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Ladies and Gentlemen:

We are at a critical juncture. Issues that shape our experience and quality of life, our policies, have shifted. From being primarily focussed on national importances, our sphere of influence and interests have been extended to include global concerns as well. In fact, global issues have, in some areas, begun to overshadow national ones, as evidenced by global trade, information exchange, and global treaties on the environment.

We enter a period where we can no longer exploit natural resources with impunity and where global and local trade-issues intersect to an ever increasing degree. This is not to say that national issues, culture and character, are not important. I believe they will become even more important than they currently are because they reflect our essence and very core of our being. However, it remains a challenge to sort out how to protect our individual cultures and national heritages, indeed our individuality, while addressing environmental concerns and adapting to challenges like increased openness between countries, competition, and globalization of markets.

In my talk I will focus on technological issues that cut across many of the problems mentioned above as it has to do with the development of an energy source, with unimagined potential. In order to exploit this source we need to solve policy issues and technological and organizational problems. We need to cooperate.

I extend my sincere thanks to the Emperor Akihito of Japan and King Harald of Norway for their presence and support of this important event. I thank the Norwegian Export Council, the Norwegian Research Council, and the Embassy staff for arranging this event. I also want to point out that I have had valuable help from colleagues in ELKEM, Norwegian University of Science and Technology and Carnegie Mellon University to prepare this presentation.

About 150 years ago Beguerel discovered that certain metals create a current when they are struck by light. It took another 60 years before Einstein laid the theoretical foundations for the photo-electric effect. And yet another 50 years before practical semi-conductor devices were made to convert the energy of sunlight directly to electricity in a remarkable device called a solar cell.

Our present technological challenge is to make this technology work on a large scale.

There exist many ways to convert sunlight to electricity. Natural processes take CO_2 from the atmosphere and make carbon materials via a process called photosynthesis. This process forms the basis for our current energy economy which is based on coal, oil, and, to an increasing degree, natural gas.

The photo synthesis process has less than 5% thermodynamic efficiency. So bearing in mind that a coal Rankine power plant has less than 50% efficiency, we find that the total energy conversions from sunlight to electricity is about 2%. However, the major issue with this process is not its efficiency. Coal, oil, and gas still are present in enormous quantities in the earth's crust. The problem is the accelerated emission of greenhouse gases to the atmosphere and its consequence on the environment and way of life.

I now want to contrast this with solar cell technology. Current Silicon based technology produces electricity directly from the sun with about 15% efficiency without producing any emissions. Solar cells provide a reliable, virtually maintenance free, source of electricity at the rate of about 0.1 kW per m^2. Which means that a roof integrated with 30 m^2 of solar cells provide more than sufficient electricity for an average US family. Such installations require about 3 kg of Si, one of the most abundant, inert, and environmentally friendly elements on earth.

On a larger scale we note that the world's energy requirements are met if we cover 0.1% of our deserts with solar cells.

The solar technology based on the Photoelectric effect for producing electricity has only very recently been developed to a point where it can be called an industry. During the last few years it has seen a remarkable growth, however. And the areas of application extend into a wide range. The most important being residential markets driven by government incentives, telecommunications where access to grid based electricity may be more expensive than solar based technology, mobile applications, and a limited number of grid based power generating installations. In the total energy market the installed capacity for solar cells is still miniscule. The total PV generating capacity in the world was a little more than 400 MW last year. This is equivalent to one medium sized coal power station. Even at 25% growth, as indicated in the figure, this industry will remain small in the near future. However, 25% leads to doubling every three years. And in year 2010 such a growth will amount to building a 1000 MW power plant. Not enough to solve the current energy crisis in California, but a significant contribution nevertheless. The growth rate expected in Japan is even more spectacular. It is predicted to lead to a doubling of installed capacity in less than two years.

Silicon is without doubt the most important material on earth. It is a group IV element and an almost perfect insulator at room temperature. However, the addition of small amounts of group III and group V elements like Boron and Phosphorous gives Silicon the semiconductor properties that have formed the basis for the entire microelectronics industry and the information and communications revolution witnessed the last 20 years.

The physical properties of Silicon, measured in terms of its band-gap, limit its efficiency in converting sunlight to electricity to about 22%. This limit has nearly been achieved by the Japanese company Sanio by depositing amorphous silicon on a silicon crystal using a Plasma CVD process. The production technology for silicon based solar cells is well established. Silicon is available in the form of quartz in about unlimited quantities. More is known about the solid state properties of silicon than any other material on earth. However, there are manufacturing challenges. I will return to these later..

So this leads us to the question of whether we can use alternative materials for producing electricity from the sun. In space we rely on compound semiconductors based on rare-carbon materials like Gallium, Cadmium, Telluride, etc. We achieve higher efficiency, but at a considerable cost. Some materials are toxic, they are scarce and there are significant challenges in industrial production and scale up. These technologies account for less than 2% of the total PV market today. Alternate materials based on biopolymers are also being considered. It is very unlikely that any of these materials will come into large scale production any time soon. Silicon, therefore, is the material of choice.

