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Assessing the strength of the Norwegian solar power industry – a cluster analysis

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EXECUTIVE SUMMARY

This thesis studies the Norwegian solar power industry and aims to answer the following research questions:

1. How did Norway become such a significant nation in the solar power industry?
2. Do the actors in the Norwegian solar industry constitute an industrial cluster?
3. How sustainable is Norway’s international position in the solar power industry?

Investigation of the history of the industry and the most influential companies and research institutions lead us to two main factors contributing to the strong international position, namely building on existing competences within metallurgy and energy in general and the ability to commercialize and industrialize good business ideas. Porter’s diamond model was applied to structure industry information. Our analysis suggests that the industry cannot yet be called a full-fledged industrial cluster. The main reason is that there are uncertainties as to whether the industry has reached critical mass of competitors. However, there is more than one substantial actor in all parts of the upstream part of the value chain, and the industry as a whole displays strong qualities particularly in research competence and related and supporting industries. We therefore choose to classify it as a latent/underachieving cluster.

There are strong rival nations around the world, and this thesis provides a benchmarking against China, the US, Germany and Singapore, finding that these nations have relative strengths that will be challenging for Norway to compete with. Our research indicates that action must be taken for the cluster to maintain or improve its position. The analysis results in three recommendations for the Norwegian government: increasing support for R&D and test production, as well as facilitating an increase in the number of relevant graduates. We believe that these measures will help develop Norway in regard to the main challenges we have identified and that the knowledge-based cluster has every opportunity to further prosper if appropriate measures are taken.
ACKNOWLEDGEMENTS

Writing this thesis has been an interesting process through which we have learned a lot. We have been fortunate enough to get first-hand accounts from key persons in the Norwegian solar power industry, and for this we are very grateful. In particular we would like to extend our appreciation to Reidar Langmo, Egil S. Marstein, Otto Lohne, Marit Dolmen and Øystein Hop for their time and valuable insights.

We are also thankful to our lecturers in strategy courses at BI for providing us with the necessary foundation for this work. We have also valued the contributions of our fellow students the past two years. Last but not least we offer our sincere appreciation to our supervisor, Torger Reve for challenging our work and offering invaluable guidance.
INTRODUCTION

In the course of the last 15 years, a significant Norwegian photovoltaic solar industry has emerged. Some might find it surprising that solar cells are produced in a country situated partly north of the polar circle, with some of the harshest climate conditions on earth. This paper investigates the underlying factors to find the reason why such an industry has been able to blossom in Norway. We will also analyze the relative competitiveness of the industry as a group compared to other competing locations in order to acquire an opinion on its strength and sustainability. In a globalized world, it is important to provide favourable framework conditions in order to attract and retain companies that can create value for the country. We will thus come up with a few recommendations for the government and other public institutions on what to adjust in order to facilitate further development of the Norwegian solar industry.

RESEARCH STATEMENT

Relevance of topic

Climate concerns are growing due to the increase in average global temperature, and the world is in desperate need of alternative sources of energy to replace the polluting fossil fuels that dominate energy production today. The sun provides the earth with more than 15 000 times its total energy demand, and solar power is infinite and inexhaustible. Solar power also has the potential of increasing the standard of living in developing countries. These societies might skip the step of building the massive infrastructure to provide electricity and communication that the industrialized world had to invest in. By fitting solar panels to each house and communicating wirelessly by mobile technology, these societies would be able to organize efficiently and develop much faster than what would otherwise be feasible. The energy is there, it just needs to be collected more effectively, and that is an impetus to commercialize the industry. We assume that a strong cluster in solar power will be beneficial for the success of the development and commercialization of advances. We are therefore of the opinion that studying Norway’s role in this is of high interest.
Norway’s financial situation to a large extent stems from activities related to oil and gas. These fossil fuels will run out in the foreseeable future, so finding a replacement is of great importance, both for the employment level, the further development of advanced skills, the research community and financial welfare. Due to the enormous market potential for solar energy, the consequences of becoming a leading nation in this field would be tremendous, and studying the industry in the context of clusters will help identify how the situation is today and what measures need to be taken to enhance the position in the future.

**Research questions**

1. *How did Norway become such a significant nation in the solar power industry?*

2. *Do the actors in the Norwegian solar industry constitute an industrial cluster?*

3. *How sustainable is Norway’s international position in the solar power industry?*

The research questions indicate that we will investigate why Norway appears to be a successful location for the industry. To accomplish this we will study the establishment and development of the industry to identify strengths and weaknesses in the context of clusters. Industrial clusters are said to exist where “rival and competing firms sharing the same industrial knowledge base” (Reve, 1996) are located close to each other. We will explore whether the actors making up the Norwegian solar industry qualify as a cluster and if so, assess the strength and the sustainability of Norway as a location for further expansion. The aim of the thesis is not to predict the future of the industry, but to say something about how favourable the conditions are for further growth and strengthening of the potential cluster.

**Object of study**

The thesis is mainly concerned with assessing the strength of the potential Norwegian solar energy cluster. The technologies will be explained later in the thesis, but Norwegian producers are only engaged in first generation solar cells. We will therefore focus mainly on this technology in our analysis. Since the wafer is the core component in a solar cell, we choose to focus on the largest producers of silicon, wafers and cells. Our main objects of study will thus be REC, Elkem...
and NorSun. Many other companies, such as waste handlers, investment companies, niche players and research organizations, are necessary in the value creation process from silicon to solar panel, and we will study these as part of the actors making up a cluster. Our object of study is the Norwegian potential cluster, i.e. all entities in the industry located in Norway.

LITERATURE REVIEW

Concentrations of industry actors within a limited geographical area are a phenomenon which has received much attention in business, politics and academia. Economic geography has been a field of interest for a long time, but Porter’s diamond model made the topic more accessible and mainstream. We will begin by introducing cluster theory, presenting two strands of theory which are of high relevance to this thesis, namely cluster formation and growth/path dependency and the beneficial role of clusters. This part will encompass the history of the field from agglomeration economies to newer perspectives on clusters. We will then move on to a thorough presentation of Porter’s diamond model, explaining what he sees as the important factors constituting a cluster. The reason why this has been given so much attention in this thesis is that the analysis of the Norwegian solar power industry will be built up around this model. We will round off this part with a section on criticism and limitations of cluster theory.

Cluster formation and growth

The origin of clusters and the path dependence of its development is a topic of little consensus, despite the many empirical accounts. Of particular importance is the role of government and whether public policy can seed clusters (Wolfe and Gertler, 2004). Porter (1998) states that clusters can emerge from a variety of sources, such as historical circumstances, special local demand conditions, prior existence of related industries, one or more innovative companies stimulating the growth of others, or by chance. Dating the exact origin and the critical founding event of a cluster is a matter of degree and may be difficult to identify.

The positive feedback between size and growth is emphasized by van Wissen (2004). There are three ways of growing the cluster apart from incumbent expansion (Maskell, 2001). Already existing firms in other locations may relocate
or establish new subsidiaries in the cluster, entrepreneurs from the cluster area or other locations may start new ventures, or spin-offs may be established, driven by a former employee in an incumbent firm. Also, inertia plays a role by retaining companies in their area of origin.

Feldman (2001) argues that entrepreneurship tends to cluster spatially, depending on sufficient amounts of venture capital, supportive social capital, entrepreneurial expertise and support services and research universities working in co-operation with the industry. A full-fledged cluster offers positive externalities such as agglomeration effects, characterized by Bresnahan et al (2001) as new economy forces. They argue, however, that for a cluster to develop to a state where these become reality, old economy inputs are required. Examples of these are traditional firm-building capabilities such as lengthy investment periods later to be exploited, connection to market and demand and economies of scale at the firm level. Porter (1998) argues that successful cluster emergence and growth should be built on existing resources. Also, he states, they must be firm-based, because that is where competitive advantage is built.

**Cluster rationale**

Economic geographers ascribe cluster benefits to the reduced costs and increased access to factor and labour markets. Social network analysts emphasize relationships rather than physical space when analyzing the context of firms. Another stream of research is focused on the knowledge and learning effects of clusters. Also, the positive externalities are subject to empirical studies. These different viewpoints will be elaborated on in the following.

Alfred Marshall introduced the concept of agglomeration advantages, arguing that large pools of industry-specific skilled labour, production of nontradeable specialized inputs, e.g. particular services, and informational spillovers created positive externalities for clustered firms (Krugman, 1991). Hoover, referred in Simmie (2004), divided the sources of agglomeration economies into internal economies of scale, urbanization economies and localization economies. Internal economies of scale arise as an effect of locating close to new potential customers, as the company can increase production levels and achieve lower unit costs. Urbanization economies are the advantages of being located in a city, with ample
choices of various specialized business services and infrastructure of high quality. Localization economies, on the other hand, are not as general in nature, but more specialized to the particular industry. These typically develop as more actors within the industry establish themselves and grow. The most significant advantages include local expertise and competences and other industry-specific factors.

Gordon and McCann (2000) have identified three ideal-typical rationales for co-location, namely pure agglomeration, industrial complex and social networks. The model of pure agglomeration assumes opportunism, where interactions are only motivated by individual self-interest and not characterized by loyalty. The main benefit of being in a concentrated area is increasing the opportunities for exchange. The main focus of the industrial-complex model is the effect of location on spatial transaction costs, such as transport and logistics costs and telecommunications costs. The complexes consist of relatively stable trading links, to a large extent dictating their locational behaviour. The rationale for locating close to other firms is minimization of distance costs. The social-network model is characterized by stable relations, where trust acts as a substitute to vertical integration, parallel to the hybrid solution in governance of the firm (Williamson, 1991). Here the focal firm avoids investing much capital and efforts internalizing transactions, while also reducing opportunism and negotiation costs of the pure market contracting solution. The implied trust in the network facilitates risky joint endeavours, working toward common goals and reorganizing relationships without fear of reprisals. The determinant of this model is the relationships, and the location pattern is a consequence, as relationships are easier to govern over short distances.

Chiu (2009) argues that firms’ network competence, namely ability to handle business relationships, and centrality in the network, operationalized as number of relationships in the network, have a positive effect on innovation performance. There are also several accounts attempting to separate the social and the physical effects of spatial concentration of industry actors. Whittington et al (2009) have integrated the viewpoints of economic geographers and social network analysts to explore the individual and joint effects of propinquity and centrality on innovation. Centrality in the local network should provide greater returns of
agglomeration effects than less central positions. Global centrality is said to counter ‘inbreeding’ of knowledge and lock-in to the resources of the restricted local area. Formal, proprietary efforts make transferring complex information over great distances possible. They find that “centrality yields the greatest return when coupled with proximity to public-sector sources of scientific and technical know-how”.

The role of knowledge and learning in clusters

When firms, organizations, research and educational institutes in related industries are located in close proximity, knowledge is proposed to flow more effectively between these entities than would be the case among geographically dispersed actors. Maskell (2001) argues that the existence of clusters may be explained in terms of knowledge, in the sense that learning and knowledge creation is enhanced and asymmetric information is overcome. In addition, the legitimacy and existing knowledge pool attracts new industries and firms due to reduced ambiguity and costs. One of the most common explanations for the knowledge effects is the importance of face-to-face contact for the exchange of knowledge which is highly technical and tacit in nature. Boschma (2005) argues that geographical proximity may facilitate inter-organizational learning, but is neither necessary nor sufficient, because other forms of proximity may substitute geographical and be of a more critical importance to learning, for instance cognitive proximity. For example, different branches of a multinational corporation are likely to be organizationally close, and scientists with a common professional language may also collaborate despite long distances. Nonetheless, it is stated that geographical proximity may still be of vital importance by stimulating the other dimensions of proximity, possibly impacting on the learning process more directly. Ponds et al (2007) suggest that geographical proximity is a remedy to institutional differences between organizations, facilitating successful collaboration. Thus, being located in a cluster gives easier access to a local base of knowledge specific to the industry and region.

Wolfe and Gertler (2004) argue for the distinction between four kinds of knowledge spillovers. Technical research results are often more visible at earlier stages to geographically close competitors. Maskell (2001) argues that monitoring
and learning from competitors enhances knowledge creation. Innovation, defined as combining known elements into something new which adds value, is spurred by the process of comparing and imitating part of competitors’ discoveries when integrated in the focal company’s research/activities/products. Another source of knowledge spillover is skilled labour. Graduates with temporary or permanent employment in firms bring with them updated knowledge from their university, which adds to the competence already in the firm. Labour mobility in general is another example, facilitating interfirm-learning. Spinoffs are a similar kind of innovation-spurring, where research results in a company or research institute is carried forward by an individual establishing their own company. Saxenian (1994) found that by adopting a role similar to venture capitalist encouraging spin-offs and autonomous business units, firms in Silicon Valley managed to innovate at a much higher rate than its competitors, which also benefited the cluster as a whole. Entrepreneurial skills are third category of knowledge flows. This applies to general business skills and more specific market knowledge, most effectively transmitted through peer-to-peer mentoring and activities arranged by various associations. Finally, infrastructural specialized knowledge resources, such as legal, accounting and financial firms are often of crucial importance to the individual firms in the cluster.

Many accounts highlight the positive knowledge effects of being located in a cluster, but much attention is also devoted to the international knowledge community. Too high reliance on the local cluster for innovation inputs and knowledge development may lead to intellectual inbreeding and ‘lock-in’ (Simmie, 2004). Although this may work in certain situations and industries, the cluster companies will be very vulnerable to major shifts in technology and customer preferences. He therefore argues that linkages with national suppliers and international customers are significantly more important than those within the locality. According to Pouder and St. John (1996) agglomeration effects based on knowledge effects will erode with time, and the isomorphism and convergence within the cluster and the participants’ mental models will lead to inertia transforming the hot spot into a blind spot, less apt to adjust to external shocks. Kaufmann and Tödtling (2000) found that innovation, increasingly seen as a collective and interactive process, should be supported by relations to external
networks and systems to avoid being locked into the cluster’s traditions and routines.

Bathelt et al (2002) describe this as ‘local buzz’ and ‘global pipelines’. The term ‘local buzz’ is defined as “The information and communication ecology created by face-to-face contacts, co-presence and co-location of people and firms within the same industry and place or region. This buzz consists of specific information and continuous updates of this information, intended and unanticipated learning processes in organised and accidental meetings, the application of the same interpretative schemes and mutual understanding of new knowledge and technologies, as well as shared cultural traditions and habits within a particular technology field, which stimulate the establishment of conventions and other institutional arrangements”. This is the knowledge effect of being located in a cluster, not requiring significant efforts by the company in question. At least it gets a minimum of input more or less automatically, through various formal and informal channels. ‘Global pipelines’, on the other hand, are intended and formalized relationships with partners in more distant locations. The nature of the relationship and the degree of interaction and monitoring highly depends on the level of trust between the partners, which needs to be built in a conscious and systematic way. Local buzz and global pipelines complement and reinforce each other, in the sense that when more cluster firms have pipelines offering high quality information, this will contribute to their knowledge base, feeding into the local network, making the buzz benefiting cluster firms more dynamic, comprehensive and updated. This will again give the firms more to offer potential partners with whom to set up global pipelines. The main advantage of local buzz is to create a milieu of interpretation and spontaneous interaction, while global pipelines offer opportunities to tap into knowledge resources in other locations.

