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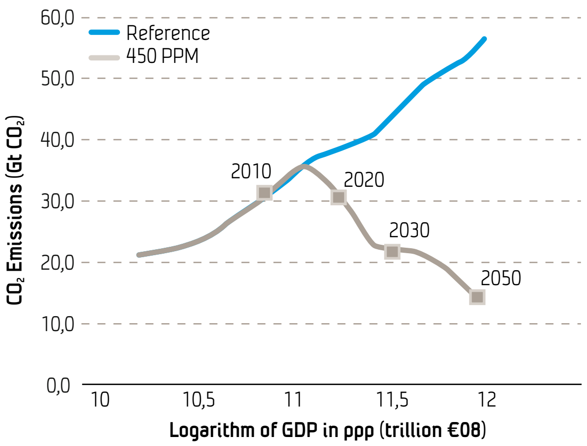
The energy revolution

Energy use and climate change go hand-in-hand and present two important global challenges. Estimates indicate that the world's energy requirements will increase by almost 50 per cent by 2030. So far, increased use of energy has been inextricably coupled with increased greenhouse gas emissions. "The energy revolution" is all about breaking this connection.

Economist Joseph Schumpeter popularised the concept of creative destruction more than 50 years ago to explain the essence of the term innovation. Innovation means abandoning old ways of thinking and doing things. Education, research and innovation become the most important tools for realising the energy revolution.



The energy revolution – changes in emissions necessary to comply with the 450 ppm scenario* (Eurelectric 2010).

The world's energy systems must be transformed; we need environmentally-friendly energy and our starting position is very poor – satisfying the world's energy requirements is principally based on fossil energy sources. The task consists of transforming the backbone of the world's energy supply while causing the least possible harm to the patient. This transformation has become known as one of the world's Grand Challenges. It is referred to in the Lund Declaration of 2009, which states that "Challenges must turn into sustainable solutions in areas such as global warming, tightening supplies of energy, water and food, ...".[1] This means that research and innovation must be structured to make it possible to tackle the major challenges facing the world.

The transformation cannot take place without significant investments in education, research and innovation. This is also the main message in the report "A business plan for America's energy future"[2], published by the American Energy Innovation Council. Investments in energy research and development are far lower than necessary to tackle the challenge, and have been practically disregarded in the last 25 years. As far as the US is concerned, the recommendation is for an increase in R&D investment to three times the existing level. The Stern Report[3] recommends a global doubling of R&D investment, while the IEA estimates that investment must be increased to two to five times the current level.[4]

1 Research and Innovation for the next decade, see *www.vr.se/lunddeclaration*
2 American Energy Innovation Council 2010, see *www.americanenergyinnovation.org/*
3 The Stern Review on the Economics of Climate Change, 2006
4 IEA Energy Technology Perspectives 2010
* The 450 ppm scenario refers to the maximum atmospheric concentration of CO2 which is compatible with global warming of 2-2.5 degrees Celsius.

Ever since Copernicus proved that the sun was at the centre of our part of the universe, the motive power behind development has been based on knowledge and technology. We have pursued the path of technology. This has provided major innovations and improved our standard of living, but with significant impacts on the environment. We must now use (the path of) technology to tackle the environmental challenge and create sustainable energy solutions for the world.

Norway has particular advantages in the field of energy supply. Hydro-electricity was a factor which made the development of the modern Norwegian society possible. The first electrical dynamo was produced in Germany in 1866, and enabled the production of electrical power from hydro-electric plants, first using water wheels and later turbine technology, transmission lines and electronic control systems: this was a true paradigm shift. There was a transition from fixed, local installations based on mechanical energy to distributed systems based on the transmission of electrical energy.

Access to reasonably priced energy promoted industrial innovation and the establishment of so called "industrial locomotives", and attracted foreign capital. The power of our waterfalls could be tamed to produce electricity for industrial development and general supply. This is expressed, for example, in such historical statements as, "Norway is undoubtedly in a better position than any other country in the world as regards hydro-electricity"[5]. Today we have an electricity supply which is unique on a global basis, with 96 per cent of Norwegian electricity generation coming from hydro-electrical plants. We have the largest hydro-electric production in Europe, at 122 TWh in a normal year.

Petroleum exploration on the Norwegian continental shelf has given the world an important and stable supply of oil and gas and has had major economic spin-off effects for the nation. In 2007 the petroleum industry represented about a quarter of the Norwegian economy. Thanks to visionary thinking leading to the ban on production flaring of gas on the shelf in the 1970s, we have become a significant gas supplier to Europe.

