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Towards a Sustainable Energy System - A Long Term Transition Strategy

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1. Introduction and Summary

The scope and the format of this report was developed in cooperation between CICERO and the Ministry of Oil and Energy and the financial support from the ministry funded the project.

The analysis presented in this report is an attempt to evaluate the development of the energy system and what realistically can be achieved by aggressive policy initiatives and promotion of new technology to change the current trends in a more sustainable direction. The current trends are determined by the combined development objectives for the nations of the world and while each one of these objectives are justified in its own right, the sum does represent an intolerable environmental stress to the global environment as highlighted by one representative example, the potential climate destabilization and accumulation of greenhouse gases in the atmosphere.

Rather than developing in the direction of a sustainable energy system, the predominantly carbon based energy system is year by year widening the gap to a sustainable system, and in doing so makes it progressively more complicated to turn around, with a set of new objectives in mind. It is a growing international recognition that business as usual is not a sustainable option. Even with a political will to change, the current initiatives are too few and too small to have a meaningful impact, and the inertia of the current system so enormous that the transition challenge is exceeding whatever mankind ever has encountered.

The project objective is to analyze the conditions required to change the direction of development toward sustainability. With this objective in mind the instruments required to make things happen has to be focused as well as the technological options sufficiently developed to be part of a realistic strategy. In this report no attempt to include “science fiction” alternatives is made, although the very real possibility exists that “science fiction” type technologies well may be realistic alternatives from 2025 onwards.

The project addresses resource constraints and other supply/demand related issues. It is not the purpose of the project to collect information and present an updated list of other studies. However, in order to have a basis for a meaningful analysis it is obvious that authoritative documentation of other system analyses has to be studied to ensure that major conclusions from expert groups were part of the data base. The concept “realistic” can be approached in different ways. Some observers and analysts will claim that the forces determining the dynamic growth of the energy system are essentially untouchable and beyond political capacity and capability to change. The change process can only be triggered by major incidents demonstrating the need to change (i.e. Chernobyl and Three Mile Island impact on the nuclear industry). The author is of a different opinion. The knowledge base is so extensive, the technical options so attractive, the policy instruments so effective, and the public acceptance of change so mature that the only essential component lacking in a program of change is leadership.

The ambition of the report is to suggest elements of a national strategy which can be locally implemented, and also demonstrate the effective use of some policy instruments currently without international implementation experience. However, the energy policy in one country cannot be developed without examining the global energy issues and understanding both the need for change and the opportunities created by the transition to a sustainable energy system. Norway may well have an international role in the energy world, but only through effective and visionary management of its own energy strategy can this influence be translated into an international impact with the environmental concerns included. The national energy situation in Norway is unique and the constantly improving trade balance and the easy access to energy resources makes a transition towards a sustainable, non-carbon energy system extraordinarily demanding. But Norway has the financial freedom to act, and being recognized as one nation with an environmental conscience, our responsibility is to take one major step in the direction of sustainability. We are aware that the environmental concerns we are facing are global more than national. To test the ability of international cooperation in this field a strong political initiative is recommended to make a joint Scandinavian energy policy/environmental policy project capitalizing on extensive expertise also in Sweden and Denmark and with a liberalized power network serving all these countries. Another very important initiative which could be supported by the Nordic group of countries is a green tax on jet fuel, to demonstrate an international willingness to use this policy instrument on a truly international product with a very limited number of tax collectors. A 12 cent/gal tax on jet fuel could finance the entire UN operation at 8 billion US$/yr. Green taxes need to find an effective introduction to the international community and have removed the negative reputation still attached to the concept. It is worth recording that the Danes have claimed, after a numbers of years with experience, that they have not damaged their competitiveness because of green taxes. In addition they claim they have developed new export activities in the environmental area.

The main conclusions in this report can be summarized as follows:

1. Current energy trends are not sustainable. A productivity improvement for energy use equivalent to 6 GTOE/yr is required by 2020 to bring worldwide energy demand on a development path towards sustainability. Of the remaining demand New Renewable energy resources should cover 1.3 GTOE/yr in 2020 and 4.3 GTOE/yr in 2050, out of which 2.5 GTOE/yr is solar based. Carbon based energy carriers are declining in total, but natural gas is expanding its role in the supply picture for many decades.

2. Conventional oil resources are limited and without any environmental concerns for carbon based energy use, production will peak around 2030 with a subsequent rapid decline. A more ecologically oriented strategy could result in conventional oil production peaking in the first decade of the next century. It is noteworthy that there only is 20-25 years difference between peaking with so vastly different scenarios. However, in the business as usual scenario, conventional oil will be replaced by synthetic oil based on coal and oil shale/tar sand, while in the ecological scenario new renewables will be replacing conventional oil and stretching the depletion curve for conventional oil.

3. An argument is put forward in chapter 2.4 demonstrating that a fall in the oil price is not an unavoidable consequence of reduced oil demand and the introduction of green taxes. In a market where 25 MB/D is produced by a cooperative with constantly stronger position due to declining reserves, unwillingness to make producing capacity available is a high probability scenario. The price consequence could easily be a price increase up to the 30 $/B level.

4. Higher prices will be a desirable and even necessary development to encourage and accelerate higher energy productivity and development of renewable alternatives. However, remarkable progress has been recorded as to commerciality of renewable options. Wind power is a success story and may shortly be the most economic supply alternative in the whole energy field. Solar energy is coming of age and unit costs are coming down with an impressive rate. Solar energy will be the major contributor in the future energy system. Biomass will be expanded with modern technologies, but will be limited by area availability and other factors.

5. One transition challenge identified in this study is the impact of very high growth rates for the renewables in the first several decades of the transition. The energy needs to develop

the new energy systems are exceeding the energy output under certain growth conditions, thus making net contribution during the growth period negative. Since the only energy available to fuel the development of competing energies is carbon based, this phenomena will extend the fossil period.

6. The suggested Norwegian energy strategy is as follows:

A. Instruments

- Develop a price strategy/taxation strategy encouraging demand side efficiency improvements

- Introduce mandatory efficiency requirements for automobiles and appliances

- Reform building codes with visionary long term targets

B. Technology

- Develop an active program for heat pumps aiming at 10 Twh net contribution by 2010

- Develop an active wind power program aiming at 10 Twh by year 2010

C. International initiative

- Harmonization of instruments is more important than harmonizing goals

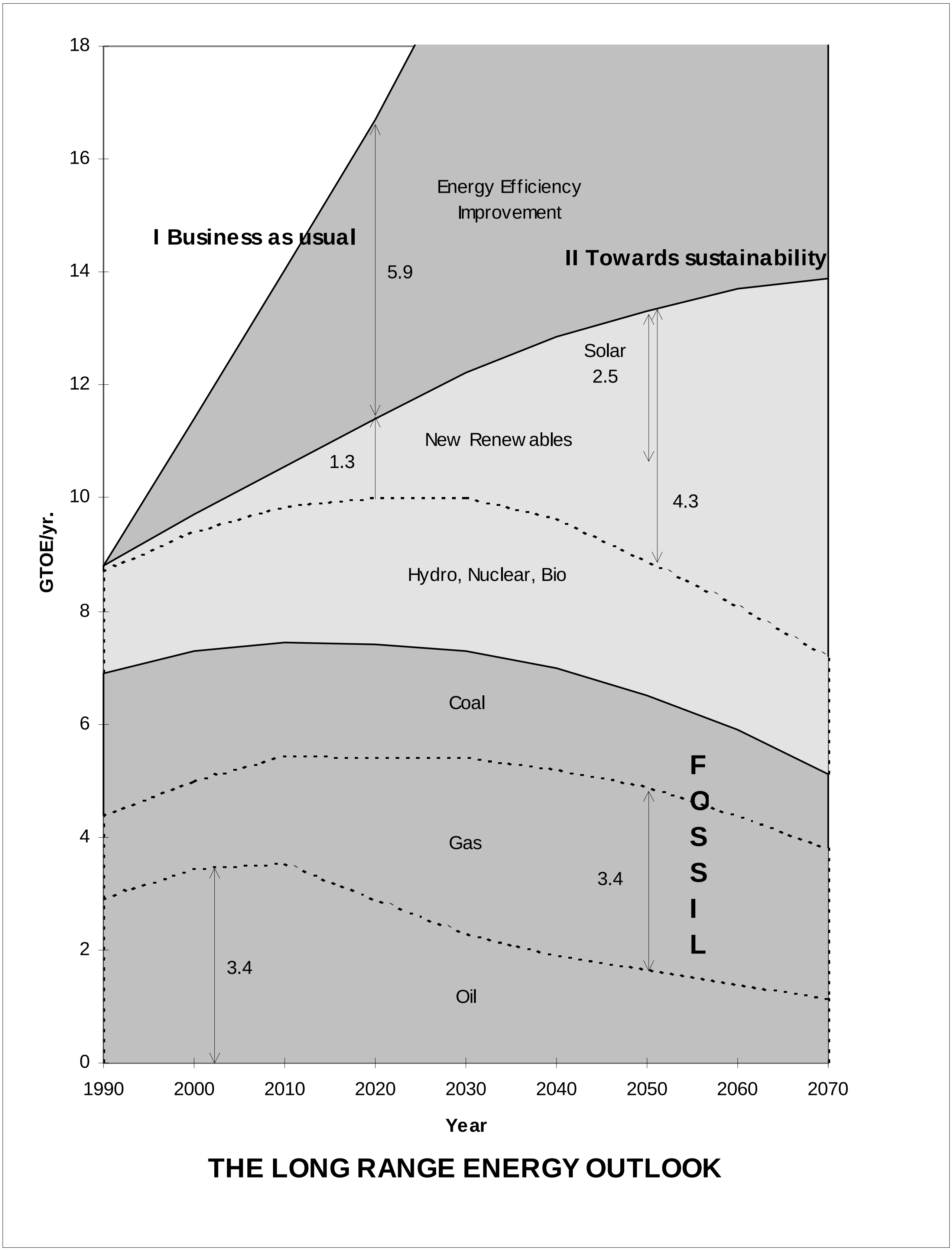
These are headlines in a national strategy aiming at stabilizing demand and introducing a new renewable alternative to the supply system. These strategies are elaborated on in the report, but not to a great deal of detail. Concrete proposals and programs could be a followup to this report.

