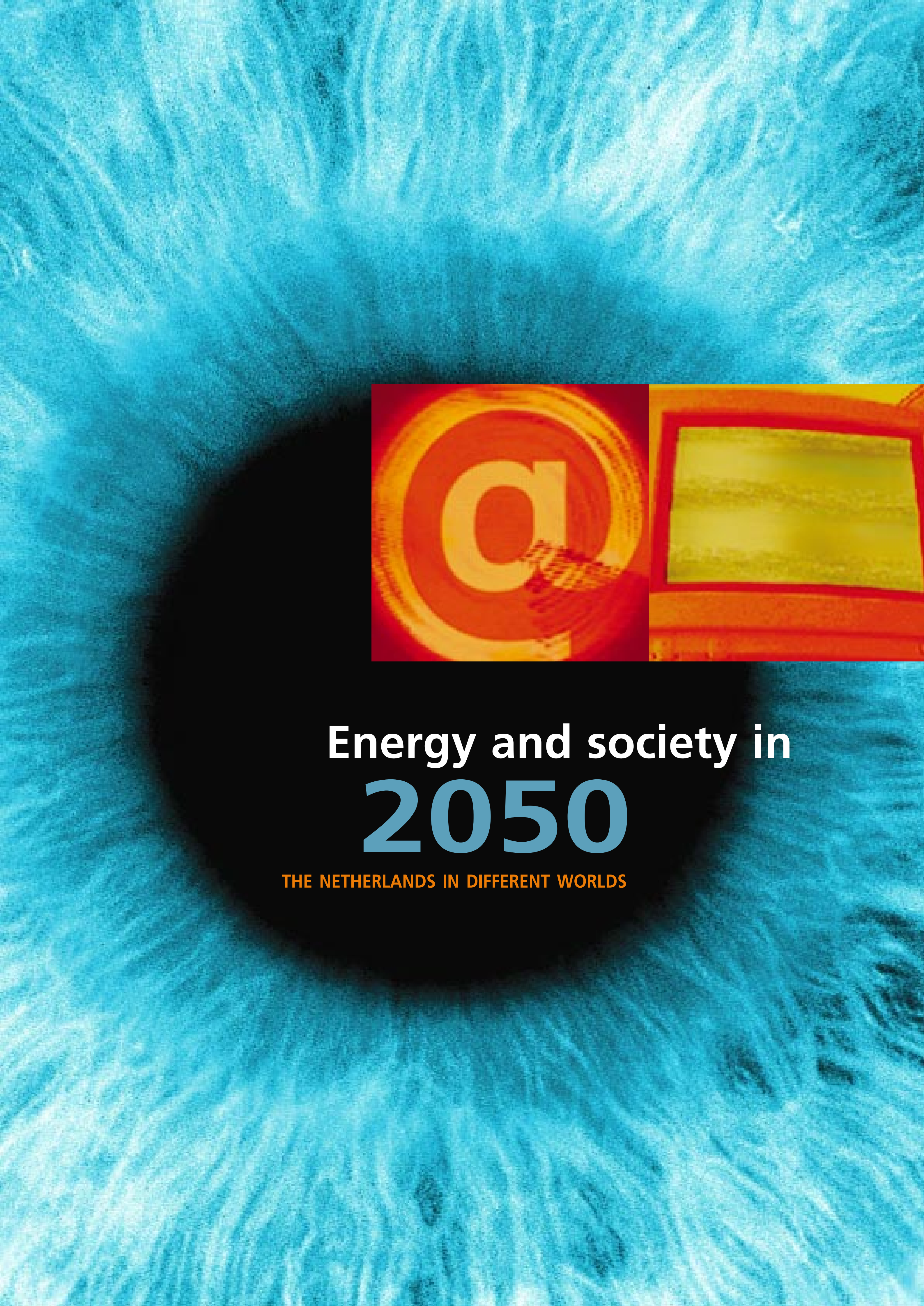
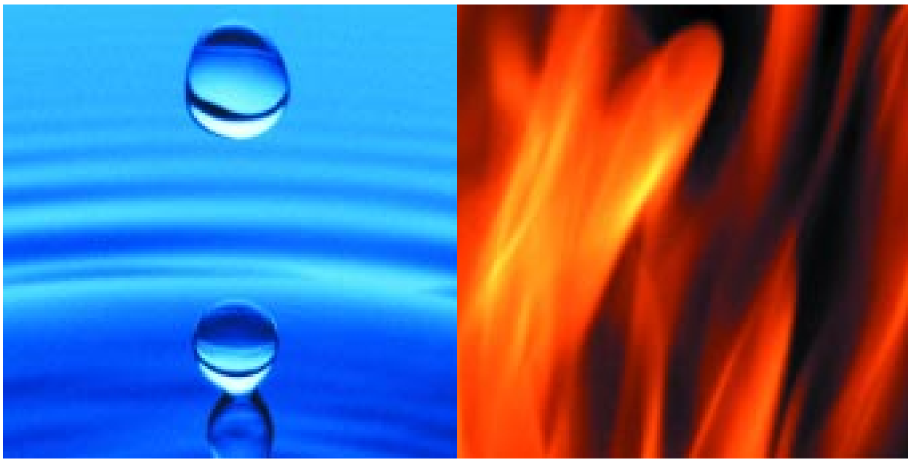