**Porter’s diamond model**

Michael E. Porter argues that a nation’s competitiveness hinges mainly on its ability to innovate. He postulates that the nation whose home environment related to a specific industry is forward-looking, dynamic and challenging is likely/has a good foundation to succeed in the given industry (Porter, 1990). Superior factor conditions, sophisticated demand conditions, internationally competitive related
and supporting industries and appropriate firm structure, strategy and rivalry are the four groups of factors contributing to cluster strength.

*Factor conditions*, most notably education, labour force, infrastructure and research institutions, should be of high quality. However, to constitute a source of competitive advantage, they should also be specialized to the industry in question. Highly specialized education and research institutions attract and develop talented individuals and world-leading companies. A well-developed specialized competence milieu requiring large investments gives the cluster a competitive edge and is difficult to copy for other potential cluster locations.

Although markets are globalizing and companies are to an increasing extent catering to customers worldwide, *demand conditions* in the home market are important. A large domestic market is naturally positive for business, also in the sense that the company has great potential before skills and competences to further internationalize are fully developed. However, what is more significant than market size is the nature of domestic demand. If a company is subject to clients with sophisticated demand, product development with active use of inputs from customers will be mutually beneficial. By being forced to continually improve to meet the requirements, the company will become better equipped to satisfy similar needs in international markets. Also, it is likely to have developed skills that make it more receptive to customer needs and more apt to adjust to these. If the domestic market has specific regulations or other requirements that will later be introduced in international markets, it is clearly an asset to have had an “early warning” in one’s home market.

Internationally competitive *related and supporting industries* in close proximity facilitate the use of high quality cost-effective inputs at the lowest possible transaction costs. Geographical proximity to one’s suppliers also makes close relationships and joint product development easier, especially in technologically advanced processes and where tacit knowledge is essential.

*Firm strategy, structure and rivalry* constitute the context for competition in the cluster. Fierce competition is destructive for firm profitability short-term, but taking a longer perspective, competition provides an impetus for continuous
improvement. A company which is forced to innovate and stay competitive is more likely to succeed internationally. In addition, closely located competitors tend to benchmark and learn from each other. Adding others’ insights to one’s own competences is a great source of innovation, further amplifying the positive effects of competition. Therefore, competition legislation and anti-trust policies are important to the nation’s ability to innovate and create value.

The diamond should be viewed as a system, where the performance on one factor influences the performance on others and the cumulative potential of the cluster. The various factors have different relative significance in different industries, but the main case is still that all factors need to be at a high level in order for the cluster as a system to be at a high level, as the factors reinforce each other.

Limitations of cluster theory

As discussed in the previous section, there is a low degree of consensus about various aspects of the cluster concept. The definition of what a cluster is and its span is another area of controversy. Porter (2000a) has defined clusters in the following manner, emphasizing the relatedness of cluster participants:

“Geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries and associated institutions (e.g. universities, standard agencies, trade associations) in a particular field that compete but also co-operate”.

An additional definition from Porter (1998) also encompasses the geographical scope of clusters:

“A cluster's boundaries are defined by the linkages and complementarities across industries and institutions that are most important to competition. Although clusters often fit within political boundaries, they may cross state or even national borders”.

The cluster concept, with its prescriptions to enhance productivity and competitiveness has gained many proponents in policy-making circles, and
nations and regions are applying its principles. It thus has a very significant influence on economic activity around the world. Martin and Sunley (2003) are highly critical of Porter’s lack of clear boundaries in his definition of clusters with regard to both industries and geography. It is increasingly recognized, even among advocates of cluster-based economic policies, that clusters are not all the same (Harrison et al, 2004).

“Drawing cluster boundaries often is a matter of degree and involves a creative process informed by understanding the linkages and complementarities across industries and institutions that are most important to competition in a particular field. The strength of these ‘spillovers’ and their importance to productivity and innovation are the ultimate boundary-determining factors” (Porter, 2000b).

The definition above uses strength of knowledge spillovers as the main criterion in setting the boundaries of a cluster, but the operationalization of such effects is not specified, leaving room for many different interpretations of the matter. This critique also applies to the use of linkages between firms as a defining indicator of cluster boundaries, as a vast majority of all companies have co-operative or competitive relations with firms in their geographical proximate area. The lack of clear and specific criteria for what linkages are strong enough to be considered allows the cluster concept to be used on extremely different objects of study. The problems connected to applying universal principles to fundamentally different cases need not be stated.

Some accounts, such as Rosenfeld (1997) and van Dijk and Sverrisson (2003) have attempted to categorize clusters based on how advanced they are. Rosenfeld argues that 'active channels' between the actors are as important as 'concentration', “(...) and without active channels even a critical mass of related firms is not a local production or social system and therefore does not operate as a cluster. The dynamics of a cluster, not the size or individual firm capabilities, are the key to synergy and thus its competitiveness”. Working/overachieving clusters consists of actors that are aware of the cluster and its benefits and are engaged in reaching its full potential, thus producing more than the sum of the parts. The main characteristics of latent/underachieving clusters are that opportunities exist but are not fully exploited and synergies are not yet realized. Potential/wannabe clusters
fulfil some of the requirements, but lack critical mass and/or other conditions for production. Van Dijk and Sverrisson emphasize network characteristics rather than spatial limitations when deciding whether a cluster exists or not.

In fact, there is limited consensus about the cluster as a viable independent concept. Many studies have found several plausible explanations why innovative firms locate in the same area that do not rely on the cluster concept at all. Simmie (2004) argues that clustering dynamics must be shown to make additional contributions to agglomeration economies.

METHOD

We identified some cluster controversy above, but we will attempt to mitigate the problematic issues by not using template prescriptions for what policy measures to take to strengthen the cluster through innovation. Rather the diamond model will be applied as a framework in which to structure the data used to analyze the industry. This will result in a rich background as basis for a discussion of what the main challenges are, based on findings in our data.

Research design

This thesis investigates the strength and relative competitiveness of the Norwegian solar power industry. The research question is explanatory in nature, as we seek to explore the causes of success up until now, and to assess the probability of future leadership. There are statistical approaches to cluster analysis, such as an employment location quotient and growth-share matrix (Wolfe and Gertler, 2004). However, the solar industry in Norway is still at such a small scale that we find these methods to be inappropriate. Also, as these methods are based on industry categories such as Standard Industrial Classifications (SIC), the application of such a framework is more rigid than a qualitative study, where the impact of interdependencies and relatedness of industries and companies are easier to discover. We therefore choose a qualitative design, allowing a holistic perspective (Eriksson and Kovalainen, 2008) in making an assessment of the strength of the industry. We will conduct a case study where the object will be all
entities constituting the potential solar power cluster, namely those located in Norway.

The case study form is suitable for investigating a phenomenon in its context (Yin, 2003). The success of an industry is necessarily impacted by a myriad of factors, both endogenous and exogenous, and the case study is thus a natural choice of approach. This will be an intrinsic case study (Creswell, 1998), in other words we will study the case itself in the context of clusters, rather than using the Norwegian solar industry to say something about the phenomenon of clusters. Since this is our approach, the conclusions and recommendations we reach will be applicable to the Norwegian solar power industry, not necessarily generalizable either to other clusters in Norway or solar power clusters in other locations.

Data collection

Primary data

The primary data mainly consists of in depth-interviews with persons representing groups of actors significant to the potential cluster. We have emphasized getting different points of view on the issue, and therefore interviewed both persons who were involved in the early establishment of the industry, such as one of the founders of REC, persons involved in metallurgy and the solar departments of Hydro and Elkem and smaller related companies. In addition, we have interviewed several researchers in the competence milieu in Trondheim and Oslo, representing SFFE, ife, SINTEF and NTNU. The main advantage of using interviews is that the researcher gets targeted and case-relevant information containing perceived causal inferences (Yin, 2003), offering a solid platform for further research. The drawbacks are that questions may be constructed poorly or in a manner which impacts on the way in which the interviewee replies, in addition to poor recall by the researchers.

In addition we have conducted e-mail and telephone interviews with representatives from the largest solar companies. The e-mail interviews were based on a questionnaire for cluster dynamics analysis developed by Scottish Enterprise (www.ekstranett.innovasjonnorge.no). Our agenda when using the questionnaire was to uncover the amount and nature of interaction between the
various actors, as well as how advanced the industry participants are internationally. We edited, added and removed questions to make them more applicable to our case. Comments were encouraged, and the respondents used the option to elaborate on their answers. Given that only three companies were eligible to reply, statistical analysis would be inappropriate. We therefore compared the three accounts and used this as a supplement to other data.

We have intentionally chosen to interview persons with different positions in the industry to get different points of view. We employed the key informant technique, where information about an organization is collected by using knowledgeable individuals as sources (Burgess, 1991). These are not selected as a statistically representative sample, but rather based on their position, experience or knowledge about the subject of study. The interviews with the researchers were semi-structured, with prepared questions, but with the option to deviate if new questions arise during the interviews or prepared questions become irrelevant, so the interviews were to a large extent fluid rather than rigid. The interviews were taped digitally to reduce the risk of misunderstandings and faulty memory or imprecise notes. Some informants might express their personal opinions as fact, leading to incorrect information in our data. We have tried to avoid this by asking precise, well prepared questions to several sources and triangulate with other data sources to improve validity.

Secondary data
Secondary data such as annual reports and the websites of companies, industry associations, reports from international organizations and other informative sources, such as newspaper/-agency articles are valuable sources for information about markets, firms, processes and industry conditions in Norway and other important locations. These sources have been employed both as background material before conducting interviews, as stand-alone informative sources and after interviews to check facts and dig deeper into insights gained in interviews.
Research limitations

The amount and nature of linkages between firms and between firms and other actors are important to this thesis, and such information is only to a limited extent publicly available. News about substantial formalized relationships is reported by news agencies and the parties themselves, but information about customer-supplier relations are not easily accessible. Some firms announce reference customers, while others are more secretive and diffuse, stating for instance that its customers are “large Norwegian solar power companies”. In addition, it is difficult to find out what innovative projects are on the way in the research milieu and which parties are involved in the process, due to uncertainty and industrial secrecy. This kind of lacking information is a weakness preventing outsiders from getting the whole picture of the industry.

Paper overview

The first section is dedicated to the presentation of the most significant Norwegian solar energy companies and their histories, uncovering the most important antecedents for the development of the industry. We move on to describe the industry in the framework of Porter’s diamond model, accompanied by a map of Norway showing where the main locations are. There is an illustration of the links between the actors in the potential cluster to show how intertwined the participants are formally. The informal part will be covered in the diamond model. The attractiveness of Norway as a solar power location is then put into context by benchmarking against four prominent alternative countries.

TECHNOLOGY

The solar industry is divided into two main branches: solar thermal technology and photovoltaic (PV) technology. In the former, the sun is basically used to heat water or buildings, or produce electricity by use of steam-based converters (Orkla, 2006). The Norwegian industry is exclusively involved in PV, so we will limit our analysis to this form of solar energy conversion. Solar cells turn the light from the sun into electricity, giving it the name PV cells, where photo means light and voltaic means electricity. PV cells are made of semiconductor materials, out of which silicon is the most widely used (www.science.howstuffworks.com). When
sunlight hits the cell, a certain portion of it is absorbed in the material and the energy is thus transferred to the semiconductor. In this process, electrons are knocked loose and flow to create a current which may be tapped to power various electronic devices or feed electricity into the power grid. Several technologies are able to make this transition, divided into three main “generations” of solar cells. Since the Norwegian producers are almost exclusively involved in first generation, this technology will receive more attention than the second and third generation.

Traditional solar cells are created from silicon and put together in panels, and can be divided into two main categories, making up the first generation. Cells created from monocrystalline silicon are the most efficient considering the energy convergence ratio on the market, but they are extremely complicated to manufacture. This makes them very expensive compared to competing technologies (MBIPV, 2008). Multicrystalline solar cells are simpler and cheaper to manufacture, but suffer from a slightly lower effectiveness.

The manufacturing techniques vary from company to company, but the basic idea behind first generation solar cell production is as follows: first, silicon of high purity is further purified into solar grade silicon and melted into a block, which is cut into smaller blocks called ingots. These ingots are then sliced into thin wafers. The wafers are chemically treated to enhance their receptivity of the sun and thus increase the energy efficiency. The wafers are then fitted with grid contacts and put into aluminium frames and assembled into solar panels (www.recgroup.com). Silicon is a relatively poor light absorber and requires a considerable thickness, varying from about 150 to 300 microns. However, the technology is stable and reliable, and typical output varies between 11 to 17 %, while the energy yield may approach 25 % in laboratory tests, as shown in the table below.
The second generation is thin-film solar cells that are flexible and more cost efficient to produce, but don’t offer as high a conversion ratio of total sun energy to contained electricity as first generation cells do. These cells are made of materials such as amorphous silicon, cadmium telluride (CdTe) and copper indium diselenide, which are very good light absorbers, allowing the cells to be as thin as one micron. This production method requires far less of the expensive raw materials (www.csgsolar.com).

The development of the third generation has not come far, but aims to “get the best of both worlds”, namely enhancing the conversion efficiency of second generation cells, while maintaining the low production costs (www.wikipedia.org). Many different technologies are being tested in the attempt to create viable third generation alternatives, many of them based on nanotechnology.

Third generation cells have not been commercially produced yet, so silicon-based solar cells are projected to dominate for at least one more decade (Lohne, 2009). Factors such as available surface area and price are important criteria in the choice between high-performance PV cells and the less efficient thin-film alternative.
INDUSTRY

The photovoltaic effect was discovered in the 1880s, based on selenium. Silicon based solar cells were invented in the 1954 and the material is still the main input factor in use today. Better and more economical use of raw materials, better knowledge of the metals involved and highly efficient production methods have altered the production process. Mainly based on manual labour ten years ago, processes are almost fully automated today. However, manufacturing and raw material costs are still substantial, and the market is not yet big enough to give sufficient scale advantages. Combined with the fairly low conversion rate achieved today, solar power is still reliant on subsidies in order to provide competitively priced energy. However, some countries, such as Germany, have had a tradition of providing favourable framework conditions in order to stimulate both production and use of solar energy. The international market consists chiefly of these nations. This policy has supported the development of the industry, and has allowed companies to come up with new and more efficient ways of converting sun into electricity. In the following is a description of the core solar companies in Norway, presenting their history and current status.