2. The Energy Outlook and the Sustainability Challenge

2.1 Conflicting Objectives

Through history the demand for energy has followed an essentially uninterrupted growth pattern disregarding political turbulence and major events. Making energy available in sufficient quantities has been a prime political objective and of course the fundamental business idea of the energy industry. The growing demand has reflected very active development patterns including industrialization and a major expansion of the transportation sector. In addition to the growth in energy use, an even steeper growth curve has been observed for the electrification of modern societies. Economic growth and energy growth have been considered interlinked although observations exist for temporary delinking in periods of significant price changes. Higher prices for energy have a clear impact on behavior - from the kitchen to the board room. History has also consistently shown improved energy efficiency for similar tasks, clearly reflecting technology development. The energy efficiency improvement has been more impressive in periods with high prices than in periods with low prices, an observation once more emphasizing how prices in a market economy has a powerful role in stimulating efficiency. While the potential for energy efficiency improvement is very significant, modern nations have only modestly started to capture the potential systematically and through a structured approach. Although constant productivity improvement has been the trade mark of developed societies, progress has been more impressive with respect to other productive factors than energy. The most remarkable example is labor productivity. Since the cost of labor has consistently been growing and expected to continue to grow as a fundamental objective in itself, massive efforts and creativity have be channeled towards the prime challenge of labor productivity. The result has been overwhelming. This unprecedented productivity achievement has primarily been fueled by increased energy use and new technology. In a period of labor scarcity and growing cost, the priority put on labor productivity may well have been right, but not any longer. The same emphasis, commitment, willingness to invest and creative approach should now be directed towards energy efficiency, since one of the major environmental challenges is directly related to the consequences of using carbon based energy carriers. New and conflicting objectives dominate the agenda.

The amount of energy resources required by man has grown significantly over this century. In terms of oil equivalents the century started (1900) with a demand of 0.5 GTOE pr. year. In 1960 it had grown to 3.3 GTOE pr. year and reached 8.8 GTOE pr. year in 1990. The most recent extensive analysis of the global supply/demand outlook is sponsored by the World Energy Council (WEC) and the horizon for their study is year 2020. Several scenarios are provided, all reflecting a continued increase in energy demand. As a matter of fact most governments and international agencies assume that oil and coal will continue to run the worlds automobiles, factories, homes and powerplants - supplemented by natural gas and nuclear power. According to most experts, any other kind of energy future would be impossibly expensive and impractical. WEC’s minimum demand case is based also on a different mix of carriers resulting in carbon emissions essentially at 1990 level in 2020. The energy community concludes that even with maximum policy support, stabilization of emissions of CO_2 is what at best can be achieved and according to the energy industry not very likely to occur.



18
16
14
12
10
8
6
4
2
0
GTOE/yr.
I Business as usual
Energy Efficiency Improvement
5.9
II Towards sustainability
Solar
2.5
New Renewables
1.3
4.3
Hydro, Nuclear, Bio
Coal
F O S S I L
Gas
3.4
3.4
Oil
1990
2000
2010
2020
2030
2040
2050
2060
2070
Year
THE LONG RANGE ENERGY OUTLOOK

Figure 1

The UN intergovernmental Panel of Climate Change (IPCC) efforts dealing with potential climate destabilization has signaled that stabilization of emissions is totally insufficient in order to avoid unacceptable risk to the climate system. According to IPCC the obvious objective should be to stabilize **concentrations** of greenhouse gasses (GHG) in the atmosphere. In order to achieve this a 60% reduction in emissions will be required. Since it is generally recognized that the developing world at this stage of development cannot be constrained with too ambitious emission targets, the industrial world have to take a 75% emission cut in order to achieve stabilization of atmospheric GHG concentrations.

Never ever has our civilization been confronted with so dramatically conflicting objectives put forward by so authoritative bodies. These objectives are clearly incompatible!

The political challenge is to develop an energy transition strategy minimizing institutional instability and disruption, and ensuring that development objectives in the developing world are met. The sustainability challenge is thus an unprecedented challenge.

2.2 Selecting Scenarios

For the purpose of this study two scenarios are selected already supported by extensive volumes of data. Those are (see fig 1)

I BUSINESS AS USUAL ［WEC A］

II TOWARDS SUSTAINABILITY ［WEC C］

For this report scenarios are extended well beyond 2020. The “Business-as-usual” scenario is representing an unsustainable world and is used only to demonstrate the importance of changing energy priorities on a global scale and also the magnitude of the task. The “Towards sustainability” scenario is identifying two major challenges.

1. Capturing an energy efficiency improvement potential of 5.9 GTOE/yr. by 2020 equivalent to 84% of 1990 fossil energy consumption.

2. Develop “new renewables” to contribute 1.3 GTOE/yr. in 2020 and 4.3 GTOE/yr. in 2050, out of which solar should contribute ~2.5 GTOE/yr. in 2050.

One important dynamic aspect often overlooked in transition periods in the energy system is the energy requirements necessary to fuel high growth rates in the incoming energy system(s). This phenomena has been demonstrated fairly recently in the nuclear introduction to the French energy system. Through a period of more than 10 years with 20% growth rates, more energy was required to build components and elements of the nuclear system for new reactors than the system itself produced. The net system contribution was negative until growth rates tapered off.

In the massive transition of decarbonization of the energy system, high growth rates for extensive periods will be required to develop “new” renewable alternatives to levels significantly contributing to the global energy balance. Over the next century this will be a net new renewable contribution growing from essentially nothing at the start to some 7 GTOE/yr. at the end or an amount equivalent to the entire fossil fuel contribution at the moment. In the graph an unidentified amount of fossil energy is required **to keep very high growth rates** towards the middle of the next century. This crucial point will be covered in more detail later and is particularly important when energy pay-back time is high (as for instance is currently the case for photovoltaic (solar).

The current assessment of investments labeled for the energy sector for the period 1990 to 2020 [Business as usual] is 30 000 billion US$ at 1992 prices, most of which is expected to go into conventional carbon based energy development. Unless a major portion of these investments are channeled into new renewables, the transition period will be delayed and extended.

The following assumptions need to be documented and is describing the “Towards sustainability” scenario.

1. Total global energy demand in 2020 is 11.3 GTOE and 13.3 GTOE in 2050.

2. New renewables at 1.3 GTOE in 2020 composed as follows: 42% modern biomass, 26% solar, 16% wind power and 16% other. Solar is projected to grow to 2.5 GTOE in 2050, i.e. **tenfold** increase over 30 years with PV being 65% and thermal solar 35%

3. No new nuclear installations and no replacements when existing facilities reach retirement age. Sum of nuclear, large hydro and traditional biomass reduced from 2.6 in 2020 to 2.3 GTOE in 2050.

4. Total fossil energy peaking in 2020 at 7.5 GTOE. Conventional oil peaking in 2003 at 3.4 GTOE, coal peaking in 2000 at 2.3 GTOE and gas peaking in 2040 at 3.0 GTOE. Conventional oil at 1.0 GTOE in 2070. Coal, including synthetics, oil shale and tar sand, 1.6 GTOE in 2050 with technology developed for CO_2 deposition from stationary coal combustion units.

5. Energy efficiency improvement strategy described in chapter 3

The key strategic considerations in energy use is 1) liquid petroleum reserved for transportation, 2) remaining large scale stationary coal combustion with CO_2 recovery, 3) gas for direct firing and new renewable plus “old” renewable for power generation.

2.3 The Resource Outlook

A resource is not a static concept, as the physical availability is a function of price and technological development. Conventional oil is an excellent example since substantial volumes are normally left in the reservoirs at conventional price levels when reported “empty”. Reservoir characteristics, pressure maintenance profiles etc. will determine if 40% of the molecules originally in place should remain in the reservoir when production is discontinued as is often the case today. This “leftovers” is a well recognized source of energy if higher prices or expectation of higher prices will permit the application of secondary or tertiary recovery technology.

A higher market price level could be a reflection of either real or artificial resource scarcity caused by one or several market actor’s unwillingness to use productive capacity (i.e. OPEC). Real resource scarcity may not necessarily imply physical lack of molecules, but rather lack of molecules produceble at prevailing prices. It may also reflect underinvestment in producing capacity if the price level does not generate sufficient return on investment.

The most effective demonstration of the market forces in the history of energy production is the supply/demand upheaval in the first half of the 1970’s (often referred to as OPECI). The supply crisis was in reality predictable since low prices over an extended period (10 years +) had stimulated world-wide oil demand increases and discouraged investments. The price consequences were text-book responses to the growing resource scarcity skillfully orchestrated by the production co-operative. The most important learning experience from this well known event was that the best cures against high prices are high prices.