# Energy and society in 2050

## THE NETHERLANDS IN DIFFERENT WORLDS

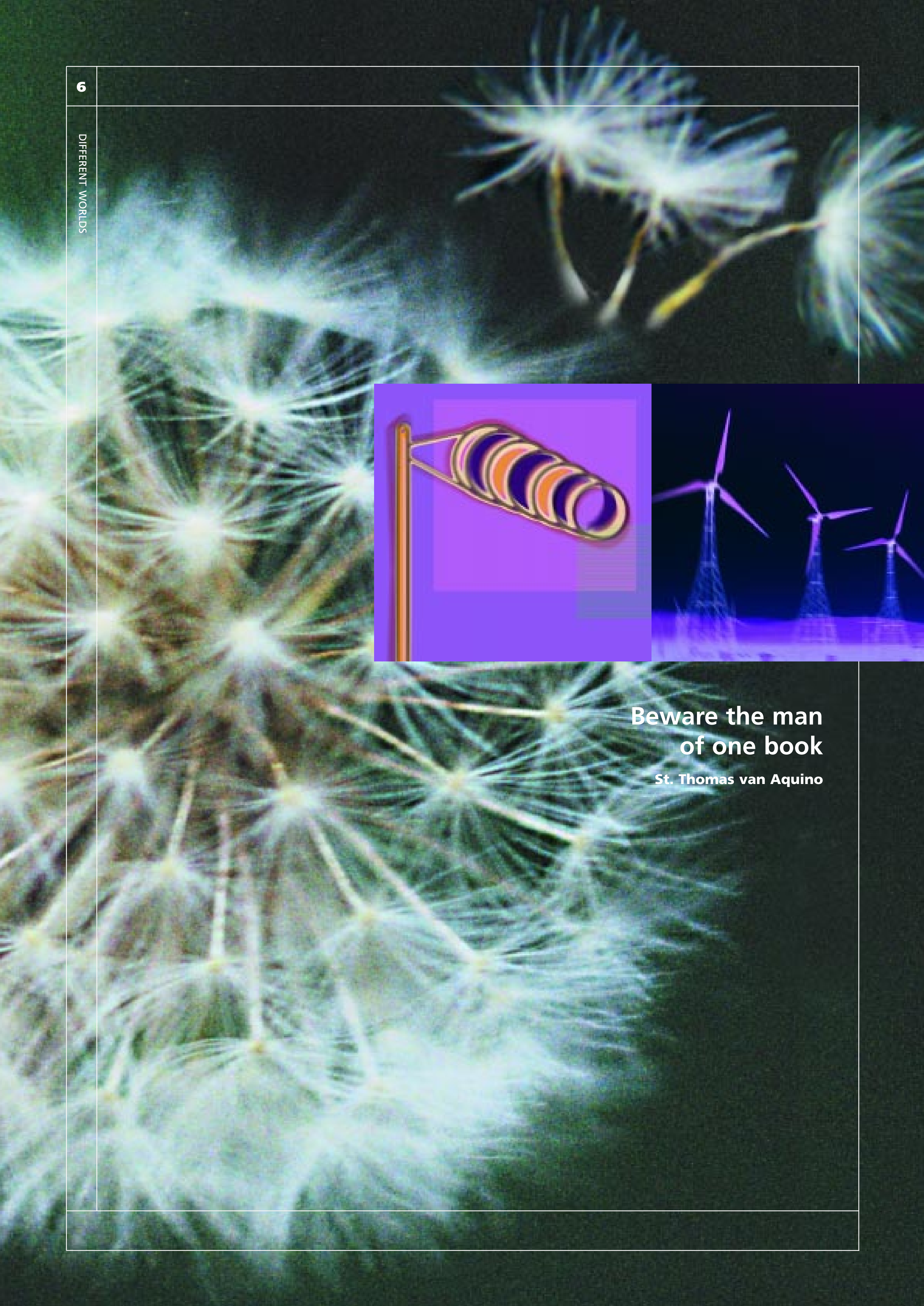


# Energy and society in 2050

THE NETHERLANDS IN DIFFERENT WORLDS

*6 december 2000*

# Contents



## Beware the man of one book

**St. Thomas van Aquino**

# 1 Different worlds

**Introduction**

**The Ministry of Economic Affairs' project Long-Term Outlook for the Energy Supply (LTVE) is intended to inspire and evoke discussion about the Netherlands' energy supply around the year 2050.**

**The report is in two parts. The first part is the Ministry of Economic Affairs' view of potential developments, together with a judgement based on current quality criteria. Annex 1 provides an underpinning of this view on the basis of global trends derived from currently available studies. Annex 2 presents an assessment of the impact of these trends and developments on the energy supply of Western Europe and the Netherlands. The Ministry of Economic Affairs will determine what policy response is required to these findings on the basis of this report.**

Why a new forecast?
- Investment decisions
- Sustainability
- Research and development

There are a number of reasons why the Ministry of Economic Affairs believes it is important to start shaping ideas now about the energy supply of our children and grandchildren. First of all, our generation has to make the right investments in the infrastructure for the energy supply. Western Europe and the Netherlands currently have an energy system which makes good use of the available energy resources and adequately meets the wishes of consumers. But this system will have to be adapted and upgraded if it is also to meet the wishes of future consumers. In order to achieve this, we need an idea of what consumers of the future will want and of the context in which the energy system will function: the energy market, the economy, institutions, quality of the environment, technology, social norms and values. This latter aspect could be particularly relevant in the long term.

*Example: there are energy systems which can achieve greater cost benefits through a steady increase in scale (power stations, pipelines, windmills), but there are also energy systems which offer advantages to consumers precisely because of their small scale (fuel cells, micropower of small-scale combined heat and power, solar photovoltaics (PV)). The future ratios of the two types of technology depends on whether consumers will value financial advantages over aspects such as small-scale application and autonomy.*

A second reason for formulating a long-term outlook for energy supply, and one which is at least as important to the Ministry of Economic Affairs, is the desire for sustainability. As the Brundtland Commission defines it ('Our Common Future', 1987), "sustainability" presents our generation with the task of meeting our needs in a socially acceptable way without compromising the ability of future generations to meet their own needs.
Such sustainable development calls for the interaction of economics and technology within the proper social context; if policy is to contribute to this, it is important

to investigate the potential context. This leads to the question of which technology can be applied now and in the future in order to achieve the desired sustainability. With this in mind, a vision of the future energy supply is important for the implementation of an R&D strategy.

### Certainties and uncertainties

The energy suppy is a complex interplay of physical possibilities and limitations, economic relations, institutions and patterns of socio-pyschological values. A lot is already known about the first: long-term forecasts can be made with a certain degree of confidence about that aspect. Experience has also thrown up quite a substantial amount of data about the second component, economic relations. For instance, we are reasonably confident that the demand for energy will be dictated by the size of the population and the level of prosperity, the energy intensity of the economy and the efficiency of the technologies used.

But the last two elements are less predictable. It is highly conceivable that current international developments will continue, but how and to what extent cannot be foreseen from empirical relations. These are trends such as liberalisation, globalisation, technological development, but also the desire for decentralisation, smallness of scale, quality and environment, etc.

Our basic argument is that the value of certainties over a period of 50 years is limited and that over such a long period uncertainties are more important and more interesting. The purpose of this project is to identify the uncertainties and then to formulate a strategy which, given the uncertainty, produces, if not the greatest benefits, at least the fewest drawbacks ('least regret strategy').

### Two uncertainties, four worlds

In making systematic guesses concerning the future, there are two usual approaches: the scenario and the story of the future, the 'narrative'.
The first is a succession of events following on from the current situation, building on established or apparently fixed causal relationships, which are usually cast in the form of a model. We rejected this approach.

We have opted for the second approach, sketching possible forms the world could have taken in 50 years' time without asking ourselves how it would have developed in that way. Alternative futures, in other words, which we have called 'worlds' in this study.
We have constructed them from four combinations of two fundamental uncertainties which, as already mentioned, lie in the pattern of society's socio-cultural values. So every world is a logically explained type of society that could exist in 50 years as a result of the dominance of one of those value patterns.

**Four different worlds: Free trade, Ecology on a small scale, Isolation, Great solidarity**

Four different worlds have been distilled from a combination of uncertainties. They are derived from a combination of two dominant global trends, each with two totally different outcomes (see figure on the next page).

*E=Economic development,*
with as possible outcomes:
a. The world economy contributes to resolving global problems like the environment and the gap between rich and poor (profit for the world and later) or
b. The world economy is based on direct (monetary) gain (profit for the here and now), without consideration for environmental consequences.

*C=Co-operation*
with as possible outcomes:
a. a mutual interdependency of a completely open economy with global government structures (global institutions) or
b. regions and countries retreat within their borders (local networks).

**Profit in the here and now**

**'Free trade: economy and money dominant without national barriers**

- Economy: strong economic growth everywhere, persistent rich-poor divide
- Technology: rapid development in service of production
- Culture: conscious world citizens, limitless consumption
- Institutions: strengthening of WTO-like bodies
- Sustainability: $CO_2$ emissions continue to rise, poverty persists

**''Isolation': monetary gain dominant within national/regional boundaries**

- Economy: rich countries withdraw behind sealed borders
- Technology: limited development, only in wealthy regions
- Culture: inward-looking, priority for internal security, egoism
- Institutions: none
- Sustainability: environmental problems and poverty very persistent

**Global institutions**

**Local networks**

**'Great solidarity': world's problems are solved jointly**

- Economy: free trade, structural changes at global level
- Technology: very strong development, also ecologically oriented
- Culture: less materialism, new standards and values
- Institutions: strong global government, responsible multinationals
- Sustainability: institutions resolve the $CO_2$ and poverty problems

**'Ecology on a small scale': global problems are solved locally**

- Economy: low growth, consumption close to production, environment incorporated in prices
- Technology: average development, small-scale applications
- Culture: an end to materialism, new values, eco-friendly consumption
- Institutions: regional government structures, strong networks, 'polder model'
- Sustainability: local environmental problems are under control

**Profit for the world and later**

**The global energy supply**

Three developments determine the energy supply around 2050: the demand for energy, the supply of energy and how they are matched.

1. The demand for energy is dictated by the size of the world's population, the level of prosperity and the energy-intensity. This raises the following questions:
• How will the world's population develop in the coming decades?
• What economic development can we expect?
• How energy-intensive will it be?

*Conclusion: The demand for energy will increase. The world's population grows, as do production and consumption, so that demand for energy increases. At the same time, technological development leads to greater energy-efficiency but not enough to compensate for the growth in the former factors.*

For the arguments supporting this conclusion,
see Annex 1 Demand for energy: global

2. The supply of energy is determined by the global reserves of energy and the use of renewable energy, both in relation to the associated technology. This raises the following questions:
• How large are the energy reserves?
• What use of renewable energy sources is possible?
• What technology is available to create this supply in the form desired by the users?
• Which energy system is preferred by the public?