The availability of a reasonable and stable energy supply has been the cornerstone of industrial development in our country, and as a consequence we have been able to combine access to natural resources in a way which has created growth and prosperity. The process industry generates considerable wealth through knowledge-based processing of forestry products, minerals, hydro-electricity, oil and gas, and represents 50 per cent of exports from mainland Norway.

So, what will the energy revolution mean for Norway and what strategic crossroads are ahead? And what role can research and innovation play?

Choices

In contributing to the energy revolution, Norway has a number of different approaches to choose from. Two scenarios are described below to illustrate possible alternative outcomes:

- Consolidation: Attempt primarily to ensure one's own energy security and efficient energy supply. Contribute to a limited extent as a supplier of energy and power to Europe by means of a few transmission cables. Ensure the efficiency of society's energy use and produce the cleanest possible power from fossil fuels.
- Expansion: Use our unique natural advantages in power production to become a global shop window for the sustainable supply of several types of energy sources to Europe and the rest of the world. Realise the vision of "the battery of Europe" and become a significant supplier of clean energy and power to Europe. Increase the export of modern energy-intensive materials based on supplies of clean energy.

The consolidation model:

In the future, Scandinavia as an energy region may have a surplus of electricity: it is possible that more will be produced than is consumed. This is connected with improved energy efficiency on the part of the consumer, possible changes in industrial structure and the implementation of the EU Renewable Energy Directive. For Norway, this involves the export of clean energy and power, approximately as we know it today. Power-intensive industry in Europe will continue to operate without strict measures for reducing carbon leakage, something which in time will probably result in a certain amount of downscaling.

The European power market will however change dramatically in coming years as regards the dynamics of the production sector. The present situation is typified by a system in which nuclear and coal-fired plants account for base load production, with gas-fired generation handling peak demand along with a certain contribution from renewable energy sources. A new situation is arising which primarily uses nuclear generation[6] as the basic source, with requirements for the complete integration of the renewable energy generated at any given time. In this situation, the entire fossil based power production system with CO_2 treatment (CCS)[7] would have to compensate for power fluctuations.

As regards consumption, it is anticipated that an increasing proportion of passenger traffic will be based on electrical power. Natural gas will also gain an increasing role in transportation systems, for example in gas-powered vessels and heavy goods vehicles, especially in the form of LNG[8] and CNG[8]. The increased consumption of electricity will place new demands on the electricity production system. Eurelectric has estimated that by 2050, demand for electricity will increase from 70 to 1600 TWh in the European transport sector alone: electricity production in the EU is currently approximately 3500 TWh/year.[9] Both controlled (hydro-electric and tidal) and uncontrollable (wind and solar) energy will dominate the supply grid. This means that fossil fuel power stations must absorb the dynamics in demand, and energy storage will become extremely important. This indicates two important areas for R&D and innovation:

- Smart, robust power grid systems
- Energy storage and improvements in the efficiency of the production system

Smart, robust power grid systems: In a system with increasing numbers of active consumers and small producers, in which energy and

[5] Thue, Lars, 2006, "Statens Kraft 1890-1947", Page 74 (The history of Statkraft) [in Norwegian]

[6] Assuming that integrated solutions are found for the utilisation, storage and containment of nuclear materials in European countries.

[7] CCS, CO_2 Capture and Storage, often referred to as CO_2 management.

[8] LNG – Liquified Natural Gas, CNG – Compressed Natural Gas

[9] Power choices, 2010, see *www.eurelectric.org/powerchoices2050*

power are suddenly phased in and out, the supply grid will be faced with new challenges. So-called "smart networks" will be needed, as well as smart metering, monitoring and control systems, facilitated by information and communication technology. Energy flow must be permitted to and from small consumers and local generators, and conditions must be created to enable more active participation in the energy markets on the part of the consumer.

Energy storage and improvements in the efficiency of the production system: There will be considerable demand for storage of energy in future energy supply systems, with as much as 20-30 per cent of production coming from uncontrollable energy sources. Increased use of pump-storage power stations clearly has potential for us. However, this places demands on environmentally-friendly operation with respect, for example, to water supplies and the cycling of fresh water in fjords. There will also be a need for investment in improving the efficiency of the existing hydro-electric power system in Norway.

The expansion model:

It may be argued that Norway should do its best to contribute to ensuring clean energy supplies to the rest of the world. Each country must contribute, based on its natural advantages with regard to resources, including expertise. Our own requirements will then become just one of a number of elements – the country will be bursting with energy!

This entails involvement in certain fields in which Norway can make a difference, and we must dare to be selective. We would like to draw attention to four areas of particular importance:

- Offshore wind power
- Environmentally-friendly expansion of hydro-electric power
- CCS (CO_2 capture and storage)
- Export of clean energy through the production of advanced materials

Offshore wind power because Europe must increase the proportion of renewable energy production. We have particularly good conditions for this in Norway as regards resources and in the operation of the research–industry–society triangle. EU's goal for 2020 includes the objective that 20 per cent of electricity supply in the EU shall be generated by wind power[10].