The purpose of this historical reminder is to emphasize the price/resource relationship prior to the discussion of depletion profiles. When prices do increase it is a predictable consequence of resource scarcity thus creating the necessary economic forces to solve the problem itself. But not only will the remaining higher cost hydrocarbon molecules offer continuing business opportunities, but other energy alternatives will become competitive, - and even more important: Efficiency improvements can be justified for demand side corrections. Not only price itself, but price expectations are of critical importance. In the early 1980's the prevailing price outlook called for oil prices in the range from 70 to 90 $/B in year 2000, and with these expectations heavy investments in solar energy and coal liquefaction were made. A few years later in the second half of the 1980's the conventional view was a long lasting relatively low oil price profile effectively halting investments in higher-cost alternatives for an indefinite period. The energy industry has clearly demonstrated a surprising lack of ability to predict price developments in any direction, a fact which should be kept in mind when the longer term outlook is analyzed, because it is in this perspective the depletion dynamics should be viewed. Higher prices will encourage exploration, but will also trigger consumer reactions and possibly government reactions if trade balances are affected substantially.

The current outlook adds up proven oil reserves globally (as of end 1995) to about 138GT, and adds another 60GT of the much more speculative resource category "remaining to be identified". Geologists characterize the sum as ultimate recoverable oil, and it is obvious that assessments of the final category easily can vary. The points to be made in this analysis are the following. 1: extending further the resource base will most likely require higher prices due to geographical inaccessibility, high extraction costs or both. 2: a classical phenomena exists in the global resource extraction industry that a substantial portion of the resource base is very low cost resources indeed, and the concentration of income on few hands is causing economic distortions which should be recognized.

The purpose of this section is to identify a time range for conventional oil production to peak and subsequently decline. This analysis is critical because declining contribution from one source in a global energy outlook, with increasing demand, require even more increasing availability of alternatives, fossil or other. The static resource horizon for conventional oil is year 2035. In a dynamic perspective as the [Business-as-usual] scenario is representing, the proven reserves are depleted in 2026. If we do add on the remaining unidentified reserves the production life can be extended 11 years at constant 2026 producing capacity (se figure 2).

These calculations provide nothing but some reference numbers facilitating the logic for the depletion profile for conventional oil. Based on the assumption that the ultimate recoverable oil volume is described by the static calculations, the area under the depletion profile must correspond to the area under the static representation (see figure 2).

In accordance with scenario II (Towards Sustainability), the conventional oil production is assumed to peak around 2003 at 3.4 GT/yr. and subsequently follow a downward trend reflecting another key assumption that oil will not deliberately be left in the ground. Production will rather be stretched out in time until physical resources are exhausted or more costly than other preferred alternatives, either due to scarcity or to taxation of environmental impact.

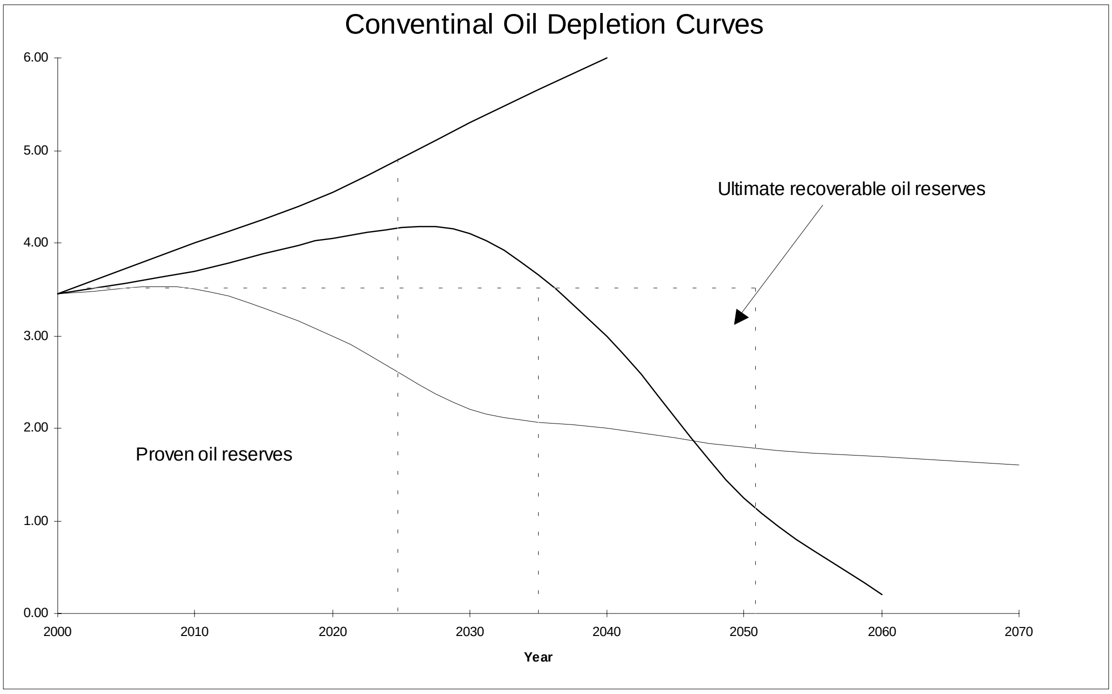


Figure 2

The time frame for peaking of global oil production is of critical importance in the overall strategic assessment of energy coverage in the next century. From a resource point of view this is unlikely to happen much before 2010 and with moderate growth rates unlikely to happen very much later than 2030. Without policy support the peaking will in a liberalized market economy tend to be delayed towards the end of the period with a subsequent much more rapid decline. This latter production profile is obviously more vulnerable to external events since a number of production countries will have their reservoirs in decline and therefore productions will be concentrated in a few countries. It is also likely that peaking in this case will reflect resource scarcity and thus be accompanied by significant price increases. In order to encourage early peaking, government-controlled instruments will have to be mobilized. The benefits of early peaking is in addition to the obvious environmental advantage, also a reduced risk for runaway prices in a volatile market, political instability and associated problems.

The depletion issues are all demonstrated by the US situation. The US is clearly the most mature oil production region in the world. Production peaked several years ago, the potential for new significant discoveries is limited, and declining production is significantly increasing import dependence and vulnerability if oil prices should increase. The US gasoline consumption is exceeding Saudi Arabia crude oil production and jet fuel consumption is exceeding crude oil production in Kuwait. With mature producing regions, additional exploration efforts is unlikely to change substantially the static resource horizon of some 10 years. This study is based on an assumption that conventional oil essentially is depleted in the US within the time frame of 2015-2020. A consequence of this assumption is that the policy response of the US government to their energy outlook will be of critical importance. The US has very significant resources of oil shale and coal, and has the technology to convert these resources to synthetic oil with qualities non-distinguishable from conventional oil products. However, in order for commercial production to take off, energy price levels need to be significantly higher than the average price level for the last 10 years, probable around 30 $/BOE. The US, with an oil consumption rate of 17 MB/D, appears unable - and should be unwilling - to accept a dependence on world energy markets for its entire need of liquid fuels. Its options are many, with the close-to-commercial supply alternatives wind, biomass and solar and demand side management as the alternatives with the greatest potential. It appears unlikely that the US should not vigorously pursue options reducing their oil import dependency. At the moment the non-carbon supply alternatives and energy efficiency improvements are not only competitive with carbon based alternatives, but do represent an alternative environmental strategy. It is therefore a probable US strategy that they on supply security / national security arguments will develop domestic options most of which could be environmentally very attractive. With the US developing an environmentally attractive energy agenda, although triggered by resource constrains rather than environmental logic, they may as well utilize the strategic outlook to capture what could be interpreted as an environmental initiative. It may well happen that the US could take a very much more aggressive role in the climate negotiations for reducing emissions of CO_2. The US is a region using 25 % of the worlds conventional oil and will face limitations a few decades ahead of the rest of the world. The US may well turn this situation into an opportunity capitalizing on the vast technological capacity of that nation.

2.4 Energy Price Developments

In the likely event of a gradual international acceptance of reduced emissions of CO_2, the instruments to achieve this objective need to be further developed. A carbon-differentiated tax is a highly probable outcome, but prior to this a gradual phase-out of coal subsidies has to be considered throughout the world. The green tax initiative failed a few years ago, and when reintroduced the whole consumer/producer dialogue has to be activated. When introduced, the intention is reduced carbon emissions and if properly designed the concept will make coal less competitive, and thus the biggest demand impact can be expected for coal. Part of the reduced coal demand will be substituted by oil and this substitution will partly offset the tax related demand loss. If the additional taxation is sufficiently high, the total impact on emissions will come quickly, as suggested by theory. The key issue is how the oil market price will react to slipping demand. In some producing countries such as Norway the prevailing theory is, that active initiatives to reduce carbon emissions will be particularly unattractive due to what is referred to as the welfare loss. This is a national economic loss reflecting declining market price for oil.

This analysis concludes that two other developments are more likely. The first is based on the producer logic when considering taxation. If the producers do observe credible efforts to introduce a crude oil tax in the OECD area, it can be expected that production cuts or unwillingness to increase oil production when demand is increasing takes place. With corresponding increasing market price, the governments suggesting a tax increase is discouraged from implementation. The fact that OPEC did not respond to earlier efforts, can easily be explained by the lack of credibility in the EU initiative, and that OPEC basically wanted to keep world markets at reasonable price levels to stimulate demand. The only reason to let market price increase would be to capture the benefits of a tax increase which under all circumstances would have lifted oil prices and discouraged consumption. Thus the fundamental rationality of the producing system will be to increase government take when a price increase is inevitable. The producers have the tools in their hands to make that happen and thus keep the additional income in their pockets.