So, what does the supply chain for solar cell production look like? The process starts out with quartz, coal, and energy to reduce the SiO_2 to Silicon in a metallurgical smelting operation. This technology is carried out on a large scale and its conversion efficiency is close to 79%. Only a very small amount of the total Silicon produced in the world is refined further to the kind of Silicon used for production of electronics. A first step in electronics process may be a leaching and crystallization step, referred to here as Silgrain, a trademark of ELKEM. The Silicon is then reacted with Hydro Chloric Acid to form TriChlorosilane, which can be distilled to extremely high purity. TriChloroSilane is unstable at high temperatures and will spontaneously decompose into HCl and pure Si when heated in a properly controlled CVD process. About 12000 t of this extremely high value added material, which is called PolySilicon, is produced every year. The PolySilicon then is processed further to produce the microelectronics components we are all familiar with.

At several stages in this process, Silicon, unsuitable for electronics, is generated. About 10% of the entire production is not usable. This socalled scrap material has supported the Solar Cell industry, where performance requirements for purity are less stringent. The Solar Cell industry has in this way been able to buy the Silicon it needs at reduced cost.

Let us now look at the production steps in a conceptual, large scale production facility using currently available technology. Please bear in mind that the total installed capacity today is of a similar magnitude as what is shown here. The study was presented to Greenpeace by the consulting group KPMG in 1999. We see here the main cost factors in producing solar based electricity in a large plant. Notice the distribution of costs also shows opportunities for further cost reduction. These are significant and point to the possibility of producing low cost electricity. The KPMG study concluded that the large scale plant imagined here would be able to compete with current electricity prices in Holland.

But, there is a serious problem underlying this picture. It is the following: The micro-electronics industry is growing at about 10% per year. The requirements for raw materials for Silicon based solar cell industry via micro-electronics is therefore threatened by its growth at 25% or more. In fact, we have reached the crossover point where the solar cell industry requires more raw materials than what can be supplied with the 10% rate generation of reject Silicon from the μ-electronics industry. Significant amounts of Silicon have been stored away so the crisis is not imminent. But, if nothing is done in this area, then there will be a structural change in the solar cell industry in the near future. To highlight the issue, consider the fact electronic grade Silicon costs about $50.kg. Currently the price for Silicon scrap material is about US $20/kg. However, this source is drying up and further growth may well lead to an increase rather than decrease in the cost of Solar Grade Silicon.

The surface area of Norway is about the size of Japan and, like Japan, it is a constitutional monarchy. Like Japan we have strong cultural traditions and we are ethnically uniform compared with most of our European counterparts. However, there are also differences. For example, there are only 1/30th as many inhabitants and that, of course, influences the relative magnitudes of the total industrial and R & D outputs of the two countries. Nevertheless, Norway has large industries in area where national resources are abundant-- most importantly, oil/gas/fishing/shipping and hydropower.

It is cheap and abundant Hydroelectric power that is the basis for Norway being the dominant world producer of Silicon. This industry has found the basis for the R & D activities in Solar Cell production. I will now outline.

Solar R & D activities are spread out over the entire country—from Kristiansand in the south and to Glomfjord in the north. This summer Scan Wafer will open a new production facility in Narvik, which is about here on the map. It looks as if they try to escape the very sun, whose energy they want to capture.

In order to understand how far north this is you can imagine placing the Osumi Islands in the south of Japan on Wakkanai in the north. Thereby we place Wakkanai all the way at Wagadan in Russia at 60º north. And this is where we find Oslo and Norway then continues north just as far again.

ELKEM is a major materials producer in Norway. It has about 4100 employees and major interests in Aluminum, Carbon Materials, FerroSilicon, Silicon, and MicroSilica, which is used as a filler to make high strength cement.

ELKEM; is the leading producer of metallurgical grade Silicon for micro electronics in the world. The ELKEM Silgrain process supplies about 80% of all Silicon for the Japanese micro-electronics industry. Based on a long history as a Silicon producer ELKEM has maintained active research in the area of producing solargrade Silicon for about 15 years. These activities have been drastically expanded during the last two years and they encompass a spectrum of activities including a search for pure raw materials for Silicon production, improvements for the Silgrain process, a new crystallization process, and improvements on the metallurgical process.

ELKEM has taken up the challenge to stretch its own production technology to the limit and develop new technology where required to provide a solution to the feed stock problem facing the Solar Cell industry

ELKEM will achieve this goal by capitalizing on its experience and expertise in the Silcon area, by forming strategic partnerships, which is one reason why Mr. Ole Enger, CEO, is here today with us, and by capitalizing on the unique structures for R & D that exist in Norway.