In Norway there is considerable potential for more hydro-electric generation: about 37 TWh/year in areas not protected from power generation developments[11]. Some of this potential can probably be made available for the production of clean energy under environmentally sound conditions.

Norway's involvement in CCS is unique and we must take care that the investments provide a broad-based return. Norway should be capable of building gas-fired power stations using CCS: we would deal with the "packaging" of the natural gas and supply clean energy. The storage of CO_2 presents considerable potential for wealth creation in Norway, and our storage capacity is important for the development of the European CCS market.

Our history in the refining of metals using clean energy has consequences in the form of, for example, the production of aluminium and silicon for use in solar cells. This role as a supplier of clean energy in the form of materials is often underestimated and must be enhanced. These are important contributions which Norway can make to the energy revolution. Improved expertise in the field of these products is an important theme in the ability to maintain global competitiveness. It is also important that Europe should find a model to provide framework conditions for this industry, so as to avoid so-called carbon leakage to other regions of the world. A possible model for dealing with this is to introduce tariffs on imports from countries which evade CO_2-related costs internally and export subsidies in connection with export to markets which do not impose adequate CO_2 penalties. This model is known as "border tax adjustment"[12, 13] and is considered by a number of economists to be an interesting approach to the issue.

The strategic role of the petroleum industry in the future is to a large extent dependent on R&D and innovation – how to combine considerations of energy supply and the environment. In the energy revolution, fossil energy sources, and in particular natural gas, are also needed. Through the introduction of CO_2 levies on emissions by means of quotas or taxes, gas will emerge as competitive as a consequence of its lower CO_2 emission per generated kilowatt-hour. With a quota price of approximately €30 per tonne of CO_2, gas-fired generation with CCS is competitive with coal-fired generation with CCS, and with increasing quota prices the advantages will generally be weighted in favour of gas. As a result of falling gas prices and expectations of higher quota prices, especially after 2013[14] we now see that gas-fired generation is being developed in Europe, while investments in coal-fired power stations are being put on hold. Quota prices and the need for load following in the energy supply are also important in this context. In other words, there is a need for investment in the sustainably improved extraction and exploitation of our petroleum resources on the continental shelf.

How to promote the energy revolution through investment in research and innovation

In a global context, most energy technologies in use today are the same as they were 50 years ago. They will become expensive, are vulnerable and lack sustainability. We need new technologies which are more efficient, more secure and sustainable. This viewpoint is supported by, among other things, the IEA , the EU's SET Plan[16] and the IPCC[17]. Energy innovation must commence now in the form of an energy revolution.

This energy revolution cannot be initiated without reinforced, long-term investment in research and innovation. A holistic strategy will

[10] *http://ec.europa.eu/energy/technology/set_plan/doc/2009_comm_investing_development_low_carbon_technologies_roadmap.pdf*

[11] Fakta 2008 Energi og vannkraftressurser i Norge (Key facts 2008: Energy and hydro-electric resources in Norway) [in Norwegian], the Norwegian Ministry of Petroleum and Energy, see *www.oed.dep.no*

[12] Jordan-Korte, Karin and Mildner, Stormey, 2008, " Climate Protection and Border Tax Adjustment: Economic Rationale and Political Pitfalls of Current U.S. Cap-and-Trade Proposals, see *www.aicgs.org/documents/facet/jordan.faceta01.pdf*

[13] Cosby, Aaron, 2008, "Border Tax Adjustment", see *www.iisd.org/pdf/2008/cph_trade_climate_border_carbon.pdf*

[14] From 2013 the EU quota system is expected to operate with quota auctions and gradual tightening of free quotas until 2020

[15] See, for example IEA – ETP 2010 and World Energy Outlook 2009

[16] SET plan; Strategic Energy Plan, see *ec.europa.eu/energy/technology/set_plan/set_plan_en.htm*

[17] IPCC, Intergovermental Panel of Climate Change, 4th assessment report, see *www.ipcc.ch/publications_and_data/ar4*

be needed to achieve this, as well as interaction between different disciplines: technology, society and economics. The EU's SET Plan indicates a need for closer connection between these elements and the linking of resources in Europe so as to deal with the major challenges. This is beginning to manifest itself, among other things through "Joint Undertakings", technological platforms, the application of Section 169 between member countries, the so-called "European Industrial Initiatives", and the establishment and application of the European Research Council (ERC).