The second producer action will be an organised unwillingness to make all supplies available and thus avoid prices reestablishing at a lower level. The effectiveness of the OPEC structure to manage this situation will be called upon. It is probably easier for OPEC to control production levels when several producing actors see diminishing reserves.

The critical assumption is whether crude oil production can be reduced with oil reserves in place without oil prices collapsing. Scenario II is assuming that this is possible. Consuming governments are prepared to reduce emissions and determined to use taxation for that purpose. Producing governments recognise the determination, and take their decisions on the basis that falling market prices will be compensated by taxes anyway. If these are the circumstances, OPEC cooperation is clearly stimulated and even non-OPEC producers probably would not reject entirely the idea of cooperation since the alternatives would have a potential profound impact on the national economies in the timeframe 2005-2010. Oil prices will be managed to a higher level, and 30$/B is a level where most of the desired response actions will be triggered on the supply side as well as on the demand side.

2.5 Technical Options in Energy Supplies

The technologies are at hand to initiate an historic energy transition, but formidable barriers remain. The largest obstacles are political and institutional. The rules of the present energy economy were established to favor systems now in place. Not surprisingly, the rules were created decades ago, when the central issue was how to expand fossil fuel use rapidly. Hastening the transition to a sustainable energy economy requires a major shift in priorities - a shift that existing institutions and industries may find threatening.

Appropriate policies to stimulate cooperation between researchers, manufacturers and government should be developed. Those may vary from region to region, but should generally include favorable tax policies, and power purchase agreements, which would create a flow of revenues to fund further developments. Such incentives often provoke questions of economic efficiency, but if these reflect the external social and environmental costs not represented sufficiently in current energy market prices, then they may offer the necessary encouragement to develop renewable energy sources.

In spite of insufficient incentives generally, several nations have seen the opportunities as well as the potential of some of the new renewable options and their efforts have resulted in rapid expansion of the most promising technologies for the most promising alternatives. Annual growth rates in the 20-30% range have been recorded over the last several years. From a modest starting point the total contribution is still not very impressive, but with a doubling time from 3 to 4 years, the dynamic force of development will soon create visible results. A description of the most important renewable alternatives follows.

2.5.1 Wind Power

Wind power is now the worlds fastest growing energy source. Global wind power generating capacity rose to 4900 MW at the end of 1995, up from 3700 MW one year earlier, an increase of 32%. Since 1990, wind power has risen 150%, representing an annual growth rate of 20% in spite of some setbacks in the US wind programs. Although it still generates less than 1% of the world electricity, the steady technological advance of wind power suggests that it could become an important energy source for a number of nations within a decade. An interesting example to demonstrate the point is the state of Schleswig-Holstein in Germany, where wind power went from providing less than 1% of the electricity in 1990 to 8% in 1995. Similarly, in Denmark more than 4000 windmills provide some 5% of current electricity demand. Denmark is a pioneer nation in wind energy for own needs as well as equipment supplier for the world market. Denmark officially plans for wind energy to contribute 40% of power demand in 2030.

The main reason for the rapid growth and impressive penetration in some markets is clearly the fact that wind power is becoming a commercial alternative and competitive with carbon based alternatives even without environmental taxation reflecting the fossil alternatives environmental disadvantage. As a matter of fact the US institute for research on electricity

(EPRI) claimed already in 1993 it was good reasons to expect that in the next 10-12 years wind will generate the cheapest electricity from any resource.

The global wind energy potential is roughly five times current global electricity use, but even if restricting it to about 10 000 TWh annually, or equivalent to the 1987 global electricity demand, it should be only moderately difficult to recover 10% of that potential or 1000 TWh (220 MTOE) within year 2020. On a global basis this will mean 5% wind power of total electricity or only equivalent to the wind power penetration in the Danish energy market today. With the current cost outlook, the accumulated investments in wind power through 2020 will be around 400 billion US$ (90 $) thus creating a significant worldwide market.

Because of the variability in wind speed, wind power is often regarded as a power source that has little capacity value. In reality, however, the contribution of wind power to the total electricity system can be significant. The capacity credit can be as high as 80% in some countries. Norway has an excellent interaction potential with its hydro electric power system and can in fact "store" wind in the hydroelectric water reservoirs by baseloading wind power. The implementation of wind power, even below a penetration level of 10% will not only be determined by an economic comparison between marginal costs of electricity production and wind power generating costs. Other aspects will influence the realization of wind power as well. Some factors can be translated into constraints that limit the penetration of wind in a specific country. Environmental factors could potentially be such a constraint. The major environmental concern is related to noise. And the acoustic emission is composed of a mechanical and a aerodynamic part, each one dominating the noise problem at different sized wind turbines. It has been a remarkable improvement in the noise problem over the last few years.

It is beyond doubt that the market potential is very significant. Further technological improvement can clearly be expected and thus further reducing unit costs. It is also encouraging to record that wind power developments are picking up pace also in the developing nations. The leader so far is India and the growth in wind contribution has all happened since India changed its policy on open access to the power grid for wind power. More than 30 MW had been installed by the middle of 1996. Wind power is technologically relatively simple, at least conceptually, but modern technology has a major responsibility for the remarkable progress, materials technology, electronic control equipment and micro siting capability. Denmark is demonstrating visionary thinking and political skills in their wind power strategy. They have also pioneered private ownership models which facilitate the siting process. In the US location issues have received a new positive attention since wind power in some regions is offering additional income to rural farmers and fishermen. An example often quoted is the hectare of Kansas prairie that now yields $400 worth of wheat annually which also could produce $10.000,- to $25.000,- worth of wind generated electricity. And unlike wheat, wind power does not preclude the land from being used simultaneously for other purposes.

In summary wind is the most immediately available renewable alternative with only minor disadvantages of environmental nature. The industry promoting its growth is modern, hi-tech, and visionary, and by year 2020 the energy contribution from this source should easily be 1000 TWh on a worldwide basis. A further doubling can be expected before 2030.

The Norwegian situation is even more favorable. Due to extraordinarily favorable interaction with the hydroelectric system and a long coastline facing a windy ocean, the potential is at least equivalent to the hydroelectric system. With the world market as a long term growth market, the opportunities for a high tech mechanical industry is enormous.

2.5.2 Solar energy

For a number of reasons it is reasonable to assume that solar energy will be the dominant contributor in the global man made energy system in 100 years, and already by 2050 the contribution from solar could exceed the maximum conventional oil contribution (3.4 GTOE/yr.). The applications of solar energy are quite diverse, including direct thermal (both active and passive systems), electric power generation using thermodynamic cycles, and direct conversion to electricity with photo voltaic (PV) systems. Storage is relatively inexpensive for thermal systems, providing some decoupling of the resource from the time of end use.

Over the last 20 years some dramatic gains in cost effectiveness have been achieved. A few of these applications are now fully commercial, but further improvements in cost, achievable through mass production and technical development, is needed for widespread application. Today thermal low-temperature systems are competitive, particularly when integrated in buildings during construction, PV systems are generally not competitive although in remote locations without grid connections the picture is different.

Solar architecture can make the building structure itself into a solar energy collection system and provide a distribution and storage system able to provide thermal comfort and daylighting for occupants. When combining the principles of thermal solar collection with those of ventilation and insulation, modern dwellings have the potential of a stepwise improvement in energy efficiency.

The most important, - and technically most demanding - solar option is PV. It was originally developed for space applications and the technology transforms light directly into electricity. PV is expected to further improve its effectiveness and thus improve its competitiveness.

It is necessary to dispel the commonly held notion that solar energy is too diffuse to harness and requires too much land. For solar-thermal and PV-schemes, land requirements are comparatively small. While they are greater than those of coal fired plants (excluding the mining area), they are considerably less than those of hydroelectric schemes. They typically require only 1/50 to 1/20 of the land needed for hydro schemes. There is also much flexibility in the choice of sites; the technology is modular and the schemes can be located in arid areas with low population densities and need not compete with agriculture or forests or people for land. They would also yield very high levels of energy per hectare (e.g. the yield of a solar farm could be over 500 TOE per hectare per year, assuming 10% conversion efficiencies. This is about 100 times that of biomass energy crops).

Solar intensity is of course varying over the surface of the earth. The peak solar intensity is 1 KW/m^2 while the world average is 0.2 KW/m^2. This means that for instance in the US a 1000 MW peak generation station operating at 20% efficiency would require some 5 km^2. More impressive is the fact that only 1% of the US land area is required to supply the US electric power need. A similar calculation has been made with respect to the global energy need and 2-3% of the global desert area is sufficient to meet those needs. Putting it differently, in an advanced country the land requirement per person for electricity is 0.1 Acre while the land for farming and food production per person is 10 times that area or 1 Acre.

While the first and second generation technologies already have made unit cost coming down substantially and efficiencies correspondingly up, the potential for further cost reductions is significant. High volume manufacturing will take unit costs down and it is expected that even PV will be competitive with fossil fuels for standard energy applications before 2010. In order to achieve the high volume output required for turning the PV technology commercial the PV industry either will need public assistance or rely on strategic investments in a potentially huge growth industry. Developing this industry into a competitive commercial operation represents all the classical development dilemmas. Where the initiatives will come remains to be seen, but a number of important actors are moving. Japan is demonstrating the most impressive strategy and have plans to increase PV capacity to 400 MW or more than the rest of the world combined. Japans "Solar Development Initiative" includes installing solar PV roofs on 100 000 buildings and could offer the quantum jump required to make solar a real alternative for grand scale application. The leading western based company in the solar field is ENRON with an impressive strategy for growth in the coming years. It can be expected that the most future oriented oil companies will mobilize resources in the field and widen the strategic approach and become energy companies. The growth potential is enormous and a multibillion dollar industry could emerge faster than any industrial activity in the past except for the IT (information technology) industry. In the Nordic area Neste Advance Power System (NAPS) appear to be the leading company with extensive cooperation with Japanese operators.