*Conclusion: There is sufficient energy available in this century to meet the growing demand. However, in the first half of the century there is likely to be a shortage of easily recoverable, cheap oil. There will have to be alternatives to meet the rapidly growing demand. Public preferences, which vary according to the different worlds, will determine these alternatives. There will probably be a transition to an energy market dominated by electricity.*

For the arguments supporting this conclusion,
see Annex 1 Supply of energy: global

3. The demand for and supply of energy will be balanced under conditions of cost control, limitation of environmental impact and guaranteeing supply.
This raises the following questions:
• Will there be institutions to properly manage the consequences of the energy supply and what preconditions could arise from this?
• What does it cost to match supply and demand?
• What environmental consequences could the energy supply have over time?

*Conclusion: The matching of supply and demand for energy will continue to take place subject to the preconditions of uninterrupted supply, affordability and ecological suitability. The relative weight of these three elements differs according to the world and depends on whether there will be (global) institutions to establish common preconditions.*

For the arguments supporting this conclusion,
see Annex 1 Matching of supply and demand: global

# Conclusions

**on energy supply in the long term (global)**

*Demand for energy will increase sharply in the coming decades. In principle there is sufficient energy to meet that demand. What is uncertain is whether the energy will always be available in the desired form and under what conditions the energy supply will take place.*

*Note:*

1. *The physical supply of energy is not a problem, but the reserves of easily recoverable oil and natural gas are no longer sufficient to meet this growing demand: energy will become more expensive, but not by so much that demand will not increase;*
2. *Because fossil energy is still the main form, reducing the environmental impact ($CO_2$ emissions) will remain a burning issue;*
3. *As regards the transition to different forms of energy transport, distribution and use, the choice of types of network is still open.*

**Interaction between energy and different worlds in 2050: Western Europe and the Netherlands**

In "Different worlds " it was stated that the major uncertainties lie in society's collective, socio-cultural values:

- will people assess the goal and results of the economic process against the monetary gain in the short term or against long-term public interests, such as the global environment?
- will people recognise problems together and leave the solution to umbrella institutions or will they only want to solve the problems closer to home, on their own?

In the next section we translate these different worlds to the Western Europe of 2050, and to the Netherlands in particular. We then indicate which energy options are the most appropriate to each world. Finally, we evaluate these options in terms of sustainability, security of supply and economic efficiency.

## The Netherlands in a world of 'Free trade'

### THE CONTEXT

The world economy is thriving. There is close economic co-operation worldwide, but no similar willingness to jointly resolve the drawbacks of economic growth. The markets are intensely competitive, there is no room for cartels. At the same time, all natural resources are used very efficiently in the production process. As a result, fuels like coal, uranium, gas, biomass and heavy oil are consequently cheap. Because short-term cost considerations are decisive for economic action, the low energy price makes investment in energy conservation and renewable energy uninteresting. Technological development is aimed at increasing productivity, not at improving the environment. $CO_2$-concentrations are high, but are not seen as a significant problem requiring immediate attention here and now, but as a problem for somewhere else and later. The European Union, now enlarged to include North Africa, is functioning well as a free trade zone, but no more than that: co-operation is restricted to the free movement of goods, services, capital and persons.

### THE NETHERLANDS IN 2050

Economic progress is greatly appreciated. This has made the business community tremendously influential. The power of the Dutch government is curbed by (trade) agreements in the WTO and EU. Divergent positions taken by the Netherlands with respect to the environment are not welcomed by other countries and would, under pressure from the international competitive relations, immediately lead to the relocation of companies. The Netherlands specialises in trade and services. Heavy industry has disappeared for reasons of cost to East European countries and Asia. There is very considerable mobility of persons and goods. The transport infrastructure dictates spatial planning: corridors. The mainports are flourishing thanks to the booming world trade. Although Dutch citizens are experiencing serious environmental problems and their quality of life is mediocre (traffic congestion, crowded cities, lack of nature areas), they regard this as the price they pay for prosperity.

## The Netherlands in a world of 'Ecology on a small scale'

### THE CONTEXT

The hectic pace of life and emphasis on prosperity at the end of the twentieth century have given way to an appreciation of the nonmaterial world. Economic growth in the traditional sense has slowed. Consequently, there are few environmental problems. Physical mobility makes way for communication and working from home with the help of ICT. There is an awareness of and concern about what is happening in the world but this does not lead to joint, worldwide action, but rather to small-scale, individual actions on a local level: start with yourself. Technological development reflects the changing values: the priority is high quality and small-scale systems. In the absence of a common global agenda, there is also no common approach to technological development. Clean technology and autonomous energy systems are very popular. International organisations like the UN and WTO are maligned. There are still European institutions but they function on the back burner; there is little appreciation of them.

### THE NETHERLANDS IN 2050

The Netherlands can make its own decisions and does not have to go along with international compromises. Because the public demands a say in decisions that directly affect them, the government is highly decentralised. The private sector has to deal with many local markets, each with different demands. Production is on a relatively small scale, products are highly differentiated. The business community also respects the change in standards and values: consumers expect nothing less than responsible business. The opposition to nuisance and pollution has driven out energy-intensive industry. Citizens are socially aware, live in small, familiar circuits and have little need for mobility. Information, contacts and other stimuli are provided by advanced ICT. They place high demands on the quality of their immediate environment and solve environmental problems quickly and preferably personally, without government intervention. They feel a strong personal commitment to and responsibility for global environmental problems and poverty and show this in their pattern of consumption ('Foster Parents', 'Max Havelaar' coffee direct from small-scale producers in developing countries). They are attracted to autonomous energy generation (solar cells, small wind turbines, biomass) and distrust large-scale energy systems.

## The Netherlands in a world of 'Isolation'

**THE CONTEXT**

The world economy is driven by direct short-term monetary gain. There is scarcely any international co-operation. World trade is restricted as a result of the creation of blocs; relations between the trading blocs are tense. China has turned in on itself again and also the US is pursuing an isolationist course. Because of the trade barriers possible advantages of scale or specialisation are not utilised. This, together with the limited world trade, has the effect of dampening global economic growth. Technology is only developed for the benefit of the region itself. Co-operation in Europe has returned to its level of before the Treaty of Maastricht; the United Kingdom has pulled out of the EU and Scandinavia has formed a Northern Federation.
Like other trading blocs, EU is pursuing self-sufficiency in food, raw materials and energy. The agricultural sector is strong, as is the defence industry.

**THE NETHERLANDS IN 2050**

The national government is stronger than the surviving supranational institutions, but is weak in relation to the business sector. The prevailing opinion is that the government should not impose any restrictions on companies that would be at the expense of prosperity. Citizens are nationalistic and heavily focused on their own well-being and that of their family.
The environment is not regarded as important, but health is. There is a clear division between city and countryside; ethnic neighbourhoods have grown up in the cities. There is limited mobility. Because world trade is languishing the position of the mainports is weakening.

## The Netherlands in a world of 'Great solidarity'

**THE CONTEXT**

Out of an awareness of a divided 'planet Earth' the solution of global problems like hunger, poverty, scarcity of raw materials and the climate are handed over to powerful global organisations like the UN and WTO.
The economy is booming thanks to co-operation. Economic growth, environmental awareness and optimism about progress have led to rapid technological development. A lively trade in emission rights has proved an effective method for dealing with cross-border emissions. Business is concentrated in multinational conglomerates, which have a substantial voice in multilateral agreements (for instance in the UN, WTO) designed to maintain a level playing field in competitive relations. To preserve public support for this, partly at the instigation of the world trade union the multi-nationals invest heavily in environmental improvement and working conditions, both of which are supervised by UN agencies. European co-operation has been deepened and broadened. All European countries, including Eastern Europe and Russia, are now members. Within the EU a group of countries, including the Netherlands, have formed themselves into a federation.

**THE NETHERLANDS IN 2050**

Like the other member states of the European federation, the Netherlands is exceptionally prosperous. The national government is subordinate to European decision-making, but it is able to adopt specific policies. For instance, the Netherlands is admired for going its own way with respect to clean technology and develop-ment aid. The Dutch business community - although it is largely made up of branches of multinationals - specialises in eco- and energy-efficiency. The Netherlands is a centre of distribution for energy. Dutch citizens are mobile, prosperous and used to luxury and comfort, especially at home. Because they also see the downside of prosperity and feel responsible for it, eco-awareness in purchasing and lifestyle is a must. Because of the enormous pressure on space, there is a great deal of attention and a lot of admiration for the effective use of land.