Scan Wafer was founded by Alf Bjørseth to form the basis for a Solar Cell industry in Norway. Aided by a strong infrastructure and development grants from the Norwegian government, he started Silicon Wafer production in Glomfjord. Producing about 2M wafer per year initially. The company is now in a major expansion phase. They will hire about 100 employees by the end of the year, and the wafer production will have expanded to 6.3M wafers per year. This gives Scan Wafer about 5% of the world production and 20% of the European production of Multi Crystalline Wafers. Scan Wafer if poised to become the leading producer of high quality, multicrystallize cells in the world. They are also set to become one of the leading integrated producers, producing wafers, solar cells, modules, and whole energy solutions.

The R & D effort in Scan Wafer if focussed on improving product quality and innovative methods for increasing throughout throught better understanding of the crystallization process. Scan Wafer is represented here today by President Kjell Sundsli.

The Institute for Energy Technology has long traditions in the energy field. One of their main responsibilities is to manage the operation of Norway's only R & D nuclear reactor. IFE is involved in many industrial R & D problems in Norway relating to the energy consuming and producing industries. Recently they have become involved in the renewable energy, focusing on Hydrogen storage and thin film technology. One major achievement is the result from a joint project with ELKEM and the European Community. Solar cells with 12% efficiency have been produced using a very cheap substrate material with a thin film of high quality Silicon. In this case, metallurgical grade Silicon was formed into wafers and coated using LPE in an Indium bath. The research now goes into a second stage with a broader range of industrial partners.

The largest R & D program in Norway in the area of Photo Voltaics is at the Norwegian University of Science and Technology, Trondheim. It is headed by Professor Georg Hagen in the Department of Materials Technology. The program enjoys broad support from industry, the major sponsors are ELKEM and Scan Wafer, and the Norwegian Research Council, who is represented by Director General Christian Hambro. NUST is represented by President Emil Spjøtvold.

The research and development program for Solar Cell research at NTNU is a broad based program which attempts to cover a number of critical aspects of solar cell basic research as well as production technology. The program has a crystallox machine for producing multi-crystalline silicon ingots and an array of instruments for characterization and analysis. The new research issues are focussed on product technology for Silicon feedstock characterization, crystallization, and architectural design.

The program also looks at total energy solutions, including the integration of wind, solar and hydropower, hydrogen storage, and fuel cells.

Finally we get to the PolytechnicInstitute in Agder outside Kristianand. Their research program, Sun, Water and Hydrogen, is supported by local electricity corporations, ELKEM and the Norwegian Research Council. One notable program is a joint effort with ELKEM and Scan Wafer aimed towards producing Solar Silicon through Silane decomposition. Silane can be deposited at lower temperatures than TCS, leading to a cheaper process.

I hope I have been able to convince you that there are exciting research opportunities as well as business opportunities in the area of Solar cells in Norway and the World. The global solar cell industry is still very fragmented and characterized by small players using a variety of technologies. In my view the real challenge in the industry is going to be to navigate the transition from being an industry based on batch processing towards more integrated process steps. The waste involved in today's wafering process, for example, is staggering. About 50% of all Silicon is lost in the wafering process.

The glass industry went from batch to a continuous operation with the development of the Siemens and Pilkington processes. Enormous gains in productivity resulted over a period of about 30 years. We have the opportunity to develop efficient processes for PV production more rapidly.

Other important issues I have not talked about here are the Public Policy and System Integration Issues. For example, Germany and Japan offer significant incentives for solar cell installation. It is clear that the principles laid down in the Kyota agreement and strong public sentiment give a foundation for accelerated growth of the Solar Cell industry.

This is what I see in Norway.

A Solar Cell industry with an ambitious vision and research institutions and universities with exciting and focussed R & D programs.

Scan Wafer's vision is to become the world's leading producer, in quality and quantity, of multi-crystalline wafers and solar cells. Scan Wafer is already a major supplier of wafers here in Japan.

ELKEM's vision is to become the leading supplier of SolarGrade Silicon for the entire solar cell industry by building upon its expertise in producing high grade metallurgical silicon. It's connections with Japan have long traditions.

Universities and Institute are ready to take on the challenge to build competence and expertise to support these activities and spearhead the development of new technology.

Our R & D networks extend to Europe and the United States. We hope with this state visit to build a strong R & D network with Japanese institutions and.universities.

A little over 100 years ago the French Academy adopted a policy. They would no longer accept patent applications for energy production that violated the laws of thermodynamics.

Solarcells, of course, obey these fundamental laws of nature, as we all must do. They do not produce energy from nothing.

Nevertheless, I believe Solar Cells are almost as ambitious and groundbreaking as perpetual motion machines. The existence of such devices shows us a way to exploit an inexhaustible source of energy for good. We have in our hands a device that can satisfy all our energy needs. It has no moving parts, it is remarkably stable, almost maintenance free, and produces no byproducts harmful for the environment.

The businesses that succeed in exploiting this potential may experience enormous gains and bring profit to us all.

Thank you Ms Chairwoman for organizing this session and allowing me to share these thoughts with you.