The institutional structure to deal with the many initiatives is also expanding rapidly. Last autumn a World Solar Summit (WSS) was called and an integrated approach was discussed including an International Solar Convention, a World Solar Charter, a World Solar Fund and a World Solar Plan of Action. It is probable that a firm commitment to mobilize international financial resource to insure implementation of a World Solar Program is more efficient than the creation of a new fund with the high management costs involved and the risk of merely draining the money from other initiatives to support renewables.

The long-term solar potential is very significant. The upper limit of the contribution possible for solar energy varies with the framework used for the evaluation. The centralized approach concludes that solar energy can supply all of the worlds needs, as long as we act like one engineering system. The distributed approach concludes that solar energy along with conservation and the sustainable use of other renewable resources can supply essentially all the energy that the world really needs. The incremental approach concludes that solar energy, if it could overcome a variety of constraints, could penetrate our existing energy market to about the 40% level. The sectoral results show little penetration in the transportation sector and penetration to about half in the industrial sector. One important thing to note is that each of these approaches concludes that solar energy could eventually supply a very significant fraction of the total energy, and much more than most people would expect.

It has to be emphasized that for a number of applications, in particular in the transportation sector, widespread use of solar has to be associated with hydrogen as an energy carrier and a storage option. Hydrogen generation from solar energy and water deserves particular attention since this would be a fuel that is inexhaustible and also environmentally benign. When hydrogen is burned, either directly for thermal or mechanical end-uses, or in fuel cells for electricity generation, only water is released. Since hydrogen can be used both for transport and long-term energy storage, it could displace our dependence on fossil fuels. Concentrated sunlight could drive thermochemical reactions or high temperature electrolysis for the generation of solar hydrogen. Solar hydrogen can also be obtained from photo electrochemical systems, that yield hydrogen and oxygen directly from water. One recent development in this field that may deserve particular attention mimics the role of chlorophyll in photosynthesis by means of titanium dioxide particles coated with a ruthenium-based photosensitive dye.

In summary solar energy has a resource base which makes it a logical long term work horse for the global energy system. The characteristics of solar is its intermitted nature which could be overcome with a global transport infrastructure tying the global deserts together. With a global electric grid, there will uninterrupted be sun on collectors and the optimization issue will be whether to invest in extra generation capacity or in conversion and storage capacity.

With hydrogen as a carrier for non stationary applications the main components of a future energy system appears to fall in place.

2.5.3 Biomass

Unlike PV and solar-thermal schemes, which capture the sun directly, biomass converts the carbon dioxide in the atmosphere into sugars and then releases the carbon dioxide and energy when burned. It can be used directly to produce electricity - as in numerous cogeneration plants found in agriculture regions, using the wastes from agro-industries - or it can be transformed to produce alcohol and gaseous fuel.

On the electricity side, a promising new development is the use of biomass gasification methods in electric powerplant cycles to take advantage of the high efficiencies of combined cycle technologies. Emission control technologies are available to eliminate particulates and reduce nitrous oxides. And if the biomass is produced in a sustainable way, the net emissions of carbon dioxides are negative on account of the enlarged standing stocks of biomass.

However, the biomass option is land intensive. The maximum theoretical conversion efficiency via photosynthesis to useful biomass energy is 6.7% for crops such as maize and sugarcane and 3.3% for rice, wheat and trees. In practice the rate is much lower at 0.2 to 3.0%. Thus it is often rightly argued that the technology is best used, when it is to be used at all, in areas where the crops can serve other purposes too. Further, a mixture of species is recommended, even if this raises costs, to avoid the dangers of the monoculture syndrome.

The availability of sufficient high-quality land is probably the biggest cloud hanging over the plans of biomass energy advocates. The above mentioned average of 1% when harnessing solar electricity through biomass should be compared with the 10-15% efficiency for solar cells. Producing ethanol from sugar cane in Brazil today is roughly eight time more land-intensive than using photo voltaics to produce an equivalent amount of electricity. Biomass energy does, however, have the advantage of being in a form that is relatively easy to store,- a characteristics not shared by most other renewable energy resources.

Still, in a world with limited land capable of producing food, it is a big question mark how much land can be devoted to energy crops. If in the future energy crops and food will compete for land, it is feared that those buying energy have a higher purchasing power than those buying food. This may result in fuel receiving priority over food even if people are starving.

In a national strategy with emphasis on biomass, a hot-water distribution system is essential. Such an infrastructure provides also a valuable flexibility not provided by electric cables. The two nations with the most effective biomass strategy is Finland and Austria. In Finland 15% of the energy use is provided by biomass and in Austria a very extensive system of 11000 district heating schemes have been installed all supplied by biomass.

It is extremely difficult to assess the technological prospects of bioenergy conversion processes. There is the split between the modern and traditional uses of bioenergy, the industrialized and non-industrialized, developed and developing economies. Certain processes such as direct combustion, anaerobic digestion and gasification could be regarded as mature, proven bioenergy technologies, in both the developed and developing economy contexts, although there is obvious room for improvement of all three.

Increased yield is the key to providing larger feedstocks. Currently the yield is 3-7 t/ha/yr. In some areas it has reached 35/t/ha/yr. And it is claimed that in most forests trees grow at rates far below their natural potential.

The critical question is how rapidly the exploitation of biomass for energy purposes can be expanded. Several countries offer clues as to the possible expansion rates. In the US biomass based electricity production has expanded 36 times over the last 10 years up to 9000 MW. In Brazil alcohol production has expanded 20 times over 12 years. In favorable circumstances biomass power generation could be very significant given the vast quantities of existing forestry and agriculture residue - over 2GT/yr. worldwide.

In Norway it has been estimated that energy from biomass can be increased by 10 TWh over a period of 10-12 years within a price range of 15-40 øre/kWh.

2.6 Demand Side Management

The threat of serious, unpredictable and probably irreversible changes in the earth's climate has moved from conjecture via suspicion to near certainty, and denial is now confined to the uninformed. Global warming is not a natural, - and unavoidable -, result of normal, optimal economic activity. Rather it is an artifact of the economic inefficient use of resources, especially energy. Advanced technologies for resource efficiency, and proven ways to implement them, can now support present or greatly expanded worldwide economic activity at much lower energy input. And most importantly, the policies, methods and mechanisms to achieve the results are reliant not on dirigiste regulatory intervention, but on the intelligent application of market forces.

Most of the best energy-saving technologies, - especially the super efficient lights, motors, appliances and other end-use devices that save electricity - are supplanted by still better models approximately annually. Todays best electricity-saving technologies can save twice as much as five years ago, but at only one-third of the real cost.

To demonstrate the potential some examples are tabulated below.

	Unit	**Todays Average**	**Todays Best Technology**	**Advanced Technology**
Automobile	l gasoline/10km	0.9-1.4	0.5	0.23-0.36
Home heating	kJ heating pr m^2 pr degree day	120-160	50	15-18
Refrigerator/ Freezer	kWh/l/yr.	3.4	1.3-1.7	0.7

The technological potential is enormous. However, the mechanisms to achieve the savings are subject to considerable debate. Among the instruments, the political most sensitive, but by far most powerful instrument, is the energy prices. It has not been properly understood that the pricing mechanism is not a fiscal instrument transferring financial resources from the private sector to the public sector. The so called green tax strategy is supposed to be revenue neutral, i.e. energy taxes are compensated by other tax reductions. Higher prices are justified by a technical assessment of social and environmental costs not properly reflected in the market price. Higher prices will obviously reduce demand, encourage substitution, stimulate efficiency improvements and increase supplies. If properly managed the price option is very effective, but extremely unpopular. The revenue neutrality is very important and if communicated skillfully should dampen the political opposition to green taxes.

Another tool so far underutilized is the mandatory performance standards. For cars and domestic equipment appliances the potential is particularly interesting. The instrument is only functioning on the margin through new purchase, but since average lifetime for cars and refrigerators are less than 15 years, the replacement profile is predictable and the efficiency gain is very significant.

A combination of prices and mandatory performance standards should be designed to achieve a total worldwide efficiency gain of 5.9 GTOE/yr. by 2020 relative to the "Business as usual" projection.

3. Elements of a Global Energy Strategy

The transition Challenge

The purpose of this chapter is not to suggest a global energy strategy, but rather describe some elements of a desirable global strategy and assess the implications for Norway. Contrary to widely held beliefs, the future for energy is very much more a matter of choice than of destiny. Energy futures compatible with the achievement of a sustainable world are within reach. The choices require visionary political leadership, but the rewards are significant, - not only in terms of environmental quality and reduced risk for climate destabilization, but also because the sustainable energy system is less vulnerable to geopolitical turbulence and price volatility.

In the past the primary goal of energy planning has been to make energy supply expansion possible. This approach has been a formidable engineering challenge which has been met in an impressive way, although the environmental costs have gradually become more visible.