**The times they are a-changing**
**Bob Dylan**

# 2 *The Netherlands' energy supply* in the long term (2050)

**Given the current state of the art, the forecasts and the steady increase in knowledge, there are a range of possibilities for the West European and Dutch energy supply around 2050. Annex 2 presents a modest outline of the current insights into the new opportunities. The new forms of energy supply described will not automatically appear on the market: each one of them has advantages and disadvantages which may be assessed differently depending on social circumstances, rational or irrational arguments and socio-cultural considerations. Because these differ from one world to another, we also see that some energy developments are more liklely in one world than in others.**

## Energy in 'Free trade'

### THE NETHERLANDS' ENERGY DEMAND

The Netherlands is a service-oriented economy, at the cutting edge of e-commerce. Niche activities are high-tech horticulture and 'intelligent' distribution. Energy-intensive industries have moved to countries closer to resources and markets and over the years have made way for more knowledge-intensive business activity, such as fine chemicals. The demand for primary energy has declined to approximately 2500 PJ. Electricity accounts for almost half of the final demand for energy: roughly three times as much as now, and most of it imported.

### THE ENERGY SUPPLY

There is abundant supply of energy on the world market; thanks to the open markets and supported by technological development there is practically no difference any longer between the prices of the various energy carriers. The Netherlands' natural gas reserves are sold out: they were sold in time to get a good price. The overriding question is which carrier is cheapest: cost differences are now only the result of the infrastructure and equipment needed. Cost considerations mean that maximum advantage is taken of advantages of scale and of existing infrastructure. Electricity production is a European affair: other countries have specialised in this sector and the Netherlands buys substantial quantities via a well-equipped European network. But there is still also gas-fired capacity for peak demand.

- *Coal:* because there is little awareness of global environmental problems the use of coal is not regarded as a problem; there is more than enough coal and it is cheap to transport. In Europe coal is widely used to produce electrcity.
- To keep down costs existing infrastructure which has already been written off is used as much as possible. *Coal gasification* is an attractive option in the Netherlands because the former natural gas network can be used for for it.
- *Nuclear energy:* in so far as the costs of keeping the European nuclear capacity operational have remained low in relation to the competing coal (gasification) capacity, importing nuclear power is not a problem.
- *Wind energy:* power from offshore wind parks has become a Dutch export product, not from considera tions of sustainability, but because major advantages of scale have now been achieved. Cost factors move energy storage abroad; Switzerland is Europe's electricity banker.
- *Natural gas:* the Netherlands' natural gas reserves are depleted, but gas of various different qualities is imported, exported and used in high-quality combined heat and power generation plants. The Netherlands is Europe's gas banker.
- *Biomass* is cheap and plentiful. It is also much in demand on the world market and hence a lucrative export product for some countries, upgraded or otherwise. The Netherlands is Europe's main distribution centre for these upgraded products.
- *Transport:* because there are still cheap oil products, the electric car has not made a breakthrough. Petrol and diesel engines have been greatly improved. Prosperity and individualism lead to growth in the use of cars (by a factor of 2 to 2.5). Large, luxury cars dominate. Goods transport is also increasing rapidly (by a factor of 3.5 to 4) and the economy dictates that road haulage plays a major role in it. The demand for energy for mobility is higher than in 2000.
- *Space heating:* because electricity is relatively cheap compared with gas, the heat pump is widely used for climate control (heat and cold). But efficient gas heating is still possible. Driven by a demand for comfort, houses and public buildings have a standard energy quality.
- *Solar energy PV* is a nice gadget but too expensive as a source of power.

## Energy in 'Ecology on a small scale'

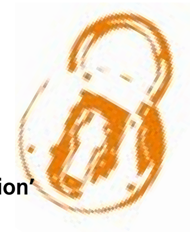
### THE NETHERLANDS' ENERGY DEMAND

The Netherlands is a service-oriented country, with the emphasis on care. Industry has evolved towards small-scale activities with a high added value ('The Netherlands design land'). Recycling is a profitable sector and the Netherlands is a distribution centre for waste and secondary raw materials for this part of Europe. The regions in the Netherlands are self-sufficient in vegetables and meat substitutes.
With the disappearance of large-scale industry and the constant attention to eco-efficiency the demand for primary energy has declined to around 2000 PJ; just less than half of the final demand is for electricity.

### THE ENERGY SUPPLY

Small is beautiful. There is no public support for large-scale infrastructure and supply structures.
The indigenous gas reserves can still be used as a supplement as little gas is exported.

- *Gas:* the gas network has been preserved and is suitable for various types of gas (natural, biogas, hydrogen). The gas flows that are not produced from biomass ('$CO_2$-neutral') are decarbonised as far as possible. The emphasis is on local and regional gas supply; the national gas reserves serve as emergency stocks.
- *Space heating:* gas is preferably delivered to small-scale installations (fuel cells, small-scale combined heat and power, at local or at dwelling level).
- *Renewable energy* is very popular from the perspec tive of self-sufficiency: especially PV, solar heating and wind at home or wind PIMBY ('please in my back yeard'). Where necessary, energy is stored locally or if need be regionally.
- There is very little interest in *clean coal:* the large-scale nature of its development and exploitation make it unattractive. Moreover, there are enough alternatives.
- *Nuclear energy:* all large nuclear power stations have been closed. They have been replaced with inherently safe, small-scale nuclear power stations.
- *Biomass* is processed locally or regionally, but there is no large-scale production and distribution organisation. It is therefore mainly a source of energy for built-up rural areas; the large cities depend on gas.
- S*torage of energy* is handled locally as far as possible, for instance through low temperature energy storage in aquifers. Summer biomass is used in the winter and so also serves as seasonal storage.
- *Mobility* is relatively low. The bicycle is as popular as ever. Cars are hybrid: driven by electricity in the city, by fuel cells outside. There is little public support for collective public transport. The growth of goods transport is relatively modest (a factor of 2) and is primarily national. The demand for energy is only slightly higher than in 2000 thanks to greater efficiency.



## Energy in 'Isolation'

### THE NETHERLANDS' ENERGY DEMAND

The economic structure does not differ much from the present. The service sector is less dominant than in the other worlds. There is still industry for local and regional markets, and there is also domestic electricity production. The agriculture sector produces for the domestic market. The energy demand is around 3000 PJ;
electricity accounts for one third of the final demand.

### THE ENERGY SUPPLY

Self-sufficiency is important. The Netherlands relies on its 'own' natural gas reserves, just as other European countries are trying as far as possible to expand their 'own' energy systems (coal and renewable energy in Germany, nuclear energy in France). Oil is relatively expensive because there are still production cartels in the world energy system. Because of this dependency oil consumption is restricted as far as possible. 'Domestic' coal reserves are drawn on; renewable energy and nuclear energy are attractive options for guaranteeing energy self-sufficiency. The supply is a mix of central and local because this offers optimal security of supply.

- ***Nuclear energy*** is an ideal European option which guarantees energy self-sufficiency. There are also breeder reactors in operation which require virtually no raw materials for the energy supply.
  The Netherlands does buy nuclear power but does not venture into building its own nuclear power stations.
- ***Coal*** is also used to generate electricity because it ensures energy self-sufficiency, although conditions are imposed on the local environmental impact ('clean coal').
- To avoid the variations in the pattern of demand electricity from base load power stations is used in off-peak periods for the production of ***hydrogen***, which can be used in cars, for instance.
- ***Renewable energy*** (wind offshore and on land, solar) is frequently used with a view to energy self-sufficiency; there is also extensive energy conservation.
- The Dutch ***natural gas*** is used as a strategic reserve. In order to use it for as long as possible the efficiency of gas use has been raised to a very high level: the Netherlands has adopted combined heat and power (small-scale and large-scale combined heat and power generation).
- ***Biomass*** is used mainly in agricultural areas. It mainly involves agricultural waste, because there is no space for cultivation for energy purposes because of the emphasis on food production.
- Rural areas have turned away from the cities so there is a distinction between the urban and agrarian energy supply: the former is based on (gas-fired) district heating, the latter primarily on renewable energy and biomass.
- ***Mobility*** has declined, there is less tourism. Cars are smaller, fuel efficient and spartan. Because oil is expensive and scarce the fuel cell and electric car have taken off. Investment in public transport has lagged behind so that there is only a skeleton public transport service for people who cannot afford a car.
  Good transport has increased slightly. Railways and inland waterways account for a substantial share of the transport. The demand for energy for mobility is on balance roughly the same as in 2000.