Renewable Energy Corporation (REC)

The Norwegian solar energy industry is largely dominated by REC, which employs about 1 800 people worldwide. The company is the result of the 2000 merger between ScanWafer AS, SolEnergy AS and Fornybar Energi AS. The story about REC started with the founding of ScanWafer in Glomfjord by Reidar Langmo and Alf Bjørseth. Langmo was hired by a local development company to create new jobs in Glomfjord after Norsk Hydro decided to shut down their ammonia factory, which had been a cornerstone for the small community. He contacted Alf Bjørseth, who at the time was ending his work in Elkem (Langmo, 2008). The location in Glomfjord provided them with cheap electrical power and unlimited supply of cooling water. After considering several options, they decided to establish wafer production for solar energy application.

Bjørseth had considerable experience in the area from his work at Elkem. During his time as Technology Director in Elkem he was chairman of their British investment, Crystalox, which produced ovens for wafer production. Elkem had just sold its shares in Crystalox and its founder, Dr. David Hukin, was about to
retire. Bjørseth persuaded Hukin to join ScanWafer, and thus acquired invaluable industry-specific knowledge. No groundbreaking discoveries were required to start the company, because the technology was known, and the equipment and input factors were available on the international market (Langmo, 2008). The founders, however, brought with them useful networks and valuable technology knowledge and experience from the industry. In addition, their knowledge about the market was essential to the process of finding customers for their products, and the rapid growth of what later became REC could never have been realized if it was not for their ability to engage in long term contracts ensuring business for their factories.

The company is divided into three branches: REC Silicon, REC Wafer and REC Solar, and is one of the world’s largest integrated solar companies. It is currently the world’s largest manufacturer of multicrystalline wafers (www.recgroup.com) through a combination of acquisitions and organic growth. REC is still growing rapidly, and is investing approximately USD 3.6 billion in a giant plant in Singapore. The production facility will be the world’s largest of its kind, establishing REC as one of the leading producers of solar energy worldwide.

**NorSun**

When REC was listed on Oslo Stock Exchange in 2006, Bjørseth sold his shares and founded Scandinavian Advanced Technology AS (Scatec). This is a company whose mission is to invest in and develop business ideas in renewable energy (www.scatec.no). NorSun is one of several subsidiaries in Scatec. This company produces high-performance PV wafers from single crystal silicon (www.norsuncorp.no). Production capacity was established in Vanta, Finland in 2007, the facility in Årdal opened in 2008 and a new plant in Singapore is under construction, expected to be ready in 2009. This will become one of the largest mono-crystalline wafer plants worldwide.

**Elkem Solar**

Elkem’s priority of solar energy started in 1999, although sporadic customer-driven projects had been undertaken since the early 1980s. Elkem Research had three employees look into the possibilities of processing of metallurgic silicon from their factory at Fiskaa, and gradually more people were engaged in the
project. The pre-project utilized important experience, reports, knowledge and insights from previous projects, and combined with further research and lab work, they came up with a fundamentally different way of producing solar-grade silicon where the production process uses only 20% of the energy required relative to the industry standard (Ausland, 2008). This resulted in the decision to establish Elkem Solar, a wholly owned subsidiary focusing on production for solar energy, in 2003. They now have a dedicated plant producing solar-grade silicon.

**Hydro Solar**

In 2001 Norsk Hydro set up a NOK 350 million venture fund called Hydro Technology Ventures (www.hydro.com), whose mandate is to keep an eye out for interesting technology within oil and gas and renewable energy (Hop, 2008). This department was transferred to StatoilHydro in 2007, but the business in solar energy remained in Hydro, now called Hydro Solar, because of the highly relevant metallurgical competence in the company. Solar power became a priority in 2002, and the first business opportunities of serious interest emerged in 2004. Hydro invested in NorSun in 2005. Another of Hydro Solar’s investments is the US thin-film solar cell producer Ascent. In 2007 Hydro and the Belgian company Umicore entered into a joint venture called HyCore, whose main area is research and development within silicon, and is opening a pilot plant for the production of solar grade silicon at Herøya in Porsgrunn (www.maritimeandenergy.com). Hydro is involved in both of the established technological trajectories in solar cells, and its engagement in the solar industry has transformed from being mainly financial investments to becoming an industrial partner.

**Others**

Umoe Solar was founded as a subsidiary of the industrial corporation Umoe AS in 2007 (www.umoe.no). The company has not yet started production, but is planning to be operational in the beginning of the value chain in 2011, possibly expanding to cell production in the long term. Operations will be located in Canada, so as of yet this company will not be significant in the Norwegian potential cluster. Established in 2007, Scatec Solar is owned 90% by Scatec, running all downstream PV activities developed by or invested in by Scatec (www.scatecsolar.no). It operates as turnkey supplier and operator of solar power solutions through a global network of subsidiaries and partner companies in
Germany, the Czech Republic, Italy, Bulgaria, Singapore, India and the US. Norsk Solkraft operates as project developer and system integrator in selected international markets (www.norsksolkraft.com). Its Norwegian operations comprise fitting solar modules into aluminium frames and some R&D activities related to cooling equipment.

INDUSTRY EMERGENCE

Being innovative is crucial to stay competitive in high-technological industries such as solar energy, which needs to work toward grid parity to become a viable alternative energy source. Innovation is fresh thinking or the ability to reconfigure known elements in new ways (Reve and Jakobsen, 2001). This does not only concern the ability to come up with new products, technologies and ideas; the ability to commercialize the products into competitive products with substantial demand is just as crucial (Haanæs, 2000). We have studied the establishment and development of the companies which constitute the Norwegian solar energy industry and our conclusion is that the main reasons for its emergence are building on competences which have been developed over time and the ability to commercialize these.

Building on competences which have developed over time

Elkem is one of the world’s largest producers of metallurgic silicon (www.elkem.no). The competence and technology required to establish Elkem Solar was to a large extent generated internally through a long history in metallurgy. In addition, new employees brought with them valuable competence. The company decided to build the necessary capabilities in-house because what they sought did not exist externally in any one company to be acquired (Dolmen, 2008).

Alf Bjørseth held prominent positions in Hydro, Elkem and other technology companies before co-founding ScanWafer. The pioneer and anchor firm of the Norwegian solar industry, REC, did not rely on substantial R&D assistance in the beginning, but in the further technology development of e.g. REC and Elkem Solar the research communities at universities, in particular NTNU, and SINTEF have been valuable partners. After Bjørseth’s engagement in REC he proceeded to
found NorSun, a subsidiary of Scatec. Bjørseth gathered invaluable experience and competence from previous jobs, so it is safe to say that NorSun’s technology was based on competence which was developed over time, despite its young age.

**Focus on commercialization**

Although solar cell technology is old, the industry is relatively young. Advances in technology and processes have made efficiency reach satisfactory levels to commercialize the industry which has been facing a booming demand. Still, the transformation of ideas and technologies into competitive products is a crucial skill to succeed.

REC’s growth has mainly been driven by orders whose delivery required capacity expansions. Many contracts were made by leveraging networks, and without this capability of attracting attention and projects, REC would not be the company it is today. The new plant under construction in Singapore has 150 times the production capacity of their first factory, but the approach is the same as before: the production capacity for several years was sold before the decision to build was made. Securing revenues before expansion has helped in attracting capital providers. Elkem’s approach was somewhat different. Sporadic customer-driven projects through which the company learned a lot and strengthened its knowledge base were undertaken for several years before the decision to produce solar-grade silicon was made.

Hydro is one of the metallurgical giants in the world, in particular within production of aluminium. Silicon is an important component in the production of aluminium, so this is a field in which Hydro’s competence is deep and well-established. The company therefore had technology and knowledge in this field to make use of both when deciding which companies to invest in and in the subsequent co-development of these. Other main competences that Hydro contributes to their acquired companies are project definition and -implementation (Hop, 2008). This includes running plants, concerning efficiency, safety and environment focus, the establishment of new plants and organizing large-scale production. Hydro Solar is interdisciplinary, comprising both technological, legal and industrialization competence, where Hydro’s system and external connections are utilized to mature the company’s investments. Hydro Solar is a small
organization with only 10 employees, but has access to the entire Hydro system, and engages people from various parts of the corporation on project and consulting basis. In addition to the competence in metallurgy and industrialization, the department possesses substantial capital resources which may be used to finance necessary investments.

Scatec has significant competence in renewable energy and organizational and practical aspects of starting technologically based companies. It serves to “inject power and structure into new ideas” (www.scatec.no), and seeks to facilitate rapid growth. NorSun is one of its subsidiaries, and with Scatec’s assistance it has been able to start the construction of its third factory, one of the world’s largest producing single crystal silicon, within three years after founding. This is an accomplishment out of the ordinary, illustrating the importance of being backed by as strong and competent partners as Hydro and Scatec.

This shows that the companies in the solar industry to a large extent depend on the competence in metallurgy which has been built up through generations. Many of the founders of companies producing silicon and wafers, or otherwise connected to these activities, are former employees of the metallurgic giants and have transferred competence to their new projects. The companies’ success spurred research institutions to make solar energy a priority through specialized activities, dedicated researchers and substantial investments. The emergence of related and supporting companies shows the importance of a large enterprise driving the development of an industry. We conclude that the emergence of the Norwegian solar energy industry was funded on competences that were built up over a long period of time, injected with new knowledge and competence development and the ability to commercialize and industrialize innovations.
Factor conditions

Infrastructure
Norway is a long, geographically outstretched country with mountains and fjords, posing infrastructural challenges. However, the infrastructure is considered to be of high quality, especially air transport and ports (Porter and Schwab, 2008).

Education
Education expenditures were 7.2% of GDP in 2005 (www.ciafactbook), which ranks Norway 20th in the world. Nonetheless, the quality of primary education is not so good compared to other countries (Porter and Schwab, 2008). Tests show that results are only at par with and more dispersed than OECD average (OECD, 2004). According to OECD (2008a) the compulsory education system is cost inefficient compared to international standards. Higher education is ranked highly in Global Competitiveness Report both with regard to enrolment and quality, but math and science is considered a weak area.

Labour force
The productivity of the Norwegian work force is the highest in the world when measured as value added per hour worked (ILO, 2007). The massive BNP boost from oil and gas is the reason for this, so looking uncritically at the ranking gives a somewhat too favourable impression of the Norwegian economy. However, the high rents from oil and gas puts pressure on alternative activities to yield high rents and has set the productivity bar so high that the nation cannot produce low value-added products. Unemployment rates in Norway have been lower than in the other Scandinavian countries and EU-15 since 1996 (Handal, 2006). Labour shortages in the non-traded sector are reflected in high wages, by international comparison, and the high and increasing relative cost of living (OECD, 2008b).

Tax
Norway is a welfare state which spends a high percentage of GDP on public services such as education and health care. GDP per capita in 2008 was $55,200 (www.ciafactbook.com) and the nation has ranked at the top in UN’s Human
Development Report as one of the best places to live since 1990 (UNDP, 1995-2009). As a consequence, the nation’s corporate tax rate is high compared to peer countries (www.big4.com and www.dnaindia.com). Indirect taxes are significantly higher than the EU average, which is also higher than the rest of the world, placing the Scandinavian countries at the top of the corporate tax rate scale.

**Macroeconomic stability**

Norges Bank has set a target inflation rate of 2.5%. This parameter is naturally subject to variation, depending on the world economy and the prices on the international market. Despite being a small economy, Norway has a relatively low volatility in inflation, with an average inflation the past decade of approximately 2% (Norges Bank, 2008).

**Research and development**

The government has set an objective of having R&D spending constitute 3% of GDP, the same as the long-term objective in EU. Out of this share, 1% will be publicly funded, only exceeded by two other OECD countries. Norwegian companies spent NOK 17.6 billion on own R&D in 2007. The research objectives of the governments are to resolve global challenges, provide good health care, research based welfare politics, develop knowledge-intensive business throughout Norway and conduct commercially relevant research within strategic sectors. However, without adjusting for industry structure, total R&D spending amounts to only 1.5% of GDP, which is significantly lower than the OECD average, as illustrated in exhibit 1 (OECD, 2008c). The ratio has been lower than that of EU countries for more than 20 years and there is no sign of convergence. Private sector spending is particularly low, amounting to only 1.2% compared to 2.2% for OECD countries in 2005 as showed in exhibit 2.

The Research Council of Norway has the strategy role in the research system and distributes research funds to independent research institutions and the higher education sector (www.forskningsradet.no). A small portion is allocated to basic financing, granted directly to the research institute, building long-term competence and conducting research of national importance. The rest of the funds are targeted toward competitive projects, contributing to quality and relevance of the research within selected fields and industries. Norwegian universities receive a
higher share of basic research support than in other Nordic countries. The mobility of researchers between the various research institutes, businesses and educational- and health institutions is low. This is a weakness, as extensive communication and cooperation both between the research institutions and with external actors is a documented characteristic of leading research milieu (Stortingsmelding nr. 30).

SkatteFUNN is Norway’s most extensive R&D subsidy programme for companies. It was launched in 2002, giving companies a tax credit on R&D spending aimed at new discoveries leading to new or improved products, services or processes. Large companies are granted a tax rebate of 18 % for approved projects, while SMEs may receive a discount of 20 %, with a maximum cost base of NOK 11 million (www.forskningsradet.no).

Financial system
Norway has a sound and well managed financial system (IMF, 2005). In addition, the supervision of financial institutions is said to be “active, effective and in line with EU norms”. The financial crisis that erupted in 2008 hit the major banks in the world extremely hard, and several of the institutions in the banking world have collapsed. The financial sector accounts for a moderate part of Norway’s GDP and the nation has experienced less difficulty than many others. A dramatic decrease in the key interest rate has helped the Norwegian economy and reduced the bank losses substantially. In addition, the Norwegian economy has substantial room to manoeuvre, and the Norwegian government launched “Bankpakke I” in October 2008, providing the opportunity to swap bonds with collateral in housing mortgages in exchange for government bonds totalling NOK 350 billion to aid the banks’ liquidity situation (Dagens Næringsliv, 12/10 2008). “Bankpakke II” was initiated in February 2009, totalling NOK 100 billion allocated to direct loans to the banks and strengthening the Norwegian bond market (Nettavisen, 8/2 2009). The catch of accepting the loans in this package was an obligation not to increase wages for leading employees until the end of 2010. The Financial Supervisory Authority of Norway has characterized these measures as “substantial” and “well designed” (Kredittilsynet, 2008). There is broad consensus that Bankpakke I was a success, while Bankpakke II has to date only been exercised by one bank.
GCR (Porter and Schwab, 2008) ranked Norway to be among the leading nations in regard to access to loans, equity and venture capital. Norway is ranked number one in terms of access to financing of new ventures (GEM, 2008). However, the equity market is more oriented toward established businesses. Argentum is a state-owned investment company established in 2001 which takes minority shares in private equity funds (www.argentum.no) to promote access to international venture capital and make the Norwegian private equity environment internationally competitive (OECD, 2008b). Norwegian Venture Capital Association has 90 members, out of which approximately 60 are investing companies, while the rest are advisors (www.norskventure.no).