The report "Norway – a global maritime knowledge hub" (Reve[18]) indicates two areas in which Norway can play a part on a global basis: the maritime sector and energy. The national strategy for energy is rooted in the advisory body Energi21, and that for petroleum operations in OG21[19]. The guidelines from Energi21's report "En samlende FoU-strategi for energisektoren" (An overall R&D strategy for the energy supply industry) [in Norwegian] and the broad climate policy consensus in the Norwegian parliament have given us the Centres for Environmental Friendly Energy Research(CEER) or FME (in Norwegian), dealing with the thematic fields of offshore wind energy, CCS, solar energy, hydro-electricity, bioenergy and energy use in buildings. What we now need to do is to reinforce and expand these investments into what we will refer to here as the "energy universe".

Energiunivers

According to Reve[18], the core of future innovation systems is education, research and innovation – which will, in the presence of capital, industrial association and the involvement of universities, be able to create so-called "global knowledge hubs". Norway's ambition should be to become attractive in the global context within energy and to attract human capital. We must be prepared to take chances if we are to get a return on investments and assume more than just a domestic role. The establishment of an energy universe[20] is essential if we wish to transform this potential into action. The foundation of a "national team" consisting of a close network of the strongest authorities in the disciplines of technology, social sciences and economics, along the axes of education, research and development, innovation and business development, will be a central element of this. There is a need to combine energy supply operations to achieve a critical mass, to become relevant internationally to have resources for promoting innovation, entrepreneurship and application in industry on a global basis. It is natural that NTNU and SINTEF, with their extensive laboratory facilities, should become the core of the technological part of such an energy universe. This sort of investment must be connected with new investments in infrastructure, since modern laboratories are an important prerequisite for success.

High-risk funds

Another pertinent question is whether we are promoting innovation well enough and encouraging the development of high-risk concepts – ideas of a transformative nature which involve high risk and high potential. In the United States this has been done with considerable success through the so-called ARPA-E[21]. This agency has become a breeding ground for venture creation and entrepreneurship, attracting considerable interest from private industry. ARPA-E was able to finance 1 percent of the project proposals submitted in response to the initial invitation, while 7 per cent of the projects were subsequently financed by private the business sector.

Technological pilot funding

One particular element of the innovation chain which is insufficiently stimulated in Norway is support for the financing of technological pilot projects. Except in the field of CCS, where considerable funds have been invested in Technology Centre Mongstad (TCM), investment in technological pilot projects is haphazard and more diffuse. Norwegian industry has also voiced its opinion on this, and on how to avoid the pitfalls between the development of a concept and the finished product. We propose the establishment of an appropriate scheme in Norway which can promote technological pilot projects, for example in the fields of wind power, new manufacturing methods for solar panel materials, bioenergy, and so on. In SINTEF's and NTNU's recommendations to the political parties before the last parliamentary election, we estimated this requirement to be in the region of NOK 1.3 million[22]. This will be needed to ensure the full effect of investments in research and development leading to products and returns on investments in green energy. This recommendation is in line with the initiative of the Confederation of Norwegian Business and Industry (NHO) for establishing a CO_2 fund for supporting such pilot projects[23].

Recommendations

Our recommendations for promoting the energy revolution from, for and in Norway are as follows:

- Consolidate the role of Energi21: efforts should be made to transform strategies developed in such bodies to a greater extent into active policy and to use the expertise which is generated more actively.
- In the same way, OG21 should be used actively to promote the sustainable exploitation of petroleum resources.
- Make use of our natural advantages with regard to access to clean energy to achieve a strong global position in the field of modern materials technology, based on extensive technology development and production in Norway.
- Double investments in R&D and innovation within energy.
- Establish an energy universe in Norway.
- Allocate funding for the development of new ideas for energy and climate science corresponding to the American ARPA-E, including petroleum activities.
- Allocate resources for a fund for the establishment of technological pilot projects.

[18] Reve, Torger, Norway – a global maritime knowledge hub, see *web.bi.no/forskning/papers.nsf/0/.../$FILE/2009-05-reve.pdf*
[19] OG21 – "Olje og gass i det 21 århundret" (Oil and Gas in the 21st Century) [in Norwegian]
[20] First used here in this sense
[21] ARPA-E : Advanced Research Projects Agency – Energy, see *http://arpa-e.energy.gov/*
[22] "En helhetlig satsing på klima og energi" (Aholistic approach to climate and energy) [in Norwegian], see *www.ntnu.no/info/klimasatsing-2009.pdf*
[23] NNHO's letter to Prime Minister Stoltenberg of 16 December 2008 [in Norwegian], see *www.nho.no/getfile.php/.../Finanskrisen_-_tiltak_10-12-08.pdf*