8%), other large Norwegian corporations and American, Japanese and German investors (see Table 10).

Table 8: The main owners of REC, May 2008 (Source: REC)

Rank	Company	No. of shares	Ownership
1	Elkem AS	115,935,300	23.45%
2	Q-Cells AG	84,956,767	17.18%
3	Orkla ASA	80,489,700	16.28%
4	Hafslund Venture AS	68,711,520	13.90%
5	State Street Bank and Trust Co.	16,512,929	3.34%
6	Fidelity Lending Account	9,370,714	1.89%
7	Citibank N.A.	8,837,690	1.78%
8	Clearstream Banking S.A.	4,019,182	0.81%
9	Sumitomo Corporation	3,062,000	0.61%
10	State Street Bank and Trust Co.	2,816,180	0.56%
11	Folketrygdfondet	2,693,200	0.54%
12	Fidelity Funds	2,356,700	0.47%
13	JPMorgan Chase Bank	2,338,921	0.47%
14	Skandinaviska Enskilda Banken	2,328,921	0.47%

15	Mellon Bank as agent for clients	2,293,731	0.46%
16	JPMorgan Chase Bank	2,141,302	0.43%
17	Bank of New York, Brussels Branch	2,014,365	0.40%
18	Morgan Stanley & Co. Inc.	1,971,865	0.39%
19	Vital Forsikring ASA	1,873,434	0.37%
20	Deutsche Bank Securities Inc.	1,812,980	0.36%
	Total	**494,314,725**	

Market

The current long-term expectation is that market growth will continue, and that this will become a large industry as other energy sources, such as solar energy, replace fossil based energy. In the short-term, there is expected to be strong growth in several markets. With the huge investments in new production capacity all over the world, recently large investments in China, the industry is preparing for increased price competition.

Competitors

As a response to this rapid growth, large investments are now made all over the world; there is rapidly increasing capacity for existing products. REC's specialisation in multicrystalline wafers, combined with its integration of raw material suppliers, explains its strong market position and good results. REC is selling wafers, and increasingly also cells, to other producers of solar cell panels.

In expanding into the market for solar cell *panels*, REC is competing with several larger American and Asian companies. A more serious long-term threat is new disruptive technologies, such as nanotechnology (see below).

7.6 Innovative products and practices

Innovative products

REC is producing a standardised raw material based product in large volumes and with highly competitive costs. The major innovations are process innovations, enhancing productivity.

7.7 Managing innovation: internal drivers and barriers

Management of intellectual property[19]

Proprietary silicon production technology

REC Silicon holds more than 20 approved or pending patents. The fluidised bed reactor technology is one of the latest and most promising results of our technology programme.

[19] Main source: REC homepage: http://www.recgroup.com/default.asp?V_ITEM_ID=446)

Cost-efficient wafer production technology

REC is exploiting an innovation achieved in 1998 to scale up and automate wafer production, in cooperation with the German technology supplier ADL. Before 1998 wafer production was based on small-scale, labour-intensive (craft-based) technologies. REC was the first company to introduce a scaled up and automated process of solar cell production. REC established a new world-class standard of productivity in the industry, and became the world's largest producer of wafers. REC combines state-of-the-art manufacturing equipment with proprietary technologies to ensure highly efficient production.

Highly automated plants for cell and module production

REC Solar's cell and module facilities are among the most highly automated plants in Europe, and REC is currently developing new technology to strengthen its competitiveness and ensure future growth. The facilities are focused on a few products and customers, allowing a lean approach to production.

Strategic planning and prioritisation of innovation

Due to the 1998 innovation, REC is still ahead of its competitors. It is investing the huge profits in growth in order to defend its position as world leader, by growing as fast as the market for solar cells. Unlike other Norwegian producers, such as Sol-Scan in cooperation with Hydro working on thin films, REC is not making major investments in new materials to develop new products.

7.8 External drivers of and barriers to innovation

External drivers

Short term: increasing price competition

Until now, growth has relied on institutions put in place in other countries to promote the growth in solar energy. In Europe, the future of feed-in tariffs now seems to be uncertain (Friedman-Billings-Ramsey Seeking Alpha homepage). At the same time, the promotion of non-carbon energies has become a core issue in *American national security policy*. This is expected to lead to future American policies promoting green energies. In China, low production costs now make solar cells competitive with petroleum-based energy production. At the same time, the Chinese government is implementing strong feed-in tariffs (Bai 2008).

Long term: new disruptive technologies

Since 2007 venture capital funding for PV technologies has dwarfed that for microprocessors in the American venture capital market. The most obvious short-term

technological competition to PV technology is films. Other competing technologies are paint and ink:

> "Nanosolar CEO Martin Roscheisen, who, like many new solar kings, has roots in Silicon Valley, says he can achieve radical cost savings by directly applying photoactive chemicals with an ink composed of nanoparticles. Nanosolar's PowerSheet cells roll off the machines like pages of newspaper in a printing press, at the rate of several hundred feet a minute. Roscheisen, an intense Austrian, says Nanosolar's first 18 months of production have already been purchased. 'We're looking for a 35 % market share in the next couple of years,' he says. 'The simple truth is, we can scale a lot more product out for a lot less'"(Walsh 2008).

There is a still weak but growing venture capital market in Norway focusing on new PV technologies. Hydro and Nor-Sun are now investing in thin film.

Access to appropriate financing

At REC profits are used to grow more wafer capacity, and at the same time expand cell and panel production (in Singapore). This long-term growth strategy is supported by an impressive list of highly competent global owners.

Favourable policies and programmes supporting innovation

There are fewer policies supporting PV technology research in Norway than in the other Nordic countries. Supported by funding from the Research Council of Norway, the Institute for Energy Technology is doing research on the "third-generation" solar cell. A Nordic Centre of Excellence in Photovoltaics is one of their projects (Institute for Energy Policy 2007). Here, attempts are made to mobilise the strong PV research projects in other Nordic countries to do research that may support the Norwegian industry.

7.9 Key conclusions and policy highlights

Key message 1: Short-term and long-term prospects are good

REC's growth strategy is likely to lead to further strong achievements in the near future. The long-term prospects for the PV industry look very good indeed.

Key message 2: Medium-term uncertainty

REC seems to rely on its ability to access new technology through the market. This strategy was successfully applied in the 1990s. REC investments in the USA have also given the company an upper hand when it comes to cost-efficient raw material production, with 20 approved or pending patents. Given the current situation in the PV sector, technological competition and new, disruptive and *protected* nanotechnologies are likely to surface sooner or later. This could destroy the rules of the current technological regime, and bring an end to the current the success stories.

Key message 3: Focus on technological competition

The solar industry is new in Norway. It is obviously a success story. The major industrial actor, REC, for obvious reasons is exploiting its current strong market position to grow. In this perspective, the Research Council of Norway and the government should supplement this industrial strategy with policies that take the technological competition from new materials more seriously. The Nordic Centre of Excellence in Photovoltaics is a first step in the right direction, but this first step should be followed up much more aggressively and rapidly.

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