The stages in venture capital are:

- Business angels: resource persons who offer capital, competence and/or network to companies in the development- or early commercialization phase.

- Seed capital: capital investments in early phases, before substantial sales are reached. The investment typically contains technological as well as market risk, and seed capital is often necessary to attract more equity and competence.

- Venture: investments in the expansion phase with considerable market risk. The venture capital company often takes on board positions and acts as sparring partner, door opener, strategic advisor and international networker.

- Buy-out/business development: the venture fund typically acquires underachieving established companies to restructure, bring in necessary core competence, make strategic investments and develop them to reach their potential, later to be sold off.

The percentage of business angels of the adult Norwegian population is 4.4%, which is a relatively high share internationally (GEM, 2008). These are typically male former entrepreneurs who have experience and competence to offer the start-ups, and the number of them has increased the past few years. However, the seeding and early stage financing of new ventures is still a challenge, particularly in technology based ventures and growth companies (GEM, 2008).
Demand conditions

Norway has approximately 4.66 million inhabitants, indicating a rather small domestic market. However, it has the 7th highest GDP per capita in the world of an estimated $ 55,200 in 2008 (www.ciafactbook.com). This implies that the general market potential is higher than in less prosperous countries. Approximately 80% of Norway’s exported goods go to EU countries, and almost 70% of the imports come from these countries (SSB, 2009). Norway is a very open economy, recognizing the necessity for a small country to open up for trade (www.regjeringen.no). Norway is one of four members of the European Free Trade Association (EFTA) participating in the EU single market through the European Economic Area (EEA), in which preferential taxes and tariffs are given in most sectors (USTR, 2005). However, the nation is ranked as having relatively high trade barriers and tariff rates in GCR (Porter and Schwab, 2008). This is probably a consequence of the restrictions on certain sectors, in particular agriculture and fishery. Buyer needs are characterized as being relatively sophisticated.

Firm strategy, structure and rivalry

Industrial policy

The Norwegian government’s policies are based on the position of industrial neutrality, but with agricultural and offshore maritime industries as the most significant exceptions because of regional policy. The principle is that no sector of the economy should be preferred over another and is entitled to more support than others, but rather the government prioritizes developing good framework conditions for business in general (Stortingsmelding nr. 41). The Norwegian competition legislation is partly harmonized with EU rules (www.konkurransetilsynet.no), and the effectiveness of anti-monopoly policy is characterized as a competitive advantage in GCR (Porter and Schwab, 2008). Also, the intensity of local competition is ranked to be high.

Ownership structure

The Norwegian government is among the world’s largest shareholders, controlling 1% of the world’s shares (Dagens Næringsliv, Aug. 15, 2009) A relatively large proportion of the shares at Oslo stock exchange are owned by the Norwegian
government through direct investments controlled by the Ministry of Trade and Industry. In addition, Folketrygdfondet has invested a significant part of their portfolio in Norwegian companies. In total, almost 60% of the shares at Oslo stock exchange are owned by the state. The investments make the government the major shareholder in several of the largest corporations in Norway like StatoilHydro, Telenor, SAS, DnB Nor. The significant governmental influence is currently being debated, and several industry experts claim that the “active ownership” conducted by the politicians can harm the competitiveness of the companies in question (Dagens Næringsliv, June 23, 2009). However, having an owner with seemingly limitless access to capital can be an advantage in rough times.

Entrepreneurship

Norway has a fairly high entrepreneurial activity comparatively, and most new ventures are driven by business opportunities rather than necessity (GEM, 2004). More than 98% of all companies in Norway are SMEs, accounting for more than 62% of employment and approximately 54% of economic turnover (OECD, 2005). The aforementioned policy of industrial neutrality implies that instead of selective schemes for entrepreneurial ventures, such as risk loans, guarantees and grants, the government aims to improve the general business environment. Innovation Norway was established as a merger of four separate organizations in 2004 to create synergies in entrepreneurship, innovation and internationalization (www.innovasjonnorge.no). The organization offers high-risk and low-risk loans, grants, equity and guarantees.

Norway is an innovation-driven economy, where the ability to produce innovative products and services at the global technology frontier using the most advanced methods is the dominant source of competitive advantage (Porter et al, 2008). The dynamics of an economy is measured as the ratio of attempts to start new businesses compared to the number of existing firms. The average among GEM countries is 1.35, while Norway had a ratio of 1.1 in 2008. This is still considerably higher than the average among innovation-driven countries, which is 0.95 (Bullvåg et al, 2008). According to this report, there is a relatively more positive attitude toward entrepreneurship in Norway than in many other countries, the regulatory framework is considered to be less of a burden, but the level of
ambition is significantly lower than expected for the nation’s level of wealth. These separate indices are combined to a Global Entrepreneurship Index, which gives an indication of nations’ level of entrepreneurship in relation to its GDP. Norway scores 0.6 on a scale of 0 to 1. This is moderately higher than expected given the nation’s level of wealth. Five technology transfer offices have been established to help commercialize the Norwegian universities faculty’s findings. The universities have the property right to its scientists’ discoveries, but are obliged to facilitate the commercialization of them, through for instance spin-offs or licensing (Klingsheim, 2004).

**Related and supporting industries**

Through the decades following the 1960’s findings of enormous oilfields in the North Sea, Norway has become an oil economy. Most of the oil companies are located in Stavanger. However, the entire country is influenced by the gigantic revenues the industry contributes to the economy, making the level of welfare afforded by the state feasible. Fisheries are another important and traditional source of revenue for the population along the coast. Energy-intensive industries like aluminium and fertilizer production have also strong traditions in the Norwegian economy.

Apart from the aforementioned industries, the Norwegian economy has industrial clusters in various industries. SIVA, The Research Council of Norway and Innovation Norway have appointed nine Norwegian Centres of Expertise. The selected clusters consist of world class enterprises within their field, and receive governmental R&D-support for common research projects.

NCE Maritime is a cluster of more than 200 companies located on the west coast of Norway. The companies are engaged in ship design, shipbuilding and equipment manufacturing, especially for the offshore industry. The maritime cluster in Norway is widely recognized as one of the best and most important in the world, employing around 21 000 people. The combined turnover of the cluster companies is more than NOK 41 billion, making it one of the most important industries in the Norwegian economy.
NCE Micro- and nanotechnology is a cluster of 13 companies in Vestfold, constituting the most important commercial environment in Norway within the field. Many of the companies are considered world leaders within their markets. The cluster organization is trying to enhance the current network, spur R&D activities and establish a research centre and study programmes.

NCE Systems Engineering comprise significant companies in the Kongsberg region producing advanced systems for marine, subsea, automotive, defence and aerospace purposes. The companies in the cluster employ a total of 6 000 people in Kongsberg. The companies are engaged in a very knowledge-intensive industry, and spend approximately NOK 1,4 billion on R&D annually (www.ekstranett.innovasjonnorge.no). This actually constitutes 10% of the combined R&D investment of the entire Norwegian industry.

In addition, NCE Raufoss, NCE Subsea in Bergen, NCE Instrumentation in Trøndelag, NCE Culinology in Rogaland, NCE Aquaculture in Nordland and Oslo Cancer Cluster are all considered important, competitive and strong environments.

**CLUSTER DIAMOND NORWAY**

In the following we will apply the diamond model to the solar power industry in Norway. A summary of the main findings are illustrated in exhibit 3.

**Factor conditions**

*Education*

The Norwegian education system is very good in some areas, but is lagging behind in math and science at the primary level, making enrolment to these subjects at higher level very limited. There are no university degrees dedicated to renewable energy or solar power in particular in Norway, but several universities and colleges in Norway offer Master degrees in engineering. Also, all the universities have Master degrees in chemistry, physics and mathematics. The University of Oslo (UiO) and the University of Bergen (UiB) have highly relevant competence within these fields, but the most comprehensive advanced educational institution in natural sciences in Norway are found at NTNU. Combined, these schools offer world class Master degrees (Lohne, 2009) within fields such as
material technology, cybernetics, construction, energy and environment, chemical engineering and silicon and ferroalloy production, the most specialized ones at NTNU. Nanotechnology is a field which is expected to become increasingly important in solar energy and is to a large extent used in the research on third generation PV (Marstein, 2009), and UiO and NTNU offer Master degrees within this field. There are doctoral programmes in mathematics, physics, energy and chemical process technology and material technology. Although few, the Norwegian graduates in these subjects are highly qualified for positions in the solar industry. This has made it quite difficult to find a sufficient amount of highly educated scientists, and many of the Norwegian companies have had to bring foreign workers to Norway to acquire the required competence.

Labour force
Norway is an egalitarian society with small differences in wage levels. One consequence of this is that the wage level for low skilled workers in Norway is very high compared to other competing nations, but on the other hand this makes for relatively low engineer and scientist wages. With an increasing degree of automation in the factories and need for less labour in the solar power production, the Norwegian wage level may actually be an advantage rather than a disadvantage. The labour mobility in the industry is relatively high. Ife, with 25 employees in its solar department, reports having about eight postgraduates and doctorate candidates in 2009. Most of these will be employed in solar companies, but the management hopes a couple of them will stay in ife. Among the researchers with permanent positions there is an average turnover of one or two per year, and the researchers are very attractive in the industry (Marstein, 2009).

Subsidies and other framework conditions
As mentioned in the national diamond, the Norwegian government has general support schemes to encourage entrepreneurship and R&D, but there are no special arrangements for the solar industry. Innovation Norway has played an important role in helping small companies establish themselves, but this is an agency whose mandate is mainly to help the transition from idea to business. Established and larger companies may receive funds for special projects, but even if they do, the amounts are too limited to make a significant impact on the feasibility and profitability of the project.
To further commit to the development of renewable energy, the Ministry of the Environment and The Ministry of Trade and Industry have conducted several studies in order to uncover the needs of the industry (Torrissen, 2009). In addition, FME: The Norwegian Research Centre for Solar Cell Technology has been established with government support in order to create a "national team" of research institutions and companies. The aim of the centre is to facilitate knowledge sharing and ease the access to the substantial research milieu that already exists (Johnsen, 2009). By joining forces, the industry actors also have the opportunity to voice their concerns more efficiently and effectively in order to improve the general framework conditions influencing their competitive position. The cluster map in figure 3 illustrates the extent of the centre and indicates the significant influence its members might have on decision makers when fronting their interests together.

**Venture capital**

Norwegian Venture Capital Association has 18 members focusing on oil, energy and environmental technology. None of these invest solely in solar energy, but many have defined renewable energy as an investment area. Few of these companies have Norwegian PV investments in their current portfolio, but there are several investments that have a high degree of relatedness to solar energy. When REC was listed on Oslo Stock Exchange in 2005, Bjørseth sold his shares and founded Scandinavian Advanced Technology AS (Scatec). This is a seed and venture capital company for renewable energy. It offers core competence and helps establish and develop the entrepreneurial venture, and currently holds selected investments in innovative solar companies and ownership stakes in the more established companies NorSun and Scatec Solar (www.scatec.no). Reidar Langmo is the founder of iEnergies, which is a direct investment fund involved in seed, growth and expansion stages, focusing on solar energy and cleantech in general both internationally and in Norway (www.ienergies.no). Convexa Capital has defined solar energy as a core investment area in the seed and venture phases. Metallkraft and NorSun are among their investments, in addition to some American ventures (www.convexa.no).

**Research and development**
Following the prevalence of Norwegian solar companies, considerable efforts have been made by the various Norwegian research institutions to make progress in the field of photovoltaic power. Earlier, the focus was more on metallurgical sciences and other forms of renewable energy, but in close cooperation with the enterprises, research in production and exploitation of solar grade silicon has become a priority. An example of this commitment is the new solar lab at ife and the plans of a new research centre in Trondheim.

The community surrounding the Norwegian University of Science and Technology (NTNU) in Trondheim has been at the technological frontier within material and metallurgical research for many years (Lohne, 2009). The largest private research institution in Scandinavia, SINTEF, is also located here, and the two institutions have cooperated closely for over 60 years. The Institute for Energy Technology (ife) is located at Kjeller, outside Oslo. Ife has been an extremely important player in energy research for decades, and has a broad expertise in everything from nuclear power and petroleum to renewable energy like hydroelectricity and wind power. After many years of solar power R&D at the institute, it opened a dedicated solar department in January 2008 (www.ife.no). Ife has some own research, but it mainly takes on projects for companies. The extent of collaboration depends on how advanced the employer’s R&D department is and how much it is willing to pay (Marstein, 2009). The Centre for Renewable Energy (SFFE) is a joint association between ife, NTNU and SINTEF working to promote renewable energy to government and decision makers, potential future employees and the general public, as well as build relations and coordinate co-operation and networking among central actors in the industry (www.sffe.no). Solar power is one of many focus areas and the research work is conducted by Gemini. The organization produces a newsletter and there are several Gemini centres, each with its own area of expertise. A dedicated centre for PV was established in 2006, which has greatly facilitated the flow of information among the research institutions within this field.

Climate research has received increasing focus the past few years, resulting in the establishment of a new strategic organization called Energi21, consisting of members active in or with backgrounds from business, government and research. The organization’s mandate is to follow up efforts in renewable energy, building
on corporate priorities, while aiming to increase the cooperation between companies, government and research milieu (www.energi21.no). In addition, there is a newly established strategic forum for climate issues, Klima21. The main focus is the climate change and what may be done to counter it as well as how to honour Norway’s obligation to meet emission targets, from a research perspective (www.regjeringen.no).

**Demand conditions**

Due to the fact that solar cells have not yet reached grid parity with other electricity sources, demand is to a large extent dependent on government subsidy schemes. The market for photovoltaic installations is international in nature. As showed in the solar map in exhibit 4 Norway is endowed with little and unpredictable sunlight so Norwegian manufacturers export all their capacity. The largest markets in 2008 were by far Spain and Germany, with respectively 2.46 and 1.86 GW of total global demand of 5.95 GW (Exhibit 5). The sunniest markets are likely to reach grid parity sooner than a country with less sun, not only due to access to the input factor, but also because electricity prices are high when it is hot and sunny and need for air conditioning. Norway, on the other hand, has lower electricity prices in the sunny season and would thus have a much longer way to go (www.tu.no, Feb. 28, 2008).