## Energy in 'Great solidarity'

### THE NETHERLANDS' ENERGY DEMAND

The Netherlands has a large service sector (the public sector is particularly strong), but industry is also booming and in the area of environmental protection and energy-efficiency it is still the best in the world. This image has attracted additional industries: the Netherlands is the world's chemical plant. The demand for energy is therefore enormous, despite high efficiency, life cycle management and recycling: around 4500 PJ. Thanks to the flourishing trade in emission rights we can afford this energy-intensity. The Netherlands is still a distribution centre for goods. Electricity's share in the final demand is just over 1000 PJe.

### THE ENERGY SUPPLY

International agreements have led to optimisation of energy production, transport and use. There is a world-wide, large-scale infrastructure for the transport of energy (electricity, natural gas, LNG, methanol) from which the Netherlands profits optimally.
The Netherlands' natural gas is meanwhile exhausted, because others found they could make good use of it during their transition to new, clean energy technologies. The energy supply is both centralised and decentralised; the environmental benefits of both types of system are exploited to the full. Of all the different worlds, this is the one in which it is most likely that one or more energy technologies will be used that were still rejected as 'exotic' in 2000, given the combination of rapid technological development, economic growth and emphasis on sustainability.

- Although the Netherlands' ***natural gas*** is gone, the Netherlands still has its gas infrastructure. Gaseous fuels can be used where this is optimal from an environmental perspective (combined heat and power generation, but also heat pumps). Empty gas fields are used as gas banks and for $CO_2$ storage.
- ***Renewable energy*** is used wherever possible in order to curb $CO_2$ emissions. There is also a global sharing of responsibilties on this point: where there is enough space fuels are produced on the basis of PV, biomass comes from Scandinavia, wind energy is widely used in the North Sea countries.
- ***Biomass:*** The Netherlands has undertaken to devote its agricultural expertise to the production of 'smart biomass'. The chemical industry has switched to biological materials as feedstock.
- The Netherlands' potential in ***wind energy*** is exploited to the full, partly through the use of large reservoirs at sea for electricity storage on the basis of pumped-storage systems.
- ***Nuclear energy*** is now available in a form which is considered sufficiently safe. The Netherlands provides money and know-how for European projects in this area.
- ***Mobility*** is high. To keep it $CO_2$ neutral there is large-scale electric (obtained from 'clean' fossil fuels) public transport between the European agglomerations (high speed trains (TGV), MAGLEV (magnetic levitation) trains); within the agglomerations there is also high-tech public transport, but in addition fuel cell cars (with hydrogen stored in nanotubes) are the standard. As a result mobility by car has only growth slightly; light, fuel-efficient but comfortable cars have taken over the market. Good transport has grown strongly (by a factor of 3) but half of it is carried by rail or inland waterway. On balance, the demand for energy for mobility is higher than in 2000.

# Conclusions

## Conclusions about the Netherlands' energy supply in the long term

The future energy supply in Western Europe and the Netherlands depends on the socio-cultural context, which may take many different forms over the next half century ('different worlds'). So there is no conclusive blueprint for the the future energy situation in the Netherlands.

What is certain is that:
- Electricity consumption will increase as a result of increasing affluence and a catch-up in demand in relation to the present and in relation to other countries, regardless of the world;
- The Netherlands's gas infrastructure is an advantage in all worlds;
- Wind energy (offshore) is used in all worlds, albeit for different reasons;
- Biomass will remain one of the most appropriate forms of renewable energy, although not always and everywhere on the same scale or for the same application;
- To a greater or lesser extent, the Netherlands will remain a European distribution centre for energy products, except in the world with declining world trade due to the forming of blocs ('Isolation');
- Storage of energy is an aspect requiring attention in all worlds, except in a fully integrated energy market ('Free trade').

Other significant conclusions are:
- The climate problem is only resolved in one world ('Solidarity'); in the other worlds, the problems it causes are not considered urgent enough or there is a lack of international co-operation;
- The source of energy for the growth in traffic differs in each world, ranging from oil to hydrogen and electricity;
- The lowest costs to the consumer are in 'Free trade'; the lowest total costs, including exter nalities, in the world of 'Solidarity'.

**Differences, but also similarities between worlds**

The differences between the worlds are great, as is the rating of certain energy options and hence the likelihood that an option will actually occur in practice in a particular world. Despite these differences there are also similarities.

In <u>all four</u> future visions for the Netherlands in 2050:
- electricity consumption has increased compared with 2000 in both relative and absolute terms;
- the Dutch gas network, with or without modifications, is still in use;
- offshore wind energy makes a breakthrough, albeit for different reasons;
- climate control in buildings is optimised.

In <u>three of the four</u> future visions for the Netherlands in 2050:
- the Netherlands is a distribution centre for energy products (not in 'Isolation');
- energy storage to match supply and demand for energy is an important issue (not in 'Free trade').

We summarise some of the significant themes and differences in the following table.

**TABLE 1:** *differences and similarities between worlds*

| | Free trade | Ecology | Isolation | Solidarity |
|---|---|---|---|---|
| total consumption domestic | 2500 PJ | 2000 PJ | 3000 PJ | 4500 PJ |
| Gas and gas infrastructure | The Netherlands' natural gas is exhausted, the Netherlands is Europe's gas banker | The Netherlands produces various gases for use in micro power of small-scale combined heat and power | The Netherlands still has its 'own' natural gas and is at the fore-front in the use of com-bined heat and power generation | The Netherlands' natural gas is exhausted, imports, biofeedstocks in the chemical industry |
| Renewable energy | Offshore wind, biomass import | Small-scale: PV, solar, wind, biogas and biomass | Wind offshore and on land, solar, bio-waste in rural areas | Offshore wind, import of PV and biomass |
| Mobility | Improved petrol engine | Bicycle, hybrid cars | Fuel cell and electric cars | Fuel cell car, large-scale public transport be-tween agglomerations |
| Climate problem | Not seen as a problem, also not resolved | Is a problem, partially resolved, incorporated with other environ-mental issues | Not seen as a problem, not resolved | Urgent problem, is being resolved, institutions, trade in emission rights |
| Who governs ? | The market, 'lowest costs' | The public, 'autonomy' | Nation state, 'security' | Institutions, 'the world' |

**Every advantage has its disadvantage**

**Johan Cruyff**

# 3

*The Netherlands' energy supply*

# tested against quality criteria

**Three quality criteria**

**In Chapter 1 we established what kinds of different worlds are possible. In Chapter 2 we went on to investigate what is and is not possible in each of the various worlds in terms of the Netherlands' energy supply. In conclusion, this final chapter presents an opinion on the attractiveness of these possible energy supplies, according to current insights. Such an opinion is necessary should policy decisions need to be taken in future. Our quality criteria are:**

**'SECURITY OF SUPPLY'**

This criterion is relevant from the national perspective and from the perspective of the user:

- *National perspective:* The greater the availability of the necessary (primary) fuels, the shorter the import lines and the greater the political stability in the source and transit regions, the greater the security of supply.
- *User's perspective:* The security of supply for consumers is greater the more flexible and disruption free the supply is, in other words, the more the form, quality and timeliness of the supplied energy carrier meets users' wishes.

**'ECONOMIC EFFICIENCY'**

This quality criterion also has two elements: cost allocation and equity.

- *Cost allocation.* The economic efficiency is greater the more the supply chain leads to the lowest integral ('bare') cost price of energy, the costs of the external effects (such as environmental impact and damage to health) are minimised and the price for the end user better reflects these two cost components.
- *Equitable division.* The economic efficiency is greater the more the costs of the energy supply are equitably divided among all consumers of energy and the greater the guarantee of the availability of energy for all customers.

**'SUSTAINABILITY'**

This criterion has many facets. In any case, it concerns emissions, harmful side-effects of energy supply and use, and efficiency (the manner in which theoretically finite raw materials and additives are used).

- *Efficiency.* The sustainability of an energy system is greater the more useful production per unit of energy is achieved throughout the supply chain (from source to end use).
- *Emissions.* The sustainability of an energy system is greater the smaller the sum of ecological disruptions throughout the entire chain, from source to end use: at global level the emission of $CO_2$ and other green house gases; at continental level emissions of $SO_2$ and $NO_x$; at national and local level emissions of volatile organic substances (VOS) and dust; in the entire chain the production of other waste streams.