A crucial redirection of attention is under way and is essential if a sustainable energy system is the new objective. The modified approach can be described as an end-use oriented strategy where efficiency in the application of energy resources is of fundamental importance. It is clearly possible to formulate energy strategies which are not only compatible with, but even contribute to the solution of a number of major global problems including environmental degradation. It is in addition entirely consistent with the highest priority concern in modern industrialized countries, namely productivity improvement. Efficient use of resources has consistently been a prime target for business and industry. Due to the increasing cost of manpower and the expected continuation of this cost increase, manpower productivity has received the maximum attention. Since the supply oriented energy strategy has been so successful, real cost of energy has been, - except for some excursions of relatively short duration -, constant or declining. The level of energy prices has been insufficient to promote the same productivity culture so dominant when it comes to manpower resource management.

Opportunities for energy efficiency improvement have been identified in all sectors. It appears technically and economically feasible by the year 2020 to **reduce** the average final energy use per capita in industrialized countries by about 50 % and even so, if desirable, increasing GDP per capita by a wide margin. Energy price reform is a prerequisite for the development of a sustainable energy system, and a sustainable energy system has to be based on maximum efficiency in the use of energy resources for whichever purpose. The technologies are at hand to initiate the historic energy transition, in particular on the demand side. However, there is one counteractive force often overlooked. When energy is saved the operator also saves money. When this money is recycled back into the economy, the energy consequences of the additional purchases have to be subtracted from the energy saved in the first place. It is obvious that a more efficient energy economy is a desired strategy and the demand side improvements deserves the maximum and immediate attention. Currently the total worldwide efforts to improve energy efficiency are relative modest, but spectacular exemptions have been recorded in many nations.

The instruments available for the process change are few, but have demonstrated their effectiveness. The most effective is clearly price affecting immediately all energy use. But this instrument is also politically very sensitive. Higher prices is of course the prime response to scarcity in a market economy and provide encouragement to reduce the scarcity; this could be in the form of expanded supplies, substitution, savings and alternate supplies.

Equally effective, but slower to act, are mandatory performance requirements. This instrument acts on the margin and thus will require the gradual replacement of the old, inefficient equipment over the life cycle of this particular commodity. On the other hand, the efficiency improvement is predictable within rather narrow margins. In the real world we are not faced with a choice between the two instruments, but rather how they most effectively can be combined.

The political challenge is to activate the instruments since this will require a fairly general appreciation of the need to reduce the carbon based energy carriers. At the moment this awareness is not sufficiently developed internationally to ensure introduction of effective policy measures, but the progress in the climate negotiations this year may suggest that a worldwide agreement to act could be established.

From the graph showing the two main scenarios (fig. 1) the difference between the "Business-as-Usual", demand curve and the "Towards Sustainability" demand curve is the volume of energy saved by more efficient use of energy. By 2020 the efficiency improvement considered realistically achievable with maximum policy support is the equivalent of 5.9 GTOE per year. This can only be achieved if all nations and all sectors raise energy efficiency much closer to the top of their respective priority lists.

While pursuing efficiency improvement as a prime objective, non-carbon supply alternatives will have to receive much more attention than currently is the case. It was previously referred to the total accumulated investment needs in the 1990-2020 period of 30 000 billion US$ (1992 $), most of which is currently planned for hydrocarbon developments. With these large investments channeled into carbon based energy carriers, the transition towards sustainability will be considerably delayed. Therefore the emphasis on new renewables must be followed by a substantial expansion in investments in the renewable alternatives. A preliminary assessment has been made of accumulated investment needs to reach the 1.3 GTOE/yr indicated in 2020. For solar, wind, geothermal, biomass and small hydro combined, 2 400 billion US$ (1992 $) will be required.

Although these numbers are significant, the feasibility of the strategy can be judged from the fraction it represents of total activity. In general terms about 5 % of GDP is spent on energy, and the projected investment in new renewables in 2020 is only 0.5 % of the global GDP for the same year. The accumulated investments for the entire 1990-2020 period is estimated at 0.25 % of the cumulative GDP for the same period. Provided that the manufacturing of necessary components and modules can be expanded fast enough, the financial capacity to achieve these targets is available.

Comparing the estimate of investments needed to develop the first 1.3 gigaton of oil equivalent renewables with investments needed for the same amount of conventional fossil fuels, we find that significantly higher investment will be required to develop the renewable capacity. Compared to the 2 400 billion US$ (1992 $) for new renewables, only 930 billion US$ (1992 $) will be needed for fossil energy. However, the investment comparison is only a partial story since fuel cost is not included. It is very likely that the fuel cost comparison on average will favor the renewable alternatives by a very wide margin. A very rough estimate indicate a 2-300 billion US$ annual "fuel" price differential in favor of new renewables.

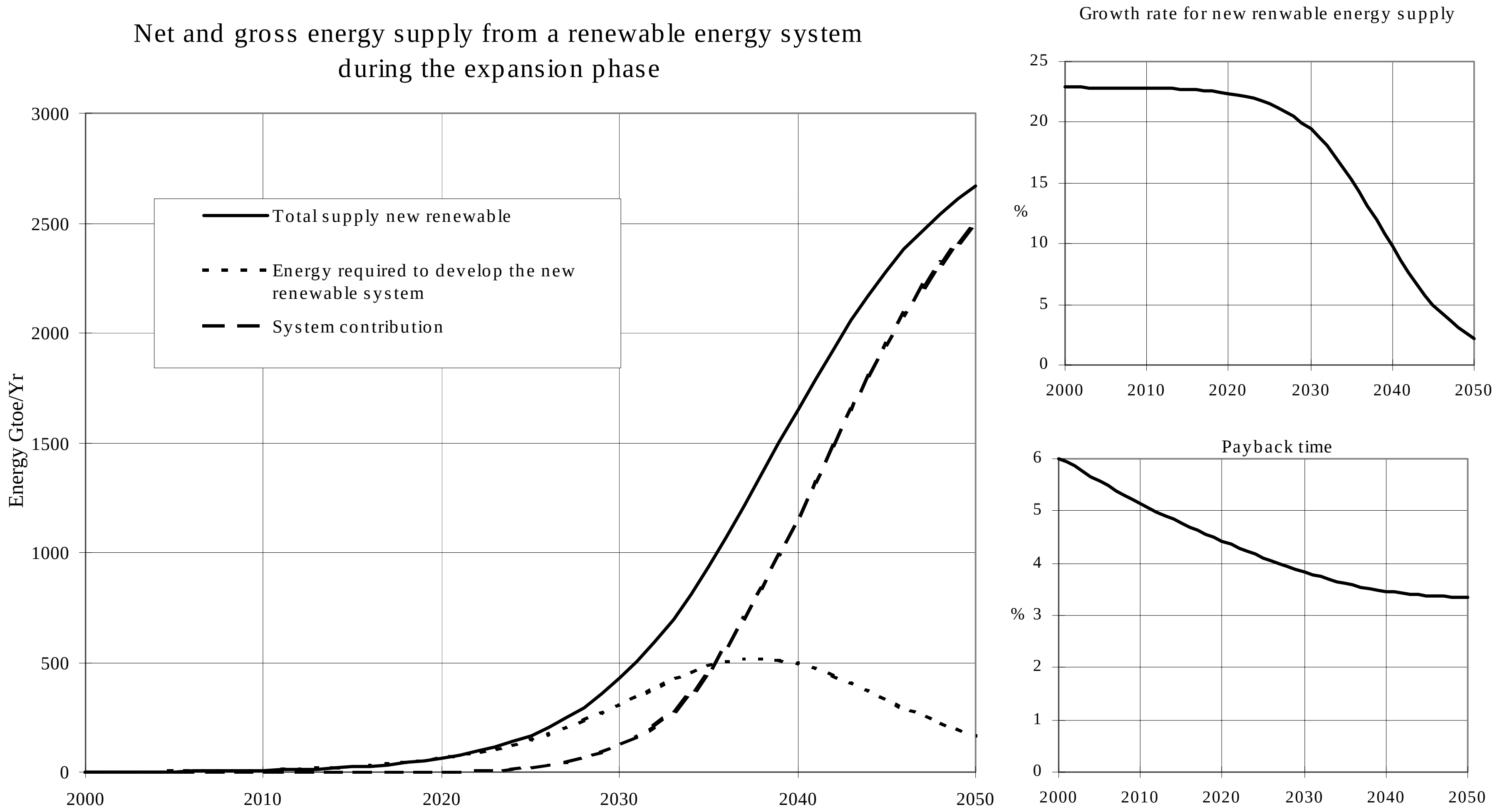
The transition challenge is primarily to manage growth and avoid constraints in the total sequence of components needed when building up capacity. The dynamics of high growth activities is worth noting. With 23 % annual growth, 3 years will be required to double the output. Starting with 1 it will take 10 doublings to expand the output to 1 000. Thus if starting with 1 mill t/yr equivalent capacity of wind energy in 30 years it could be 1 billion t/yr with 23 % annual growth. This is a well-known demonstration of the power of exponential growth at high rates. What is even more remarkable is that 2/3 of the 30 years will be required to generate 13 % of the capacity. Or in other words: significant lead time is required to be in a position to “explode” in a high growth rate scenario.

Another phenomena which should receive attention is the difference between net and gross contribution from a new energy system on a high growth development path. This has been observed in the French nuclear program over an extended period with 20 % + growth rates. In the growth period the net contribution from the nuclear program was negative since all generated energy was used to expand the system. The break-even growth rate for nuclear was around 25 % per year and the real net contribution from the system only came when the program growth rates dropped off.