The global PV market has had an aggregated growth rate of more than 40% annually the past decade (www.leonardo-energy.org). Its estimated value in 2008 amounted to USD 30 billion, expected to exceed USD 100 billion within 2011 (The Straits Times, Feb. 21, 2008). The market conditions for solar power were glorious for many years, with high margins and demand far surpassing supply and long-term contracts securing sales for a long time ahead. The values of solar power companies were soaring high above companies of much larger balance sheets because of the tremendous expectations connected to future earnings. An example of this is REC which was valued at more than NOK 100 billion in 2007, making it the third largest company in Norway despite revenues of only NOK 6.6 billion and profit before taxes of NOK 2 billion (REC annual report 2008). The net income per share was NOK 2.70, while the stock price was NOK 240 at the end of 2007 (www.oslobors.no).
However, the value of solar energy companies worldwide has plummeted since mid-2008. There are several reasons for this. The credit crunch following the financial crisis has created difficulties financing solar projects (REC, 2009), affecting especially commercial and utility installations. Also, the Spanish government decided to put a cap of 500 MW on the capacity for its generous subsidy programme, significantly reducing demand from the largest and fastest growing PV market in the world. Many manufacturers did not adjust to the new situation adequately by reducing production, leading to a situation of oversupply and price pressure throughout the entire value chain. The global production of silicon has increased dramatically during the last couple of years, and has not matched the recent falling wafer demand. This has led to a dramatic fall in silicon prices which is expected to continue throughout 2009. Analysts project that the price will fall from with as much as 78%, from USD 180 to USD 50 during 2009 (Dagens Næringsliv, July 27, 2009). This has caused problems, especially for integrated producers like REC, whose value chain positions serve as a hedge against fluctuations in the silicon market. In times of low prices, this is a disadvantage, as they are unable to reap the benefits of lower prices. The problem is to a certain degree mitigated by the majority of long term contracts at fixed prices, but in times of oversupply maintaining a good relationship with customers is important. Therefore REC is considering negotiating lower prices with key customers to reduce the gap between prices in the spot market and long term contracts (Dagens Næringsliv, July 28, 2009). Quality and total costs are the main criteria for business customers buying solar power components and systems (Survey).

**Firm strategy, structure and rivalry**

*Ownership structure*

Elkem Solar is a wholly-owned subsidiary of Elkem, owned entirely by the Norwegian conglomerate Orkla, in which Folketrygdfondet holds 11.8% of the stock. REC is the only solar energy company noted on Oslo Stock Exchange, and its biggest shareholder is Elkem, followed by Orkla. Folketrygdfondet owns 4.51% of the shares and the rest is dispersed among private investor groups (www.recgroup.com). The company board required pilot projects and proven
R&D results for the decision to establish Elkem Solar. The subsidiary’s role is as a long-term exposure towards the solar energy market. This long-term interest provides the company with time to develop and grow at its own pace. Already, the company has 250 employees, and states in its strategy that it is making an active commitment to solar energy (www.elkem.no).

REC has had long-term industrial investors ever since their start-up and was listed on Oslo Stock Exchange in May 2006. The Swiss clean energy investment company Good Energy Investments owned 30-40% of the shares, and when they sold out, their position was taken over by Orkla and Q-cells, the world’s largest manufacturer of PV cells (www.q-cells.com). Although REC’s stock price has been rather volatile, long-term investors with significant stakes in REC have made for a more stable financial situation. Although the IPO led to a dilution of the share, it made the rapid and progressive growth and international success possible.

Norsk Hydro is one of the state-owned Norwegian industrial giants, where the government holds 45.2% of the shares (www.purehelp.no). It has a 16.23% stake in NorSun and owns 49% of HyCore. NorSun’s other main investor is Scatec, and both have long-term interest in the company. Hydro also has a financial focus on renewable energy through its investment in the venture capital company Convexa Capital (www.hydro.com). This gives Hydro an updated perspective and fresh impulses on cutting edge technology.

The solar power companies are practically entirely privately held, where Orkla controls two of the three most significant companies. Orkla is a widely diversified conglomerate, and if it decided to focus more and sell out the solar power investments, there would be considerable risk of the industry disappearing to foreigners. The limited ownership by the state is not sufficient to influence the operations, and the government shows no signs of aiming to exercise active ownership.
Spin-offs

When researchers employed at research institutions make groundbreaking discoveries, spin-offs are encouraged. The institution will typically retain the property rights, but when it is natural to create a new separate venture, the researcher may apply for a leave of absence. The institution is likely to own at least part of the new venture, and the researcher may licence or buy the property rights (Marstein, 2009). An example of this is the newly started company CruSin, established by a former SINTEF researcher who during his work found a new way to make crucibles for wafer production. SINTEF was willing to help the researcher start production of the new product by permitting a leave of absence and help raise capital by investing in the new company.

Firm interaction

There is little direct rivalry for market share among the Norwegian companies. The primary reason is that the market is global and that foreign competitors are just as relevant as Norwegian ones. Another reason is that the Norwegian companies have in part different processes and products, so that the direct competition is low. The competition for competence, on the other hand, is more intense. There is consensus that members of the Norwegian solar industry hold leading edge knowledge in crucial areas for the industry. There is a weak sense of common identity among the Norwegian solar companies, and they do not perceive this to be important in the marketplace (Survey).

The solar power industry is characterized by many different production methods, solutions and technologies. Solar energy is one of the industries generating the highest growth of patents in the US the past few years (Marstein, 2009). The complexity in production methods makes patent filing challenging because it is difficult to secure the discovery from being copied by competitors with slight alterations. Therefore, secrecy is as common a way of protecting new findings. Due to the high value potential of competence and insights and the immaturity of the industry there is a low willingness to share core knowledge (survey). There is a low extent of collaborative efforts among the major companies apart from events and forum arranged by industry and interest organizations. However, the Norwegian industry and milieu are small, so the central actors know each other well and interact and socialize at events (Jøssing, 2009).
Related and supporting industries

Recycling

When the ingot is sawed into wafers, silicon dust called kerf loss is produced. The silicon loss may actually approach 50% of the ingot (MBIPV, 2008). It goes without saying that this is a huge loss, making the production process less economically efficient, especially when silicon prices are high. Consequently, an industry of specialized recycling companies has emerged. By removing impurities induced in the cutting process, the kerf loss is processed back into usable feedstock for solar applications. Ekro Resirk has established long-term contracts with REC in this business (www.ekro.no), and SiPro has located a plant in Glomfjord to recycle REC’s kerf there (www.glomfjordindustripark.no).

The wafer cutting process requires great amounts of cutting slurry. The slurry in the saw needs to be replaced, and the disposal of exhausted slurry is an environmental issue, as it is contaminated by silicon dust and other metal particles. Therefore, regulations have made disposal costs frequently exceed the cost of new slurry (www.mfg.mtu.edu). SiC Processing is a German world leading company in this line of business (www.heroyaindustripark.no) with Norwegian operations. Metallkraft is a Norwegian competitor with a long-term contract with NorSun, in addition to having customers among European and Asian wafer producers (www.metallkraft.no). The company has secured financing for a MNOK 200 plant in China, aiming for a market share of 20% within the next five years (www.tu.no June 3, 2009).

Production of solar cells with electrical, mechanical or visual defects exceeding tolerable levels is an increasing problem to the industry with regard to profitability and to meet the ambitions of considerable growth over the next years (www.solarcellrepower.com). Innotech Solar is a Norwegian company established in 2008 which repowers non-prime solar cells. It has operations in Germany and Switzerland as well as in Norway and has been characterized by industry experts as cutting edge (Jøssing, 2009).

Since the waste of wafer producers is the input factor for the recycling companies, geographical proximity is an advantage. While some companies rely on transporting the waste, others build dedicated plants next to the wafer producers.
One example of this is Metallkraft’s six year contract to set up a dedicated plant next to REC in Singapore (www.nrk.no), and there are similar arrangements in Norwegian production facilities.

**Crucibles**

ScanCrucible is a Norwegian company which was established in 2006, commenced production of crucibles for stacking silicon in 2007 and is still at pilot stage, but planning to ramp up production. The main input factor is quartz sand, and the proximity to this material is of the essence. Therefore, the company plans to remain located in Norway in the foreseeable future. It delivers customized products to solar grade silicon producers, developed from the customer’s specifications. It has Norwegian customers and is facing increasing demand. There are currently no established competitors on the Norwegian market, but CruSin is a newly established company which plans to manufactures crucibles that can be used several times in contrast to the disposable pots used today. The company has had great success in the trial stages of the product development, and is currently working on raising the capital required to start full scale production (Solheim, 2009). International competition is also still at an early stage, with some competitors from the US, Germany and China (Sørsandmo, 2009).

**Machinery**

The machines and equipment used in the production are mainly acquired from international suppliers, some through Norwegian distributors. One example is RobotNorge, which distributes ABB’s machinery. There are competent Norwegian contractors and machinery maintenance firms catering to the solar industry. Two examples are Semek and Bandak. Semek produces coated steel barrels in which the wires cutting ingots are placed for REC Wafer. Bandak assists REC Wafer with recoating of the wires used in the wafer cutting process and general maintenance.

**Metallurgical industry**

There is broad consensus that the competence from the aluminium and metallurgical silicon industry has been of utmost importance in building the competence required to make a competitive solar. This is highlighted by the fact that many of the founders of the solar companies have backgrounds in companies
like Elkem and Norsk Hydro. Aluminium is an important component in the last part of the value chain, where solar cells are fitted into aluminium frames for mounting on rooftops. In addition, the aluminium industry can offer a broad competence in production of building systems and be a vital partner in the integration of solar cells in new buildings. SINTEF has had a research project on environmentally friendly ‘smart houses’, where building integrated photovoltaics (BIPV) is one of the subjects. The commercialization of BIPV is, however, not likely to happen on a large scale in Norway, but numerous countries with more sun are prioritizing this to an increasing extent. HyCore is a new company that relies on this expertise from their owner, Hydro.

**IT systems**

Prediktor develops IT solutions tracking the production from raw material suppliers to end customer. The system produces detailed reports on production volumes, production efficiency and effectiveness as well as on details related to off-spec production (www.prediktor.no). It is a Norwegian company with operations in Fredrikstad and Porsgrunn and recently expanded to China, Singapore and Germany. The company is the leading MES supplier to the solar industry and is present in all significant markets. It serves Elkem and REC in Norway.

**Renewable energy**

Norway has always utilized renewable energy. For half a millennium, waterwheels were the prime source of energy for the Norwegian industry. Hydroelectric power has been used to generate electricity since 1877 and during the last decades other renewable sources like wind, waves, etc. have been subject to significant research. The research in new sources of renewable energy is being conducted by many of the same organizations engaged in solar research, and several programs and centres like SFFE are unifying the resources put into the field. The strong competence base is definitely mutually beneficial for all of the sectors, and an advantage for the solar industry. Also, the abundance of hydroelectric power gives the Norwegian solar companies access to cheaper electricity than many other countries (Dagens Næringsliv, Dec. 14, 2006).
GEOGRAPHICAL OVERVIEW OF THE NORWEGIAN SOLAR INDUSTRY

The most important locations in the Norwegian solar industry are marked in a map with size and significance indicated by the dots.

Figure 1:

1: Narvik
REC Solar commenced production of solar cells at REC Scancell in Narvik in 2003. The plant initially had a capacity of 45 MW, but reached 225 MW in 2008 (www.recgroup.com). The college in Narvik offers technical education which is very suitable for recruitment to the factory (www.tu.no. Sept. 21, 2006). Innotech Solar is also headquartered and has operations here.

2: Glomfjord
Glomfjord is widely recognized as the birthplace of the Norwegian solar energy industry. It was here Reidar Langmo and Alf Bjørseth decided to start wafer production in 1994, and by 1997 ScanWafer had its first production facility up and running. REC Wafer Glomfjord Mono was opened in 2004, in addition to ScanCrucible and SeMek. The industry development in Glomfjord is to a large degree fuelled by the local initiatives for industrial development by Meløy Næringsutvikling AS.
3: Trondheim
The region surrounding Trondheim has been an important part of the metallurgic industry for decades. The region’s force is R&D competence in NTNU and SINTEF, which has spurred spin-off companies such as CruSin. In addition, Fesil, which is among the largest Ferro Silicon (FeSi) and Silicon Metal (SiMet) manufacturers worldwide (www.fesil.com), is located in this area.

4: Årdal
Årdal is a small, but not insignificant, part of the Norwegian solar industry. Like Glomfjord, the small society was heavily reliant on the cornerstone company Norsk Hydro. The community development society Årdal Fremtid attracted NorSun, which built a new factory for silicon wafer production, utilizing the excellent infrastructure and skilled labour the society had to offer.

5: Oslo
Oslo and its surrounding areas is in many ways the centre of the Norwegian solar industry. All the large players have their headquarters or offices in Oslo, so a large share of the workforce is located there. REC, NorSun, Scatec Solar, Norsk Solkraft and 3G Solar are all based in Oslo. Even in businesses where most of the production takes place elsewhere, the major decisions are made in Oslo. In addition to the R&D activities conducted by the companies, several independent research institutions, including UiO and various environmental organizations such as Zero, are based in and around Oslo. Ife is by far the most important one. Oslo Renewable Energy and Environment Cluster (OREEC) and the Norwegian Solar Energy Society (ISES Norway) are industry organizations localized in Oslo. The Norwegian capital is also the national financial centre, making Oslo an important place to raise capital to realize planned projects and create and maintain a healthy relationship with the various investors through Oslo Stock Exchange. Several venture capital funds dedicated to investing in renewable energy, like Convexa and iEnergies, are working on a daily basis on assessing new companies within the industry.

6: Porsgrunn/Herøya
The large industrial park at Herøya contains a large number of technologically advanced companies within advanced materials and chemicals, like Norsk Hydro
and Yara. The region has a long tradition of engineering competence, and makes for a suitable location for the solar companies. REC has produced multicrystalline wafers at Herøya for several years, and HyCore is planning to build a plant for full scale silicon production in 2010. The past few years a number of related companies have established themselves at Herøya, including SiC Processing, Ekro Resirk and Bandak.

7: Kristiansand

Elkem is headquartered in Kristiansand, and its most complex activities are located here. Elkem Solar just completed a new NOK 2.7 billion solar grade silicon plant to be opened in August 2009. Metallkraft is also located here.