## Testing against the criteria

These criteria do not have equal weight for everyone or in every situation. If a decision-maker can choose from two energy options, one of which more than meets the requirement of 'security of supply' (for example, coal) and the other clearly meets the criterion 'sustainability' (such as solar energy), the criterion that weighs heaviest will dictate the ultimate choice. As already emerged in the description of the different worlds, our criteria will play a greater or lesser role in them.

For an assessment of the possible energy situation in the Netherlands in 2050 as it emerges from the various worlds, we use today's criteria without any weighting: we are implicitly stating that from our current perspective all criteria are equally important. The degree to which the energy supply in the four worlds meets these criteria, according to our current insights, is as follows.

**TABLE 2:** *the extent to which the energy supply in each world meets present criteria.*

| World/criterion |  Free trade |  Ecology |  Ilsolation |  Solidarity |
|---|---|---|---|---|
| Security of supply | | | | |
| A. NATIONAL PERSPECTIVE | + | + | - | 0 |
| B. USER'S PERSPECTIVE | + | 0 | + | 0 |
| Economic efficiency | | | | |
| C. COST ALLOCATION | - | 0 | - | + |
| D. EQUITABLE DIVISION | - | - | - | + |
| Sustainability | | | | |
| E. EFFICIENCY | + | 0 | 0 | + |
| F. EMISSIONS | - | + | - | + |

+ = is met 0 = is met to a limited extent - = is not met

## Security of supply

**A. NATIONAL PERSPECTIVE**

The geopolitical security of supply is sufficiently guaranteed in two of the four worlds: in 'Free trade' and in 'Ecology'. The 'Free trade' world assumes the success of worldwide exploration for and production of (according to current insights) less profitable and less accessible energy stocks. In addition, there is substantial import of biomass and some renewable sources are added to the energy arsenal thanks to cost benefits (offshore wind!). In 'Ecology' the security of supply is guaranteed by the large number of decentralised energy systems based on renewable energy, with the country's 'own' natural gas supply as emergency reserve.

In 'Solidarity' the supply structure appears similar to that in 'Free trade', although the price of $CO_2$ treatment and storage have to be added when talking about the use of coal. The supply is slightly less certain because it depends on compliance with mutual agreements.
If these come under pressure, for instance due to an international crisis, it is conceivable that regions will choose to look out for themselves; in that case the European federation will have insufficient reserves.
This is the actual situation in 'Isolation': Europe has no access to Russian and Arab natural gas reserves.
The security of supply is maintained with domestic coal, nuclear energy and "renewable energy", but it is not optimal.

**B. USER'S PERSPECTIVE**

At the level of the customer as well, three supply structures score reasonably well: 'Free trade', 'Ecology' and 'Isolation'. In 'Free trade' undisrupted supply to customers is guaranteed by the interwovenness of the energy networks, whereby sufficient back-up contracts have been concluded in the European energy network ('Switzerland as electricity banker'). The situation is similar in 'Solidarity', although the back-up is based on agreements that are less firm than the contracts in 'Free trade'. Moreover, the storage and back-up is based on a few central systems which are inherently more vulnerable than many decentralised systems.
In 'Isolation' and 'Ecology' undisrupted supply is reasonably guaranteed by having the users provide their own storage and back-up as far as possible.

## Economic efficiency

**C. COST ALLOCATION**

The values in the different worlds in which the priority is on short-term economic gain, 'Free trade' and 'Isolation', are such that there is no question of integral cost allocation (including 'externalities'). Apart from that, the price of energy to end users is the lowest (open markets, no cartels, sufficient availability) in the 'Free trade' world. In 'Isolation' it is a good deal higher. In the other two cases, people are prepared to pay the external costs of the energy supply: in 'Ecology' people pay the higher price for the ecological benefits and autonomy of small-scale energy systems, in 'Solidarity' people pay the price for combating (global) environmental damage. The greatest possible economic efficiency is achieved where this pricing is based on trade in emissions.

**D. EQUITABLE DIVISION**

Only in 'Solidarity' is there a guarantee of an equitable division of the costs and benefits of the world energy supply. In the other cases, the division between the energy 'haves' and 'have-nots' remains: in 'Isolation' there are still people, countries and maybe even continents (Africa?) outside the trading blocs; in 'Free trade' there is some convergence between countries but the gap between rich and poor (including access to energy) continues to exist within countries; in 'Ecology' technological development is so fragmented that once incurred technological arrears are difficult to make up.

## Sustainability

### E. MATERIAL AND ENERGY EFFICIENCY

Material efficiency is optimised in three of the four worlds, albeit for very different reasons. In 'Solidarity' and 'Ecology' there is a large degree of recycling, reuse and repair because they have a positive effect on the consumption of raw materials and the associated depletion and pollution. In 'Isolation' the pretext is more likely to be achieving maximum self-sufficiency in raw materials. In 'Free trade' recycling is only an issue in so far as secondary materials are cheaper than primary; given the assumed abundant availability of raw materials this is unlikely to be the case.

Energy efficiency displays a slightly different pattern. This is greatest in 'Solidarity' and in 'Free trade', partly due to the accessibility of energy sources and partly from the assumed technological development and the pace at which new technologies are disseminated.
In 'Solidarity' Dutch industry, through constant "bench-marking" and improvement, is also the most efficient in the world. In 'Ecology' and 'Isolation' it is uncertain whether an optimal energy-efficiency can be achieved, although that is the aim in both worlds. In the case of 'Ecology' the uncertainty lies in whether the absence of large-scale systems will not in fact lead to sub-optimisation through the loss of benefits of scale; in the case of 'Isolation' the uncertainty lies in the assumption of less rapid development of know-how and technology.

### F. EMISSIONS

The need to reduce greenhouse gas emissions, especially $CO_2$, is currently the main driving force behind the effort to increase energy-efficiency and produce more renewable energy. Whether this will continue to be the case in the longer term heavily depends on the world:
in 'Free trade' and 'Isolation' $CO_2$ is not a major issue. The situation even deteriorates in both cases due to the use of coal, and in the case of 'Free trade' also because of possible further deforestation for the cultivation of crops for energy. The other two worlds differ in the manner in which emission reductions are achieved:
in 'Solidarity' via global agreements and the trade in emissions, in 'Ecology' as a spin-off from other environmental quality requirements (such as measures to curb smog from road traffic). Only the world of 'Solidarity' produces an adequate solution for the world's climate problem.

$SO_x$ is produced mainly by coal and oil combustion without adequate environmental measures.
We expect these measures to be a common feature in all worlds in 2050 so that this source of acid rain will have disappeared. The situation with $NO_x$ is different. Where this comes from stationary sources flue gas treatment is already an option, but its application depends on the world - in 'Free trade' and in 'Isolation' the investments needed are too high. However, a steadily increasing share of $NO_x$ emissions comes from traffic. These traffic emissions, together with those of volatile organic substances and fine dust, are not adequately tackled in all the worlds. In 'Free trade' technological progress is more than offset by the growth in road traffic and smog remains a problem.
In 'Ecology' the solution is near, because the traffic growth itself is less and the tech-nology is also focused on environmental quality. In 'Isolation' the emissions are smaller because the scarcity of oil means there is less road traffic, which is moreover based on fuel cells and electric traction. In 'Solidarity', although mobility is high it is based on '$CO_2$ neutral' techniques (electricity or fuel cells on hydrogen) which also lead to a reduction of other emissions.

Waste is a familiar problem in the application of coal and nuclear energy: mining waste (which increases as less rich seams are mined), waste from exploitation (fly ash and desulphurisation waste from coal, radio-active waste at nuclear power plants) and finally end waste (coal ash, nuclear waste products, waste from the decommissioning of reactors). We assume that the techniques will be developed to minimise the risks from these waste streams, but whether people will bear the cost or take the trouble to use them depends on the world. Less well known are the risks of waste from new developments: for instance, $CO_2$ storage can be seen as waste disposal, it is not known to what extent scrap from offshore wind platforms can be adequately salvaged and it is uncertain whether the materials from PV plants can be completely recycled.