The foreseen rapid expansion of the solar energy system, - in particular in PV-, could present a similar delay in net system contribution. As a matter of fact, the high growth expansion of the solar PV system can only be fuelled by traditional fossil alternatives and the net contribution will rapidly grow when the growth rate tapers off. A numerical example is shown in fig. 3 for solar electricity production with a growth profile suggested. The energy payback time is shown starting with 6 years in 2000 and declining to 4 in 2027 as the experience factor impacts the technical efficiency. It is noteworthy that in order to reach 2.5 GTOE/yr net solar PV contribution in 2050, “other” energy, - in reality fossil energy-, was required in amounts up to 0.5 GTOE/yr in the program period to fuel the growth of the system.

The transition challenge therefore is to start early in developing the new-renewables, in order to be in a position to make a grand scale contribution by the middle of the next century. A delay in active program development now cannot be subsequently compensated by accelerating program growth due to energy needs to expand the system itself more rapidly.

In summary, a major shift away from carbon based energy carriers to a sustainable energy system based on renewable alternatives will require considerable time and priority attention. In spite of maximum realistic efforts to introduce energy efficient technology, it appears unavoidable that total energy requirements will continue to grow although at a slower rate. In order to reduce carbon emissions, the renewable energy system has to be expanded with maximum efforts resulting in carbon based energy peaking in 2020 at a production level only modestly above the 1990 level.



Net and gross energy supply from a renewable energy system
during the expansion phase
Energy Gtoe/Yr
3000
2500
2000
1500
1000
500
0
2000
2010
2020
2030
2040
2050
Total supply new renewable
Energy required to develop the new renewable system
System contribution
Growth rate for new renwable energy supply
%
25
20
15
10
5
0
Payback time
6
5
4
3
2
1

Figure 3

4. The Norwegian Energy Situation

The Norwegian energy situation is unique and has been unique most of this century with abundantly available energy at low to moderate prices. Norway has a dual energy carrier system with hydroelectricity as a dominant resource for domestic consumption and with oil covering the remaining demand. Natural gas has no domestic role in spite of vast resources and significant export volumes. To put Norway into an international context the following figures are important

Norwegian population as % of European population	1 %
Norwegian GDP as % of European GDP	2 %
Norwegian primary energy consumption as % European primary energy demand	3 %
Norwegian production of renewable energy as % of Europe	25 %
Norwegian oil/natural gas production as % of greater European oil/natural gas production	32 %

In words, Norway is a small, rich and energy hungry nation with a major role in the region as an energy supplier. Not only is Norway producing 32 % of Europe's oil and gas production, but an equally impressive 16 % of the regions need for those hydrocarbons, - and the number will continue to grow.

The increasing emphasis on Greenhouse Gas Emission (GHG) and the concern for a possible manmade climate destabilization has resulted in progress in the climate convention negotiations, and a commitment to stabilize and possibly reduce emissions in the OECD area is highly probable. The projected growth in Norwegian emissions is probably exceeding what will be accepted by the international community even if the concept of differentiated commitments is agreed to. Norway most likely will have to develop strategies to reduce GHG emissions both within a short term and a long term time horizon. With the accumulation of financial resources due to hydrocarbon exports, the total national capacity to spend money is growing fast. With a correlation between economic activity/growth and energy requirements, the energy future is characterized by growth in demand unless active policy steps are taken to avoid this development.

It is generally recognized that growing demand for energy create a growing supply system, and there are few supply options without negative impact on the environment. Even a GHG free hydroelectric system has more and more visibly ruined the scenic beauty of Norwegian landscapes and with 2/3 of the potential developed, the environmental consequences are approaching an intolerable level. The period of hydroelectric development is rapidly coming to an end. The capacity of the power system is determined by rainfall and storage capacity for water and the variability between the maximum capacity and minimum capacity is approximately 20 % of average system capacity. In order to secure firm supplies under all weather conditions, a cooperative interaction with a thermal power generation system is essential. The Norwegian system dynamics are not well understood. Since the system is not an isolated system, but connected via an extensive network of cables to the North European power grid, it is essential to understand the incremental system impact of plus/minus demand in Norway. Since hydroelectricity not is a marginal coverage step, the marginal effect of demand variations has to be found outside Norway. And since rational logic calls for baseloading of the most efficient modern power generation capacity, the marginal source of electricity in a managed system is the least efficient thermal capacity and that is most probably coal fired capacity. In other words when additional power requirements are identified in Norway, the power supply will either be less export in a surplus situation or more import in a deficit situation. In both cases the power supply in theory is thermo-generated. This model is of course theoretical and short term imperfections or price motivated strategies could cause deviations from theory, but it should not be permitted to assume that water is running over the dams and thus offering marginal capacity at essentially no cost.

4.1 Energy Demand Stabilization

In modern history there has been a political objective to stabilize electricity consumption. In the 1970's all political parties had in their programs a stated objective of stable power requirements from 1990. Without a program to remove the causes for energy growth, the stabilization target was only wishful thinking. Furthermore it was not properly understood which cross section of the national energy flow diagram should be stabilized. A substitution of electric energy needs with for instants oil could help stabilize electricity demand, but result in higher oil demand and GHG emissions. Electricity demand could also be reduced by reducing exports of high energy products like metals, without any (at best) overall reduction of global electricity needs if the world demand for metal was constant. In a complex economy transferring manufacturing to other locations solves few problems if any, and the modern growing awareness should question the real need for metal rather than pushing manufacturing around.

A final dilemma often overlooked or underestimated in the private end-use sector may partially explaining the lack of effectiveness in energy efficiency improvement efforts. When saving energy either through deliberate non-use decisions or through installation of more energy efficient equipment, he or she also saves money which subsequently is used to purchase something. The energy requirements tied to the purchase, and financed by energy savings in the first step, must be debited the original saving. This effect is particularly significant when the saving is a highly taxed energy product like gasoline since the energy saving is relatively small compared with the money saving. The energy impact of spending money on traveling, products, services or even education and hospitalization needs to be understood to develop a proper strategy for reducing energy demand.

The objective of reducing, - or stabilizing -, energy demand is becoming constantly more important and probably has political support if a balanced strategy could be developed. The early elements of such a strategy will be dominated by efficiency improvements, but the efficiency improvements will hide the forces causing continued energy growth. The fundamental growth issue will, however, reemerge when the efficiency potential is used up. The efficiency strategy is thus only buying time for a more fundamental approach to demand stabilization involving changes in the consumer culture and other restructuring steps of modern public and private life.

The instruments to make things happen are relatively few and well tested, such as

1. Prices
2. Performance standards
3. Regulations

Price is by far the most powerful signal for behavior changes in our modern market economy, and it is impossible to reach any reasonable objective in this field without using this instrument. Using the instrument implies assistance to a pure supply/demand market reaction. The concept of green taxation is crucial in this process and the technicalities of the concept is well described in extensive documentation. There are two particularly important communication issues which need to be stressed in the public debate. The first being the concept of **correct** prices. The market of course establish a price which by many supporter of free markets are deemed as a correct price reflecting demand developments and supply constraints. However, if the ecological realities are not properly reflected, then the market needs help to reestablish a new equilibrium of supply sources, and consumption patterns. It is a well established practice of discouraging consumption by taxation, but the prime objective has so far been more of a fiscal nature than seeking lasting demand reductions.

That leads to the second communication issue which so far has been ignored by the public due to lack of credibility of the tax collection system, namely revenue neutrality. Increased energy prices are not supposed to increase government income, but has to be compensated by visible cuts in other revenue sources resulting in income neutrality for a representative target consumer. Since the purpose of the reform is reduced energy consumption, it is obvious that those using more energy than average will be harder hit in the restructuring process, but there must be a political will and determination to make this happen, and an acceptance that it is impossible to change without changing.

Energy pricing policy is critical for any strategy, and its effectiveness on behavior can be demonstrated by inspecting the Danish electricity price level and the corresponding response from consumers.

The second instrument is performance standards. The technology to use energy more effectively has been developed and demonstrated. But the new more efficient technology has a long introduction period since it is only affecting on the margin through the renewals of equipment. Performance standards are forcing more energy efficient technology into the market by establishing mandatory requirements with a forward schedule for introduction. In Norway it is a feasible strategy to require mileage efficiency for imported cars, electric efficiency for the bulk commodities in electric appliances like refrigerators, freezers, washing machines and dishwashers, and finally electric efficiency for lighting. This instrument can be used in addition to price even if the proponents of the price instrument will claim that the energy efficient equipment will automatically be in higher demand in a high price situation.

The third instrument is regulation (in principle identical to performance standards) and that applies primarily to the residential housing sector and other buildings where a tougher buildings code will encourage more energy efficient building practice. The potential for saving is vast, and the normal economic justification is destroyed by the long life of the investment and the lack of appreciation for future income in a discounted cash flow logic.

In the offshore sector very ambitions target have been established and recommended through the MILJØSOK report from December 1996.

Demand side management is more complex than supply side management primarily due to the vast number of decision makers and “project managers”. By reviewing a number of energy efficient technologies in a number of fields this report will conclude that there is one particular technology which deserves to be given very special attention, **the heat pump technology**. The thermo dynamic principles on which the heat pumps are based have been known for a very long time. The heat pumps use the high quality of electricity (the exergi) to provide heating or cooling with target temperatures around 18-20 ^{0}C with significantly less energy input than conventional electric resistance heating. In Norway there exist some 19 000 heat pumps providing 3 TWh heating for 1 TWh electricity input. In Sweden the number of heat pumps are around 300 000, and the difference in emphasis on this remarkable technology between Sweden and Norway is demonstrated by the two neighbor cities Halden and Strömstad where the climate conditions should be comparable. In Strömstad the heat pumps are a main component in the energy structure, in Halden they are essentially unknown.