OVERVIEW OF INDUSTRY LINKAGES

The following figures are snapshots of the Norwegian solar industry in 2000-2001 and 2009 respectively. The figures illustrate the actors in the industry and the formal linkages between them, differentiating between ownership, supplier-customer linkages and other relations. We would like to emphasize again that some linkages are difficult to discover and some companies are reluctant to disclose who their customers are. In these cases we have drawn separate boxes with no linkages, meaning that the entity is a relevant part of the solar industry, but the linkages are unknown. We have marked the core companies in bold letters, and important forums are coloured.
Figure 2: 2000-2001
As the maps illustrate, the growth of the industry has been substantial. One of the most notable differences from 2000-2001 to 2009 is the formidable development in related and supporting companies. Also, the competence in the silicon producers Elkem and Fesil has been exploited through the establishment of
devoted solar subsidiaries. In regard to ownership, there have also been major changes. In 2000-2001 Scatec was behind pretty much all the dedicated Norwegian solar companies, with involvement both on the owner side and taking leading positions in some of them. The company’s situation is somewhat different today, holding a smaller relative position in the solar industry, while Orkla is now the largest individual owner. Scatec’s withdrawal was mainly motivated by the interest in working with the development of smaller innovative technology ventures rather than larger, more mature companies. Another important feature in the period is the emergence of organizations facilitating cooperation and coordination between the actors. The web of linkages is much more complex today than it was in the early days of the industry, which is quite natural when new actors are founded. However, it is not an automatic mechanism, as relations need effort to be established and maintained. The Norwegian solar industry is, as can be seen, relatively intertwined.

**DOES THE NORWEGIAN SOLAR INDUSTRY CONSTITUTE A CLUSTER?**

Our opinion is that there is a cluster in solar energy in Norway. Norway is one of the major nations in solar power globally and has companies in all significant parts of the value chain. In total there are 25-30 companies we define as belonging to the solar cluster, including subsidiaries of the larger corporations. In addition there are 10-15 industry associations and research institutions with relevance to the solar industry. We therefore argue that critical mass of entities is almost reached, but Orkla controlling two of the three largest companies is somewhat problematic. The cluster would be more solid and independent if Hydro or Scatec’s operations were scaled up or foreign actors established themselves. However, comprising successful silicon- and wafer manufacturers, companies in related and supporting industries and research institutions, we argue that critical mass is close enough to qualify as a cluster. The extent of interaction might preferably be higher, but there are clear knowledge spill-overs resulting from human resource mobility between firms, research centres and educational institutions. Although the operations are spread from Narvik in the north to Kristiansand in the south, we consider Norway to be a small enough country with sufficient infrastructure and communications to mitigate the disadvantage of being
located so far apart. Alf Bjørseth (2009), who knows the industry better than most people, has characterized the industry as a cluster. The cluster is, however, at a fairly low stage, and using Rosenfeld’s (1997) typology of clusters, Norway may be categorized as a latent/underachieving cluster. As illustrated in the figure above, there is some interaction between the actors, but this is not sufficient to fully extract all the potential synergies from co-operation and competition. In our opinion, measures must be taken to further develop the cluster, and this is possibly also necessary to remain at status quo.

**COMPARISON WITH OTHER LOCATIONS**

In this section we will provide a short overview of the nations we consider to be the strongest competitors with regard to locating new operations. We will give a brief introduction to the nation, encompassing the most significant features from the national diamond relevant to the solar industry. This will be followed by a cluster diamond, ending with a sum-up where we will attempt to identify the location’s momentum and what main assets attract new establishments. We have chosen to focus on Germany, China, United States and Singapore.

**Germany**

Germany is a country with a long and strong industrial tradition, characterized by high quality and precision. This is reflected in high scores on the Global Competitiveness Report (GCR) factors measuring quality and quantity of local suppliers, intensity of local competition, breadth of value chain and world-leading market dominance (Porter and Schwab, 2008). Probably in part a result of the high performance industry, buyer needs are relatively sophisticated. Regarding enrolment and quality of education Germany ranks relatively highly. The nation is ranked number one in GCR concerning capacity for innovation, supported by high quality of scientific research institutions, high company spending on R&D and university-industry research collaboration (Porter and Schwab, 2008). Germany’s financial market is relatively sophisticated, but access to capital is a competitive disadvantage. High taxes, labour market inefficiencies and government bureaucracy are found to be the most problematic factors for business.
Factor conditions

Germany has been one of the leading countries when it comes to promoting the production and use of renewable energy. In 1999 the 100,000 roofs program (HTRP) was introduced, including loans for PV systems with zero interest and an instalment remittance constituting approximately 12.5% of the investment. This subsidy programme amounted to about EUR 1 billion, but has been phased out (Germany initial subsidy programme PDF). The first feed-in tariff programme was launched in 1991, obliging electrical utilities to purchase the renewable energy produced in their area at a price which is fixed for 20 years (www.loy-energie.de). The feed-in tariff is reduced by 5% annually. Renewable Energy Sources Act (EEG) was enacted in 2000, raising the rate granted to PV, also including utilities, considerably until a target capacity of 350 MW was reached (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2000). The extra cost associated with the production of electricity from solar power compared to other sources of energy is paid by the consumers. However, the amount per kWh is modest, since solar power makes up a small share of the total electricity production. As the share from solar power increases, efficiency improvements are expected to have diminished costs and made it a competitive energy source. Amendments were made to the EEG in 2004, including an increase in the feed-in tariff for smaller PV systems and the abolishment of limitation to system size (German initial subsidy programme PDF). Some states have additional subsidy programmes that can be combined with the national feed-in tariff (www.solarbuzz.com).

Demand conditions

Renewable energy made up 14.3% of total energy consumption in Germany in 2007. Photovoltaics made up 3.5% of this, constituting a share of 0.6% of all electricity consumption (Stryi-Hipp, 2008). The impact of the EEG may be illustrated by exhibit 6, where the annual growth in installations accelerated notably in 2000 and on. Germany was the world’s second largest PV market in the world in 2008 (www.solarbuzz.com). According to EUPD Research (2008), private customers make up 45.5% of the German PV market, commercial customers 27.4%, agricultural customers 12.7%, public customers 5.7% and professional investors 8.7%. A study of German citizens showed that one in five home owners is considering investing in a solar system in the short term, and the
solar industry is one of few industries to report growth in the hardships the world economy is going through (www.solarplaza.com).

**Firm strategy, structure and rivalry**

As illustrated in exhibit 7, the German Solar Industry Association (BSW-Solar) has records of six companies producing silicon, five producing wafers, seven making solar cells and thirteen assembling solar modules. In addition, there are four fully integrated corporations covering wafers, cells and modules. German producers are among the leading solar companies in the world, with Q-cells the number one manufacturer worldwide (www.worldwatch.org and www.q-cells.com) and Schott, one of the fully integrated actors, with a 125 year history as industrial conglomerate.

**Related and supporting industries**

The strong industrial position held by Germany puts the solar companies in a beneficial position, as highly competent suppliers emerge to cater to unfulfilled needs in the market. Germany is one of the leading nations in the production of solar energy, with a well established supply chain of high quality.

**Sum-up**

The feed-in tariff scheme is the main driver of the growth and development of the German solar energy industry, making investments financially attractive and offering predictability of cash flows. Jürgen Kaiser-Gerwens, finance director at Schott AG, has stated: "The FIT gives companies a good basis for planning but also makes them become more efficient and competitive. It is a win-win-win – for the industry, the government and individuals" (www.guardian.co.uk). Hans-Josef Fell, energy spokesman for the German Green Party has said “A factory is not built because of research money. Create a market, and the factories will follow”, and for a nation with a well-developed industrial competence and solar conditions making for a significant home market, this has proved to be a success.

**China**

China is a country of great contrasts, spanning from highly developed and industrialized cities to vast poor rural areas lacking electricity and basic...
infrastructure. This results in a relatively weak score on infrastructure (Porter and Schwab, 2008). Also, the nation has significant trade barriers and high tariff rates, but trade agreements provide it with top ranking regarding foreign market size. The nation’s financial system is currently not very advanced, but the security exchanges are among the largest in the world and are increasingly opening up to foreign companies and investors (www.china-briefing.com). Educational indicators are mediocre, especially in higher education, and the quality is significantly lower in rural areas (www.gallup.com). Local suppliers are numerous, but the quality is not very high. However, buyer sophistication is high. Capacity for innovation is characterized as a competitive advantage, reflected by high company spending on R&D and a high degree of university-industry research institutions. Quality of scientific research institutions, however, is ranked to be mediocre. Tax rates and tariffs are high and bureaucracy produces inefficiencies. The most problematic factors for business, however, are access to financing and political instability (Porter and Schwab, 2008), as the nation has a history of nationalizing/appropriating both land and business.

Factor conditions
China is a low-cost country with abundant cheap labour. The two most significant cost components in solar cells are silicon and labour. Now that silicon prices are low, labour will have higher relative importance, giving Chinese manufacturers an edge in the competition in the assembly of solar cells, panels and modules.

The Chinese government allocated ¥ 120 million annually in technical innovation loans to support renewable energy from 1987 to 1997 and ¥ 175 million to upgrading solar industries (including solar thermal energy) in 2002. In 2007 a “bright project” was launched, with ¥ 10 billion for PV power (www.in.chineseembassy.org). The Finance Ministry announced in March 2009 that it will finance up to 50% of the costs of setting up solar power systems larger than 500 MW, comparable to a coal-fired power plant. The subsidy rate will be up to 70% in remote areas to speed the development of green power. In addition, the government has announced a feed-in tariff programme for building-integrated PV installations, where projects of 50 KW and above will receive up to ¥20 (=USD 2.93) per watt support. This is a very generous subsidy, and no cap has yet been set. However, analysts believe Chinese companies, and possibly the larger of
these, are likely to be favoured (www.greentechmedia.com, May 21, 2009), discouraging foreign direct investment.

Demand conditions

There has been little domestic demand for PV installations (www.renewableenergyworld.com), so 98% of China’s PV production is exported (www.chinadaily.com.cn). The vast rural regions of China pose a great potential PV market. Setting up local small power plants or simply equipping buildings with solar panels would in many regions make more economic sense than building out the grid. In fact much of the 20 MW new capacity installed in 2007 was for remote off-grid applications (www.worldwatch.org). The rapid development of the Chinese economy has accelerated the need for energy supply. Several of the largest Chinese solar companies have signed letters of intent to build solar farms in various regions of the country spanning from 150 MW to 1 GW, the latter of which will become the largest solar farm in the world if implemented (www.seekingalpha.com, June 11, 2009).

China has a target for renewable energy to make up 15% of the nation’s total energy consumption (www.seekingalpha.com, June 24, 2009.), encompassing all types of renewable energy, such as biomass, wind, geothermal and solar thermal energy, where China is the largest producer and consumer of the latter. However, China is also both the largest producer and consumer of coal power, and in 2006 it made up 69% of the nation’s total primary energy consumption (www.eia.doe.gov). The abundant access to cheap coal power discourages the development of solar energy, and the plan to build 600 new coal power plants over the next 8 years (www.tu.no, Apr. 23, 2007) sows doubts about whether the ambitious targets will be honoured.

Firm strategy, structure and rivalry

According to the China Solar Association China was the number one producer of solar modules in 2007 with a production capacity of 1,180 MW (www.cleantech.com, Jan. 20, 2009). There are approximately 140 solar-grade crystalline silicon wafer makers in China (www.cleantech.com, Mar. 27, 2009). There are, however, only two major solar wafer providers, LDK solar and ReneSola (www.seekingalpha.com, June 11, 2009), but there is a myriad of small
wafer manufacturers. The Chinese government is strongly encouraging these small firms to merge with the large companies (www.seekingalpha.com, Jan. 11, 2009). The bulk of the Chinese solar companies are engaged in the production of solar cells, panels and modules. In the current situation of oversupply, Asian companies are expected to be fierce competition to the European producers, some selling modules below cost price (www.solarplaza.com).

**Related and supporting industries**

The sheer size of the Chinese economy and overwhelming number of companies enables solar energy manufacturers to access the necessary components domestically.

**Sum-up**

China constitutes an enormous potential market, and the government is starting to make commitments to entice the growth. However, similar planned projects have been cancelled before, resulting in credibility issues posing a challenge in attracting foreign investment. Low costs and a growing domestic market are forces likely to strengthen the Chinese companies in the global competition. China is one of the world’s largest economies and possesses the financial muscle to make investments which dramatically increases the competitiveness of Chinese producers.

**Singapore**

The Singaporean educational system is of very high quality from primary to higher education, but the enrolment is more moderate (Porter and Schwab, 2008). Infrastructure is excellent, and Singapore is one of the world’s main transport junctions. The financial system is advanced and access to financing is good. A low extent of government bureaucracy facilitates the process of starting business, and taxes are relatively low. The nation has a relatively good capacity for innovation, with high quality of research institutions, high company-spending on R&D and a high degree of research collaboration between universities and the industry. Singapore is a small country with a limited domestic market, but trade agreements and a very open economy with low tariffs provide the nation with a relatively large foreign market. The size of the country also limits the number of
local suppliers, but they are of high quality and value chain breadth. Buyer needs are sophisticated. Inflation, an inadequately educated workforce and restrictive labour regulations are said to be the most problematic factors when doing business in Singapore.

Factor conditions
As a sign of commitment, the Singaporean government has created a fund of USD 244 million for the development of PV solar power (www.nus.edu.sg). Solar Energy Research Institute of Singapore (SERIS) is Singapore’s national institute for applied solar energy research and commenced operations on 1 April 2008, jointly sponsored by the Singapore Economic Development Board (EDB) and the National University of Singapore (NUS). SERIS is a research institute at NUS and is located on the main university campus. SERIS conducts industry-oriented research and development as well as use-inspired basic research. In addition, it will be available for test-bedding of innovative industrial-scale tools for PV and certification testing, and is planning the establishment of lab facilities for nano-structured solar cells in 2010 (www.seris.sg, www.seris.nus.edu.sg). The institute expects to be fully operational in Q3 2009, with plans to expand from 25 to 90 researchers and produce 50 doctorate and 20 master students within 5 years (The Straits Times, Feb. 21, 2008). The institute has formal relations to several recognized research milieus around the world already, and the close relationship to NUS is also considered to be a strength. Polytechnics are schools that prepare students for the university level. Several of these offer diplomas in clean energy, renewable energy engineering and environmental science. The world-renowned solar expert Joakim Luther leads SERIS, aiming to attract top-notch foreign scientists.