**Contrariwise,
if it was so,
it might be;
and if it were so'
it would be;
but as it isn't,
it ain't.
That's logic**

**Tweedledee in Alice in Wonderland
by Lewis Carroll**

# 4 Discussion

**This report of the LTVE project is the result of an open dialogue with interested individuals and institutions. A preliminary draft for discussion purposes was published on the website of the Ministry of Economic Affairs. The Netherlands Bureau for Economic Policy Analysis (CPB) and the Fraunhofer Institute made comments on it and it was discussed during a national conference on 27 September 2000.**
**As far as possible, we have tried to incorporate observations, comments and substantive additions in this revised text.**

The discussion of our working methods focused on four elements: the aim of the project, the status of the different worlds, the underpinning of our assertions and the comparability with other future studies.

### THE AIM OF THE PROJECT

The LTVE project is designed to provide the Ministry of Economic Affairs and its clients with an overview of the most important trends and developments which could determine the nature and structure of the energy supply of Western Europe and the Netherlands in the long term.
The Ministry of Economic Affairs will use these findings as the basis for taking new policy initiatives and reviewing existing policy. The terms of reference of the project were to tailor any policy recommendations to those factors that can be influenced now but whose possible impact may only be felt over a period of decades from now: energy research and energy infrastructure.

### THE STATUS OF THE DIFFERENT WORLDS

Various reactions demonstrated that it was unclear whether the worlds we created should be regarded as “desirable outlooks”, while others asked why we did not opt for a single, ideal future world. We chose to create impressions of hypothetical worlds from uncertainties with a major impact on the substance and context of the energy supply in this part of the world. In these worlds certain forms of energy and energy systems are more likely than others. In our supporting arguments, where possible we indicate the relationship between the world and the system features of the energy options. Only in the final analysis have we given a qualitative opinion on how the energy supply will look in each world, based on our current insights and using quality criteria. From that opinion it follows that energy supply in the ‘Solidarity’ world would best meet today’s quality and sustainability criteria.

### UNDERPINNING

The actual details of the energy supply in the different worlds are based on whether the system characteristics of the various energy options are in keeping with the dominant culture of each world. This also extends to the value attached to certain economic activities, which determines whether or not they will take place in the Netherlands. The differences in primary energy demand in the Nether-lands that emerge in the different worlds are based primarily on these structural features. In other words, we conciously chose not to construct hypothetical paths of economic growth or contraction between now and 2050; we wanted to use a model based on ideas rather than a mathematical model.
Of course, we did subsequently ascertain that the structural and energy characteristics we advanced about the Netherlands in mid-century are consistent in themselves.

### RELATIONSHIP TO OTHER STUDIES OF THE FUTURE

We were asked whether our worlds are the same as those to emerge from other studies of the future; in particular, we were asked whether our work could be compared with the recent scenario study by the IPCC. We made considerable use of the many forecasts and trend studies which are available, but made our own combinations of them and have interpreted them in our own way.
Where we cite other studies - including the IPCC’s - it is intended only as an illustration and not as a quote.
In general, all the studies of the future known to us envisage further liberalisation and globalisation on the one hand, and ‘small scale’ on the other. Opinions seem to differ on the probability of a future in which the current dominant trend of globalisation will come to an end. We did, however, want to take into account some developments which may be considered rather undesirable from the current perspective, in order to draw up a complete risk profile of the Western European and the Netherlands’ energy supply.

# Energy and society in 2050

THE NETHERLANDS IN DIFFERENT WORLDS

*6 december 2000*

# Contents of annex

**Contents of annex 1**
**Demand for and supply of energy: global**



**Contents of annex 2:**
**Demand for and supply of energy: Western Europe and Netherlands**

**Drill for oil?
You mean drill into the ground and try to find oil?
You're crazy!**

**Drillers who Edwin L. Drake tried to enlist to his project to drill for oil in 1859**

*Annex*

I

# *Demand for and supply of energy:* Global

## 1. The demand for energy

The demand for energy is determined by:

- the size of the population
- the level of prosperity
- the energy-intensity

### DEVELOPMENT OF THE POPULATION

The current population of the world is 6 billion people. It is expected to grow significantly in this century, although growth is slowing. The projections vary greatly: see table 1.

According to these forecasts, the world's population will grow by at least 25% in the next 50 years, while expansion of 80% is possible. In the longer term (2100) the population is expected to stabilise (UN-M) or decline slightly (IIASA-L), although further growth is not ruled out (IIASA-H: 17 billion people).

The fertility rate depends on the level of prosperity. Greater prosperity leads to a smaller number of children and hence to a slower rate of growth of the population. There is also a correlation between population size and economic growth, although it is not the same in every country There are countries where population growth slows the economy down ('more mouths to feed'), while in other countries it actually stimulates the economy ('more hands to work') (WEC,1998).

Besides the total number of people, their distribution over continents and regions is also relevant. 90% of the projected growth will take place in developing countries. In 2050, it is said, the combined population of India and China, could almost double to 3 billion people (US98). Europe's share of the world's population would sink to below 10%.

The pattern of life will also change drastically. 'Urbanisation is growing even faster than population' (EPRI, 1999) because people continue to look for opportunities in the cities. By the middle of this century 60 to 70% of the world's population will live in urban regions and the number of 'mega-cities' (with more than 10 million inhabitants) will rise from around 15 now to roughly 60.

***Example: India***

*There are now around one billion people living in India; according to projections (US98), this figure will be almost 1.5 billion in 2050. At the moment, 70% of the population still live in rural areas. Erosion of the land and economic development (a ten-fold increase in industrial production is predicted) will drive people into the cities. Industrialisation and technological development could lead to an enormous increase in prosperity (from 1,200$ per capita to ten times as much in 50 years; World Bank 1997). On the other hand, there is a pessimistic scenario in which per capita incomes do not rise higher than 2000$ because of internal tensions, the absence of foreign investors and the exhaustion of natural resources (Hammond, 1998).*

**TABLE 1:** *worldpopulation in billions*

| Year | WB 92 | IIASA 96 | | | US 98 | UN 98 | | |
|---|---|---|---|---|---|---|---|---|
| | | L | M | H | | L | M | H |
| 2020 | 7,9 | | | | 7,6 | | | |
| 2025 | | 7,5 | 8,0 | 8,6 | 7,9 | | | |
| 2050 | 10,1 | 7,7 | 9,4 | 11,2 | 9,3 | 7,4 | 8,9 | 10,8 |

Based on the assumptions of the above studies, it can be concluded that population growth depends on which World one takes. The increase will be greatest in 'Isolation' (1%), lowest in 'Solidarity' (1/2%) and between the two (3/4%) in 'Free Trade' and 'Ecology'. What is certain is that the increase will occur mainly in the non-OECD countries.

***ICT and 'the new economy'***

*The recent new applications of information and communication technology (ICT), such as the Internet and electronic commerce, could have an enormous impact on the economy and hence on energy consumption.*

- *ICT causes physical borders and distances to disappear, so that from a socio-cultural perspective people can come to feel more like a 'world citizen'. In this sense, ICT is a driving force for 'globalisation' (figure 1), so that the associated Worlds become more likely.*
- *Under the influence of ICT the economy could enter a new phase of structural change: post-industrial society evolves further into a 'digital society' It is unclear whether this trend will lead to energy-intensification or extensification. Transport will use less energy, but information processing more (see 2, EPRI).*
- *Some people believe that the impact of ICT will lead to a permanent increase in productivity, so much so that the usual economic cycles will be a thing of the past ('new economy').*
- *This increase in productivity leads via the accompanying growth in prosperity to higher energy consumption (see below).*

***Innovation: traffic***

1. *System optimisation: the improved management of traffic flows with advanced measurement techniques; modification of fuel consumption to speed and revolutions (economiser).*
2. *Redesign: two concepts are in development, the hybrid car (a car with a combustion engine and an electric drive line, which runs on electricity in the city and on petrol or diesel outside the city) and the fuel cell car (where the fuel cell, fed with hydrogen, provides the electricity for propulsion).*
3. *System innovation: for example, entirely electric road traffic, in the form of cars with advanced batteries or of electric conduction ('CombiRoad').*

**DEVELOPMENT OF THE ECONOMY**

The major driving forces behind economic growth are:

- Population growth: More people engaged in more economic activities ('more hands to work'). This factor is particularly important for non-OECD countries.
- Growing labour productivity through technological development. In the World of 'Isolation' productivity growth is relatively low, in 'Ecology' technological know-how is aimed more at environmental objectives than at increasing productivity. In both cases, economic growth is therefore lower than in the other Worlds. In the 'New Economy' one speaks of sustained high productivity improvement (see box).
- World trade. Global free trade facilitates specialisation, which leads to an economically efficient allocation of production resources, resulting in higher economic growth. In 'Ecology' there is only partial free trade, in 'Isolation' trade is largely unfree, which leads in both cases to lower economic growth.