The obvious explanation for the lack of interest in Norway is low electricity prices. Higher prices will clearly stimulate large scale introduction. Several outstanding examples can serve as encouragement for public buildings and particular reference is made to hotel Alexandra in Loen where annually 800 tons CO_2 is eliminated due to heat pump installations. In Norway the total heating requirement is estimated at 60 TWh, 40 TWh provided by electricity, 10 TWh by biomass (wood) and 10 TWh by heating oil. The potential saving within a 45 øre/kWh price level is 20 TWh and the heat pump strategy is thus the single most important technology step identified so far.

4.2 Is a Sustainable Norwegian Energy System Achievable ?

Based on the previous chapter there is a significant potential for more efficient use of energy and thus for reduced energy demand.

On the supply side several options can be identified meeting the sustainability criteria. This report considers the hydroelectric development option essentially closed, but some highgrading of existing installations and developing of a limited number of non-controversial projects could give a total average productive capacity of the hydroelectric system of 125 TWh. This level has been introduced as a reasonable target for hydro capacity by former minister on environment Rolf Hansen and gained wide acceptance in the political system at the time, and still has a good acceptance among the environmental groups.

Increased emphasis on modern biomass could expand this option over 15 years to 7-10 TWh. However. the most important supply side option, currently only modestly developed, is wind power. Wind power has rapidly become competitive and technological improvements are being reported continually. This technology obviously will benefit from entering a higher energy-price market, but international expert judgments referred to previously has concluded that wind power shortly could become the most economically attractive option of any resource. It is of critical importance to emphasize that wind power has a high capacity value in the Norwegian power system, since the interaction with hydro permits “storing” wind in the hydro reservoirs. The potential contribution over the next 15-20 years could add up to 15 TWh.

A sustainable energy system in Norway is therefor achievable. The total renewable contribution by 2020 to the power system could be 150 TWh, consisting of **125** Twh Hydro 15 TWh wind and 10 TWh modern biomass. This will give significant export capacity and still permit reducing GHG’s by at least 10 %. From 2020 onwards Norway could benefit from international progress with respect to solar. However priority should be given to low temperature building technology rather than PV, although PV would be a logical industrial challenge connected with hydrogen manufacturing and storage as export opportunities.

4.3 The Transition Strategy

A transition strategy will have to be based on very clear objectives with respect to future GHG emissions and energy intensity. The objectives should not only reflect the growing awareness that business as usual is not a sustainable option, but also reflect the challenge of sustainability itself and the commitment to changing course over the next 10 years consistent with Agenda 21 guidance. To avoid crash programs in the future, a well designed early-start strategy will meet the objective with minimum resources and without institutional breakdown. Pioneer countries will demonstrate what can be done and show the way, and their initiative will also provide business opportunities. Norway has been, and still is considered as, a pioneering country for hydro electricity. Similarly Denmark is now taking an international lead in wind power, Austria with a national network of 11 000 biomass heating centrals is taking a lead in this sector and Japan will now fight for leadership in the solar segment. The local energy situation will determine the urgency of the national program and the Norwegian challenge will be to create a national sense of urgency in spite of overwhelming availability of energy resources.

The Transition Strategy can be subdivided in 3 components:

1. Instruments and policies

2. Priority alternatives on the supply and demand side

3. Interaction with the international system

With respect to instruments green taxation policies have to be developed to send more appropriate price signals to all energy users. It is also recommended to establish mandatory energy efficiency standards for automobiles, electric appliances using more than 1000KWh/yr and lighting in public buildings and on public roads. The automobile example is instructive to demonstrate the potential reductions over one to two lifecycles. For example assume a base case with gradual efficiency improvement in gasoline consumption without any extraordinary price or performance initiatives (see figure 4). It is then suggested that all imported cars will have to meet 0.7 l/10 km from 1998 and 0.6 l/10 km from 2000. From 2005 the performance requirement is 0.4 l/10 km and 0.3 from 2010. The number of cars are assumed to grow, but the mileage is assumed constant, since more second cars compensate for more miles on the first car. The calculations are based on 7 % annual replacement rate and the curves shows gasoline consumption being reduced by 50 % in 2018. The example demonstrates that the approach is powerful, is feasible and that it shows leadership.

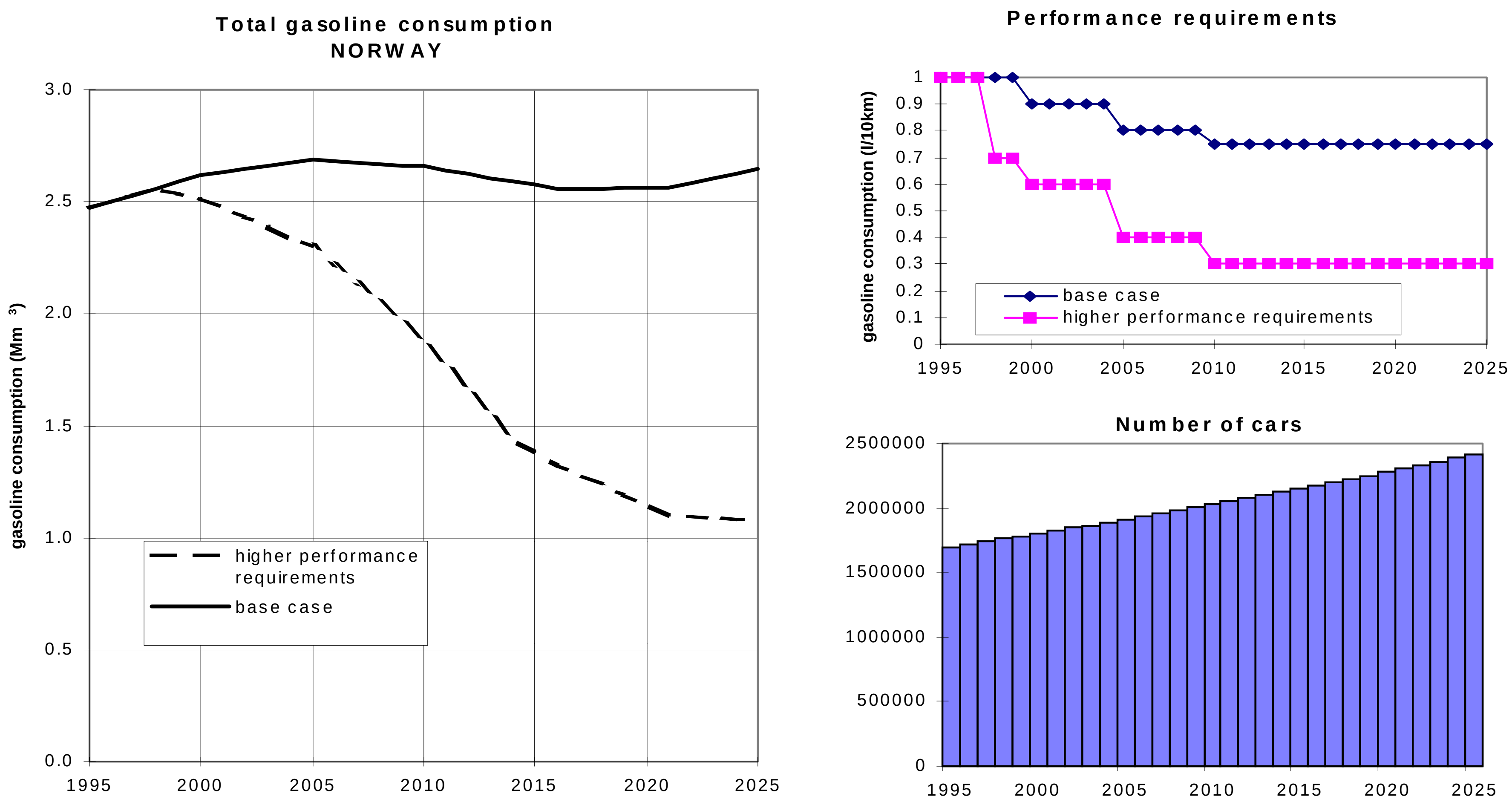
It is also recommended to start as soon as practical to modify building codes aiming at higher energy efficiency in the residential sector. Since the residential infrastructure will remain in place for 50-100 years, the efficiency targets must be visionary.

The mobilization of new technology or acceleration of existing under-utilized technology should concentrate on two initiatives initially, with a combined potential of 35 TWh in 10-20 years. The first is HEAT PUMPS where resources equivalent to a major supply initiative should be mobilized and all public building should be retrofitted for heat pump application. A significant expansion of private installations should be encouraged and a realistic development program should be established to recover 10 TWh by 2010.

The other initiative should concentrate on wind power with a target of 10 TWh additional capacity by 2010. Private ownership should be permitted to facilitate easy location of units. A commercial cooperation with Danish vendors is encouraged.

With respect to the third strategy component on interaction with the international system, the prime issue is that harmonization of instruments is more important than harmonization of targets, goals and milestones.

The strategy is concentrating on few initiatives but, will, with effective management, signal that the process change has started. With sufficient resources allocated, the result could be impressive.



Total gasoline consumption
NORWAY
gasoline consumption (Mm 3)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1995
2000
2005
2010
2015
2020
2025
higher performance requirements
base case
Performance requirements
gasoline consumption (l/10km)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
base case
higher performance requirements
Number of cars
2500000
2000000
1500000
1000000
500000
0

Figure 4

5. References

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