Demand
There is a 1,200 sq m solar park at Marina Barrage (www.wildsingaporenews.blogspot.com) and a 250 kilowatt peak (kWp) photovoltaic power plant is planned at Changi Airport’s Budget Terminal (www.phoenixsolar.com), but the demand in residential houses is presently insignificant or non-existent. The bulk of the 5 million people live in high-rise houses, where the decision to put solar panels on one’s roof is nearly impossible to make for individuals. Also, the government has provided few local incentives
or targets for the use of solar power. Singapore’s Economic Development Board has stated that the nation will not use solar power until it reaches grid parity with other electricity (www.reuters.com). When that time comes, Singapore will make an excellent candidate with regard to its sunny climate. Located on the Equator, Singapore has 50% higher solar radiation than Germany, which is one of the largest PV markets (www.nccc.gov.sg). In addition, the nation has a prime location in the Asian sunbelt, providing very good access to other Asian markets with great solar conditions.

**Firm strategy, structure and rivalry**

The Singaporean PV industry is still taking its infant steps, with only a few home-grown and foreign companies established. However, the recent government commitment has incited international major players to establish plants in Singapore, such as the Norwegian companies REC, Norsun and Metallkraft, as well as foreign companies such as Phoenix Solar and Kyocera.

**Related and supporting industries**

Singapore is one of the world’s most prominent hubs for semiconductors (www.sedb.com), with significant know-how in the field of silicon. However, being a very small country, it depends on imports of many goods. This makes close co-operation with suppliers challenging.

**Sum-up**

The driving force behind Singapore’s growing solar energy industry is the favourable framework conditions, focusing on R&D. The industry is yet not very well developed, but the generally business-friendly business environment facilitates foreign direct investment. Some key companies have opened plants in Singapore, and these combined with the growth of a competent research community is likely to attract more world-class firms. Singapore’s late entry into the industry is not necessarily a big drawback, as long as they can create momentum and grow rapidly but soundly. There may also be a second mover advantage as they can learn from other nations’ mistakes.
USA

Factor conditions
The U.S. Department of Energy (DOE)'s Solar Energy Technologies Program (SETP or the Solar Program) aims to achieve grid parity through its primary R&D efforts by 2015 (www1.eere.energy.gov). The nation has a myriad of renewable energy incentives, including solar power, on national, state and federal level aimed at producers, industrial customers and individual consumers (www.cisolar.com). A national package offering 30% investment tax credit for companies making equipment for renewable energy systems was recently launched. Grants will be available instead of a tax credit for solar companies for offsetting 30% of the cost of installing a solar energy system at a business. Large-scale solar plants, often developed to sell power to utilities, also are eligible, while residential houses are not (www.greentechmedia.com, Feb. 17, 2009). In addition there are local incentive schemes differing across states. Residential installations account for 89% of all incentive applications, but only comprise 15% of the total MW to be installed. Non-residential applications from commercial, government, and non-profit applicants make up 11% of the total applications but will account for 176.8 MW or 85% of generating capacity to be installed (www.semi.org).

Although the United States is lagging far behind European countries in solar implementation, its clean tech venture capital investments more than double those in Europe.

Demand conditions
NASA and other governmental and private space institutions have utilized solar cells in their space programs for several decades before the technology became commercially interesting as a substitution for traditional energy sources on the ground. Arizona, California, Colorado, Nevada, New Mexico and Utah have been identified by the government as suitable destinations for solar energy generation and transmission (www.news.cnet.com). Nellis Air Force Base in Las Vegas, Nevada, is home to the country's largest solar photovoltaic system. The 72,000-panel, 14-megawatt array provides a quarter of the electricity used at the base, where some 12,000 people work and live (www.rechargenews.com). The favourable incentive schemes have spurred demand, especially in the sunny state of California. The California PV market grew 100% to about 160 MW of new installed solar power in 2008. Modules are often more affordable than in Europe,
but the turnkey system prices are still almost 50% higher in California due to complexity in administrative procedures for incentives, permitting processes and the National Electric Code requirements (www.solarfeeds.com).

Firm strategy, structure and rivalry
The undisputed number one manufacturer of thin-film solar cells, First Solar (Exhibit 8), is American. Many of the leading silicon based companies in the world, such as Suntech, Schott Solar, SolarWorld, REC and Kyocera, have operations in the US, ranging over the entire value chain from silicon to finished solar panel. Several of the new establishments have been motivated by proximity to market, highly skilled workforce and a reasonable cost level.

Related and supporting industries
There are many installation companies and other project developers, especially in the states where solar power is biggest. The US is the world’s largest economy, with a very well developed industrial sector. It thus provides a good foundation for related and supporting industries for the solar industry.

Sum-up
The US has been engaged in the production and use of solar power, although on a modest scale, for decades and has built up significant competence within this field specifically and in metallurgy generally over time. The growing domestic market is a strength both to American manufacturers and in the attraction of foreign firms. The US is so large and has a large technologically advanced industrial environment, so it is ready to produce literally anything.

Benchmarking
We wish to emphasize that this analysis does not go very in-depth on the various nations, as that is beyond the scope of this thesis. The strengths of Germany and the US are pretty similar. Both nations have strong and established positions in the global solar energy industry. Many of the companies have several years of experience in the domestic and the international market, out of which many are among the largest and most notable firms in the global industry. The industrial competence in both countries is world-class. Also, both have large and well
established domestic markets with incentives mainly targeted at stimulating demand. To sum up, the German and American main strengths are their established position, well developed industry in general and in solar power and large domestic markets. In other words, their main force is within conditions for production and market demand. We would characterize the German industry as a full-fledged cluster. The US, however, is more uncertain, as the industry is more geographically dispersed. The nation definitely has good opportunities, and there seems to be new political will going in for prioritizing renewable energy.

Singapore, on the other hand, has little established industry within solar power, but is growing rapidly due to favourable framework conditions. The government’s financial and R&D support has already attracted some of the world-leading manufacturers, and the trend is expected to continue. As of yet, the conditions for R&D are not fully built out yet, but there are high-quality facilities and top-notch researchers to be recruited. The limited industrial competence is likely to be improved if the pursuit to attract companies is successful. There is practically no domestic market, but the nation has a vast foreign market, as mentioned in the cluster diamond. Its strongest selling point is the new research facility and financial support. Singapore does not as of yet possess a solar power cluster, as critical mass of companies is not reached and the research competence is not yet established. If the development is as rapid and extensive as the government hopes, it will be an emerging cluster the next few years.

China has an enormous potential domestic market and is home to some of the world’s largest cell producers. It also has plans and letters of intention to generously support the further development of the industry. However, the credibility of the government is somewhat weak, and being a patriotic and nationalistic country, it is expected that these measures will mainly benefit Chinese companies. The protectionist nature of China makes it likely that direct investment will be required to access the market. This might also help build the industry and improve the conditions for production in the long term. The main attraction here is the vast market potential and the prospective good conditions for production. China is not yet a cluster, but has strengths to build on in order to become a major location in the future.
DISCUSSION

There are many attributes relevant for deciding where to locate a new solar power plant. We consider the most important dimensions to be conditions for R&D, production and market. In the following we will present the most important strengths and weaknesses of Norway in regard to these three dimensions.

Conditions for research

The metallurgical competence built up continuously over decades is a great strength to the Norwegian solar industry, both in terms of metallurgical firms which have branched into solar energy and spin-offs or new ventures from former employees in the sector. The Norwegian companies have been characterized by industry experts as being technologically advanced in an international context. Compared to rival locations, the Norwegian government is not competitive in sponsoring R&D. The strong competition for the funds means that good projects are likely not to get the support they should, and this might harm entrepreneurship in solar power directly and in related and supporting industries.

SINTEF and NTNU’s facilities and equipment are not at par with the standards in for instance Germany. One example is that they just acquired a pressure chamber for growing thin-film for second generation cells worth NOK 1 million, but according to Egil Trømborg from SINTEF, German competitors have more high-tech machinery worth 5 times what the Norwegian institutions have (KILDE: Gemini). The work force within solar power is highly competent, but according to several industry representatives there is a labour shortage, and new graduates are too few to satisfy the companies’ needs. Summing up, we argue that the conditions for R&D in Norway are good when it comes to competence, but scarce financial and human resources limit opportunities.

Conditions for production

The facilitation of spin-offs is positive for the emergence of new ventures in the solar industry and in related and supporting industries. However, the importance of REC cannot be understated. The company’s leading position nationally as well as internationally has driven the emergence of the industry. There is no doubt that
having large domestic customers to serve is an asset for suppliers and new ventures in related and supporting industries. Most of these will have Norway as primary market, at least in early stages. A domestic market of high quality is a good arena to build experience, improve technology and products and financial strength before expanding to a global market, thus reducing risk. Also, some of the most successful related companies follow their customer in their expansion. One example is Metallkraft which is, as previously mentioned, building a dedicated plant at REC’s site in Singapore. Many of the small specialized companies which have been founded the last few years have been characterized by industry experts as innovative and possessing cutting edge technology. This is an advantage for the established solar companies getting access to high quality components and building relationships to them at an early stage. At the same time, the supplier’s earnings are secured at a crucial time of its life span. There are examples of tailoring products, such as ScanCrucible which produces crucibles from customers’ specifications. This is mutually beneficial, as the customer gets exactly what it needs, while the supplier’s competences may be expanded to give them an edge also in relation to other customers. This is not a characteristic which can be said to be distinct to the Norwegian industry, but it is still a strength helping the cluster as a whole develop.

Firm interaction is found to be low, but industry organizations such as SFFE and OREEC arrange events where the most significant people interact informally. Also, associations such as SFFE and ife coordinate co-operation within the research milieu and work with all the companies, so there is some indirect knowledge transfer.

The Norwegian government does not support the establishment of new plants unless the objective is to replace obsolete cornerstone firms in local communities. Corporations like REC are thus “on their own” financially when making the decision on where to locate a > USD 3 billion factory, while other nations offer huge subsidies and tax credits to attract projects. Also, whereas Singapore’s new research centre offers testbedding of new products, this is a gap in the Norwegian system.
The conditions for production are thus to a large extent the same story as R&D: companies possess world-class technology and competence, but financial incentives from the government are practically non-existent.

**Market conditions**

Market conditions are very poor, but using solar cells in Norway is not appropriate because solar conditions are insufficient to reach a satisfactory efficiency. The fact that Norway does not have a home market is a drawback to the cluster. By studying new establishments we have learned that FDIWs are to some extent motivated by proximity to market. This will make the attraction of new operations comparatively more challenging than for a country with a flourishing market. Also, founding a company with a domestic market is less risky than founding one where the market is global. Therefore, one might experience a higher rate of entrepreneurship in countries with a domestic market than in Norway, affecting the degree of rivalry in the industry and demand for related and supporting industries. In the global marketplace, the most important parameters in competition are said to be quality and total costs. However, the importance of reference customers and having “made it” in one’s home market is emphasized by some (Lauvstad, 2009). Another aspect is attention and national relevance. The industry in a nation which utilizes solar power is likely to receive more focus and financial support from the government and have more devoted research resources than a nation in which solar power is merely an export industry. Several sources in the solar industry say the government’s support of wind energy is disproportionately large compared to solar power and that the focus appears to on increasing the share of green energy in one of the smallest countries in the world rather than facilitating solutions that may give a large number of countries the opportunity to reduce their emissions (MENON Business Economics, 2009). Hence we see that poorer demand conditions in Norway than in other nations is likely to dampen the levels of the other three factors in the diamond model.

**RECOMMENDATIONS**

Our opinion is that the government is going to have to take action if it wants to sustain or enhance the position Norway holds in the solar industry internationally.
Comparing with the rival locations above makes it clear that Norway will not distinguish itself positively in the competition as the situation is today. It is not likely that companies which are established with operations in Norway will choose to relocate these as a result of poor framework and cluster conditions, but new establishments are likely to be done elsewhere. Our recommendations are aimed at aiding the weaknesses and challenges identified in the previous section to improve conditions for the existing actors in the industry and to encourage new ventures and attract foreign direct investment.

**R&D support**

The market should not be stimulated, because of the low degree of solar radiation. Germany has the necessary amount of sun to justify solar panels. Norway does not, so feed-in tariffs are inappropriate here. However, we argue that some subsidy scheme is necessary in the international competition for the establishment of plants. Our analysis suggests that the best way to do this is through increasing R&D support. The most appropriate way of doing this is increasing the pot available for project applications. These have to be considered competitive to receive the support, helping secure the quality of the research money. In addition, the funding of research equipment at NTNU should be increased, as many innovative ideas are conceived by students and professors in a creative research lab. This may spur new venture creation and enhance the learning for graduates entering the solar industry. Although the quality of the research milieu is high, other locations are setting the agenda of the most avant-garde technology. Alf Bjørseth (2009) has stated that for input on the newest and best technology he goes to California.

**Supporting test production**

Industry experts have emphasized the problematic transition from experiments to ramping up production. The process in between, namely test production, is very costly and contains a high degree of technological risk. We suggest that producers of products that are novel and offer something new to the industry should be assisted through support for test production. This could be organized as part “scholarship”, part loan, which would be repaid if the product became a success.
The government would also gain tax income from the venture and enjoy the benefits of cluster development in the future.

Increase the number of graduates

The number of graduates that are qualified for research positions in solar companies or research institutions is currently too low to meet demand. We therefore recommend that PhD positions be facilitated both financially and by promoting the opportunities well at the most suitable campuses. A tailored master degree is another measure that would help distinguish Norway and produce even more dedicated graduates for the industry. Such a specialization would likely have many common subjects with existing degrees in material science, physics and chemistry, and there is wide competence in the solar field at NTNU.

CONCLUSION

The emergence of the solar industry represents a knowledge-based business development. As we have illustrated, the growth of the industry the past decade has been substantial, but there is a high degree of uncertainty regarding further cluster development. The cluster is weak compared to solar clusters in other locations, and if it is not further nurtured, it will erode and lose its edge. If we were to make a prediction, we would say that in the short term Germany and the US are the strongest of the locations we have studied in the competition for future establishments. Singapore is pursuing the industry aggressively, but we assess them to be too small to fully compete with Germany and the US. China is generally viewed as a country whose strength is in low-price manufacturing of mature products. We predict that this will apply to solar power as well and that they will become even more significant in the years to come. Our opinion is that it will be difficult for Norway to become the PV cluster in the world, but if the government makes the industry a priority, there are qualifications in Norway to make it a nation to be reckoned with. This is not to say that the government funding should be the driving force of the cluster development, because competitive advantage is created in firms by serving one’s markets in an efficient and effective manner. However, until the industry can stand on its own, in the words of Michael E. Porter (1990): “Government’s proper role is as a catalyst and challenger”.

RECOMMENDATIONS FOR FURTHER RESEARCH

The research on potential hot spots for solar power might have been more extensive and in-depth, but this is beyond the scope of this thesis. We therefore suggest for future research to further highlight the differences between Norway and rival locations in hosting the solar power industry in the years to come.
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EXHIBITS

Exhibit 1 – R&D intensity OECD countries

2005 or latest available year

1. Gross domestic expenditure on R&D as a percentage of GDP.

Exhibit 2 – R&D business intensity OECD countries

2005 or latest available year

1. Business enterprise expenditure on R&D as a percentage of industry value added.
Exhibit 3 – Cluster diamond Norway:

- **Factor conditions**
  - High quality metallurgical education
  - Too few graduates
  - Relatively high labour mobility
  - Small differences in wages
  - Poor support schemes
  - Attention from venture capital
  - High quality research milieu

- **Strategy, structure and rivalry**
  - Mainly privately held
  - Spin-offs encouraged
  - Little direct rivalry for market share internally
  - Fierce competition for knowledge
  - Low willingness to share core knowledge
  - Some social interaction

- **Demand conditions**
  - No domestic market
  - High growth past decade
  - Credit crunch making it difficult to get funding
  - Oversupply throughout the value chain putting pressure on prices and margins

- **Related and supporting industries**
  - Recycling
  - Crucibles
  - Machinery
  - Metallurgy
  - IT systems
  - Renewable energy

Exhibit 4 – Solar map of the world

Exhibit 5 – Market demand for PV 2008

![Pie chart showing market demand for PV in 2008](chart.png)

Source: Solarbuzz

Exhibit 6 – PV Installations by Year in Germany (in Megawatts):

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**Exhibit 7 – Overview of the German PV industry**

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Exhibit 8 – Top global producers of PV cells

GRA 19001
Preliminary Thesis

The Norwegian solar industry:
How have Norwegian companies become among the leading producers of solar energy in the world, and is this strong position sustainable?

15.01.2008
BI Nydalen
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Industry

The solar industry is divided into two main branches: solar thermal technology and photovoltaic (PV) technology. In the former, the sun is basically used to heat water or buildings, or produce electricity by use of steam-based converters (Orkla annual report, 2006). The latter transforms power from the sun to electricity by use of solar cells manufactured from silicon or other metals. The Norwegian industry is exclusively involved in PV, so we will limit our analysis to this form of solar energy conversion.

Silicon based solar cells were discovered in the 1950s and is still the main input factor in use today. Better and more economical use of raw materials, better knowledge of the metals involved and highly efficient production methods have altered the production process. Mainly based on manual labour ten years ago, the processes are almost fully automated today. However, manufacturing and raw material costs are still substantial, and the market is not yet big enough to give sufficient scale advantages. Combined with the fairly low conversion rate achieved today, solar power is still reliant on subsidies in order to provide competitively priced energy. However, some countries, such as Germany, have had a tradition of providing favourable framework conditions in order to stimulate both production and use of solar energy. This policy has supported the development of the industry, and has allowed companies to come up with new and more efficient ways of converting sun into electricity.

Technology

There are three generations of solar cells. In short, the first generation cells are rigid solar cell panels, created from silicon. Monocrystalline, or single crystal silicon, is more electricity efficient than multicrystalline silicon, which means that a higher share of the solar energy that hits the solar cell is converted into electricity. The second generation is based on thin-film solar cells that are flexible and more cost efficient to produce, but don’t offer as high a conversion ratio of total energy from the sun to contained electricity as first generation cells do. The development of the third generation has not come far, but aims to “get the best of both worlds”, namely enhancing the conversion efficiency of second generation
cells, while maintaining the low production costs (www.wikipedia.org). Although still at an early stage, experiments involving nano technology seem promising, and might have vast implications for the use of solar cells if it proves successful.

**Market**
The market for solar power has increased by an annual average of 40% during the last couple of years, and is expected to grow even faster in the future (www.recgroup.com, www.usatoday.com). Because of the low efficiency and high price of today's solar panels, the main markets are countries and areas where solar power is subsidized by the government, such as Germany, California and Italy. This is an impetus to commercialize the industry, and facilitates the financing process through subsidies from governments eager to fulfill the Kyoto Protocol. Due to the factors above, the industry has yet to come up with solar panels providing competitively priced electrical power. However, the development is rapid, and various industry organizations believe that solar power will be cheaper than regular power by the middle of the next decade (www.solarwirtschaft.de).

**Norwegian actors**
ScanWafer was the first Norwegian company to produce solar cells, and after mergers and organic growth it is now called Renewable Energy Corporation (REC) and is one of the biggest solar energy companies in the world. Later, new companies have emerged, and the metallurgic giants Elkem and Norsk Hydro now have own departments committed to solar power. The establishment of the first solar energy company, ScanWafer, may seem a bit coincidental. Timing was definitely important, but this is not the whole story. Although cheap power and cooling water were central to the decision of starting production of wafers, the industry has blossomed since, with both competitors and complementary companies.

The most important aspect to why the industry has developed so well in Norway is in our opinion competence. In the start-up of ScanWafer, both founders were experienced in Norwegian and international industry and had comprehensive knowledge about metallurgy and chemistry. The metallurgic technical
environment has also spawned most new start-ups, including the initiatives made by the metallurgic giants Elkem and Hydro. However, equally important was the ability to turn good ideas into business. The industrialization process of most successful companies in the Norwegian solar industry has been facilitated by the help of established companies with competence in this area.

Research statement

Research question
How have Norwegian companies become among the leading producers of solar energy in the world, and is this strong position sustainable?

The research question indicates that we will investigate why Norway seems to be a successful location for the industry. To accomplish this we will study the establishment and development of the industry to identify strengths and weaknesses. Industrial clusters are said to exist where “rival and competing firms sharing the same industrial knowledge base” (Reve, 1996) are located close to each other. We will determine whether the group of Norwegian solar energy companies can be said to make up a cluster, and if so, we will attempt to assess its strength and significance for the further development of the industry. This is not to say that we will try to predict the future of the industry, but try to say something about the potential synergy effects and how favourable the conditions for further growth and strengthening of the potential cluster are.

Relevance of topic
Climate concerns are growing due to the increase in average global temperature, and the world is in desperate need of alternative sources of energy to replace the polluting fossil fuels that dominate the energy production today. The sun provides the earth with more than 15,000 times its total energy demand, and has a huge potential as supplier of clean, sustainable power for all eternity. This is an impetus to commercialize the industry, because the energy is there, it just needs to be collected more effectively. The potential for doing so is great, and the various research environments on solar power around the world are likely to be crucial.
We assume that a strong cluster in solar power will be beneficial for the success of the development and commercialization of advances. We therefore think that studying Norway’s role in this is of high interest.

Norway’s financial situation to a large extent stems from activities related to oil and gas. These fossil fuels will run out in the foreseeable future, so finding a replacement is of great importance, both for the employment level, the development of advanced skills, the research community and financial welfare. Due to the enormous market potential for solar energy, the consequences of becoming a leading nation in this field would be tremendous, and studying the potential cluster will help in assessing the probability of this happening.

Solar power also has the potential of increasing the standard of living in developing countries. These societies might skip the step of building the massive infrastructure to provide electricity and communication that the industrialized world had to invest in. By fitting solar panels to each house and communicating wirelessly by mobile technology, these societies would be able to organize efficiently and develop much faster than what would otherwise be feasible. This scenario is currently not likely, but if such a development was financed and/or significant advances were made in the electricity-efficiency and prices of solar panels decline, it is a future possibility.

**Object of study**

The thesis is mainly concerned with assessing the strength of the Norwegian solar energy cluster. Since the wafer is the core component in a solar cell, we choose to focus on the largest producers of silicon and wafers. Our main objects of study will therefore be REC, Elkem and NorSun/Scatec. Many other companies, such as waste handlers, investment companies, niche players and research organizations, are necessary in the value creating process from silicon to solar panel, and we will study these as part of the actors making up a cluster.
Porter introduced the diamond model in 1990, where a company’s competitiveness is explained by examining factor conditions, demand conditions, related and supporting industries and firm strategy, structure and rivalry (Porter, 1990). In the following we present the main points from the theory.

**Factor conditions**
Input factors of high quality help companies produce competitive products, and the most difficult factors for a nation to copy are those that “involve sustained and heavy investment and are specialized” (Porter, 1990). Investment in cultivating an advanced competence and research environment is an example that is relevant for the solar industry.

**Demand conditions**
Challenging and demanding customers in the home market may prepare the company for tough conditions on international markets. If the needs of the domestic customers are representative of emerging trends in global customer needs, the company may also gain a competitive edge. This is accentuated if the company collaborates with its customers to develop products, because it gets a “direct line” to customer needs and develops a mutually beneficial relationship which may bring the company to a higher level internationally. The end-customer
market is practically non-present in Norway, so here we will mainly focus on business-to-business relations.

**Related and supporting industries**
Competitive actors of related and supporting industries provide the company with cost-effective inputs at high quality and frequently at lower transaction costs than it would otherwise have access to. Close relationships, similar to the ones discussed above, are also facilitated. We expect the most important related and supporting industries to be found within metallurgy and waste handlers and other companies that have established themselves to serve the solar industry, but we will be open to find out.

**Firm strategy, structure and rivalry**
Internal rivalry has a destructive side to it in the short run, but is seen as advantageous in the long run, because it is a driving force for the companies to innovate and continuously improve. The market for solar energy is, however, not by far saturated, so we don’t expect the companies to be fighting for market share. Government also plays a role in subsidies, investing in public institutions supporting the development and setting framework conditions for the industry, which may alter the viability and strategy of firms.

Reve (2008) introduced the concept of global knowledge hubs for better analyzing knowledge intensive industries. The main focus is here on creating an infrastructure and atmosphere for developing and commercializing ideas. The importance of specialized universities and public research institutions is emphasized in order to attract young brilliant minds that thrive to learn and excel. If a prominent education environment is established, it will become an increasingly attractive location for globally leading companies’ R&D units, and accompanied by a competent venture capital market, innovation is accelerated. This is a self-reinforcing system, often driven by the rivalry between companies and R&D institutions, at the same time as ideas are shared and developed jointly.

Solar energy is a knowledge intensive industry, but it is as of yet very young in Norway, counting only 15 years since the first start-up. We therefore don’t expect
to find that there is a global knowledge hub, but we will use the theory to assess the strength of the research environment in Trondheim and try to identify which parts of the system are strong and which need more attention in order to blossom.

Studies have shown that firms that are part of dynamic industrial clusters have a competitive advantage (Reve, 1996). We will use the theory to identify Norway’s position in each of these categories, where the aim is to present them as a coherent system.

**Innovation**

Solar power is a technology intensive industry where the economies of scale are significant. Thus, in order to become efficient enough it is important to gain a certain size. Staying competitive in the race toward more cost-efficient production of electricity-efficient cells hinges on companies’ ability to innovate. Closed innovation, where companies rely on their own research (Wikipedia), was prevalent prior to World War II, whereas more and more firms have become more open the past decades when it comes to both generating and refining ideas and innovations. We intend to use theory on open innovation by Henry Chesbrough in specific in the analysis of how well the potential cluster has been utilized.

**Method**

**Data collection**

The nature of the research question supports an explorative design. We will conduct a case study of the Norwegian solar energy industry. This will be an intrinsic case study (Creswell, 1998), in other words we will study the case itself in the context of clusters, rather than using the Norwegian solar industry to say something about a phenomenon such as clusters. We have written a term paper about the establishment of the Norwegian solar industry in GRA 6825 Technology Strategy, and we will use insights reached through this process as a basis for the thesis. We have used and will continue using both primary and secondary data. Annual reports and the websites of companies, interest organizations and other informative sources, such as Wikipedia, will be useful in gathering background information about markets, firms, processes and the
industry in general. The primary data will mainly consist of in depth-interviews with key players. We will emphasize getting different points of view on the issue, and therefore interview both persons who were involved in the early establishment of the industry, such as the founders of REC, persons involved in metallurgy in Hydro and Elkem, researchers and possibly also politicians to learn more about the framework conditions and the policies relevant to the solar industry’s success and Norway’s attractiveness as host country.

**Analysis method**

To get a better understanding of the subject we hope to visit some of the companies to see their production sites. We have already made contact with Elkem Solar and hope to confirm a visit within the next few weeks. Also, we hope to visit the research community surrounding NTNU and SINTEF in Trondheim. Although the pure technology and chemistry behind solar power are not our main focus, we anticipate a visit to provide us with a better understanding of the current status of research and the challenges ahead. In addition, this might give us some indication of how advanced Norway is in comparison to other countries and to which extent Norwegian solar energy companies utilize the competence within institutions such as SINTEF and The Norwegian University of Science and Technology (NTNU).

The conclusion in our paper in GRA 6825 Technology strategy is that the industry’s origin was somewhat coincidental, but the foundations for its development were to a large extent based on the competence in the metallurgic industry and the ability to industrialize. In order to get a good understanding of exactly what type of competence and technology has been most crucial to the development, we plan to map what kind of silicon the various Norwegian companies base their products on and the processes involved. This will hopefully help us identify which actors in the cluster have been most important for the emergence of today’s industry. We will also try to discover more about the interaction between actors through interviews. Both the extent and the nature of interaction are of interest. Finding out how open they have been and how much they have relied on input from other parties. Assessing the extent to which the leading companies have utilized other companies, competence milieu, capital
market and research institutions will help us determine how strong the cluster is and to which extent the companies in it make use of it.

**Time schedule**

Since we have written a paper on the Norwegian solar industry earlier, we have already conducted some interviews and established contacts with some key persons in Hydro Solar, Elkem Solar and REC. We will use the information we have gathered from these as well as doing additional interviews with these and other actors. All main interviews are preferably to be conducted before April 1, 2009. Some follow-up questions and additional interviews are expected to occur after this date, but our goal is to have finished the material collection of primary data by April 1. We aim to have the first draft of the paper ready by June 1.

**Research limitations**

Our limited knowledge in the area of metallurgy and chemistry might lead to some misunderstandings when it comes to the highly technical products manufactured by the industry. We will try to limit this by discussions with more technically skilled individuals when needed. Another potential limitation is the fact that we base most of our findings on primary data gathered from interviews. There might be both advantages and disadvantages connected to this approach, as some of our informants might express their personal opinions as fact, leading to incorrect information in our data. We will try to avoid this by asking precise, well prepared questions to several sources and investigate further if discrepancies occur.
References


Torger Reve, “From industrial clusters to global knowledge hubs”; Working paper, BI Centre for maritime Competitiveness, Oslo, 2008 (21 p)