All this leads to the following growth figures for world output. (see table 2)

These figures follow from a number of other studies. The assumptions in the scenarios of these studies correspond with those for the different Worlds.
These figures are averages over a very long period. It should also be noted that growth in the period up to 2020 is stronger than in the subsequent period. This is due to slower population growth after 2020 and because non-OECD countries start to catch up in terms of technology in the first decades of this century.
Despite significantly higher growth outside the OECD, poverty remains an intransigent problem in three of the four Worlds because of the pace of population growth and an unequal distribution of prosperity.

**DEVELOPMENT OF ENERGY-INTENSITY**

The growth of energy consumption does not increase in step with economic growth. The economy's energy-intensity, the quantity of energy needed for all its activities, changes because the energy needed for each activity changes (efficiency effect), as does the relationship ratio of the various activities within an economy (structure effect), both under the influence of technological progress. The energy-intensity has declined worldwide by 1% per year in the last few decades (IIASA/WEC, 1998).

**ENERGY-EFFICIENCY**

Over the years the use that has been made of the same volume of energy has steadily increased. The efficiency improvement of an average of 1 to 1.5% per year is the result of the market penetration by improved equipment under the influence of policy or price incentives.
Experience shows that high economic growth, due to the greater rate of circulation of capital and consumer goods, leads to a more rapid improvement in energy-efficiency than would otherwise be the case. Benchmark studies show that the countries in Eastern Europe and North America still have scope for substantial improvement in energy-efficiency compared with Western Europe and

**TABLE 2:** *growth figures for world output*

| ECONOMIC GROWTH IN % PER YEAR | Free trade | Ecology | Isolation | Solidarity |
|---|---|---|---|---|
| Growth of world economy | 3% | 2% | 2% | 3% |
| Growth of per capita income | 2% | 1% | 1% | 2% |

Japan; the former mainly in industry, the latter mainly in mobility. But in addition to these arrears, improvements are also possible in other respects.
A useful breakdown by steps in innovation is the following (TNO 1998):

- system optimisation: improved method of meeting demand for energy functions;
- redesign of systems: optimising the exis ting supply chain of energy carriers in relation to the demand for energy functions;
- system innovation: rethinking the end functions themselves. Developments in the traffic system provide a good illustration of this (see box page 34).

**CHANGING THE PRODUCTION STRUCTURE**

In the pre-industrial society energy consumption was relatively low, the energy carriers (wood, manure, harvest waste) were collected for personal use and the means of energy consumption were primitive (wood fire, pack animals).
The transition to an industrial society is accompanied by the introduction of new, commercial energy carriers (coal, oil, natural gas, electricity) and a sharp increase in energy-intensity. Over time, the services sector becomes dominant in the economy, so that energy-intensity declines again.
The next step could be 'informatisation' or 'digitalisation' under the influence of a new technological wave (see box page 34).
It is suspected (by the Netherlands Bureau for Economic Policy Analysis - CPB) that urbanisation in the OECD countries has gradually reached saturation point, so that the observed energy-extensification of the economy will also decline. Since many developing regions are still on the eve of industrialisation, the energy-intensity there is likely to increase for the time being (although industrial efficiency and ICT are 'trend breakers'). All in all, the justifiable conclusion is that for the time being the worldwide economic structure is tending towards intensification of energy consumption.

**CHANGING THE STRUCTURE OF CONSUMPTION**

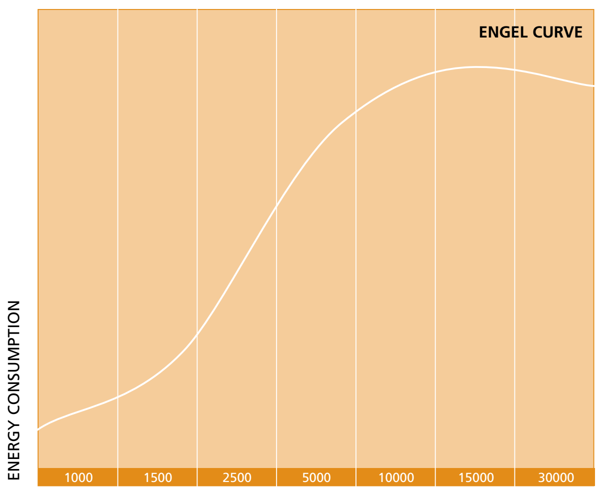
Technological development can cause the demand for energy to rise or decline.
An example of the former eventuality is the replacement of pack animals and bicycles with cars. An example of the latter is the replacement of primitive wood-burning stoves with oil or gas-fired ovens.
We generally regard the first type of substitution as a structural change, the second as an efficiency-improvement.
Increasing prosperity leads to structural change in the pattern of consumption.

The relationship between changes in energy and growth of prosperity (the income elasticity of energy) is described by the Engel curve (see box and curves 1 and 2).
At the moment, the average per capita income in developing countries is 2,500$ and in the OECD 25,000$. On the basis of the assumptions behind the Engel curve it is plausible that energy consumption in developing regions will grow strongly, even more strongly than the economy itself.

**MIT: ECONOMIC DEVELOPMENT AND THE STRUCTURE OF DEMAND FOR COMMERCIAL ENERGY**

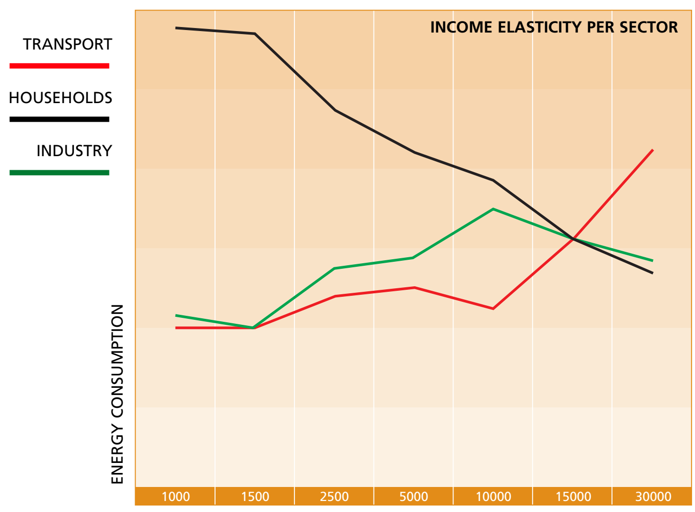
UResearch into various sectors (households, industry and transport) in 123 countries (both OECD and non-OECD) in the period 1970 - 1991 by the MIT shows that per capita income explains 80% of the per capita energy consumption. The income elasticity of energy consumption (as shown in curve 2) declines with income.
This effect is stronger among higher income groups and among households.
When incomes rise, energy consumption shifts from households to transport, while industry's share in the economy declines.

**CURVE 1**




INCOME PER CAPITA [SOURCE: MIT]

**CURVE 2**




INCOME PER CAPITA [SOURCE: MIT]

***Methane hydrates***

*Methane ice or methane hydrate is to be found on deep ocean beds (> 1 km). It is estimated that there is at least 10,000 Gtonne of carbon material, twice as much as the largest estimate for other fossil energy reserves.*

*Opinions differ on whether it can be recovered, the opportunities and the risks. One advantage would be that countries like the USA, Japan and India would become energy self-sufficient by recovering methane hydrates.*

*Because the presence of hydrates is concentrated on continental fault lines exploration and production would increase the chance of earth-quakes. In addition, production would increase the chance of emissions of methane, a powerful greenhouse gas (World Oil, 1999). IIASA and WEC con-clude that the more than 55,000 EJ commercially/technically recoverable reserves are more than enough for energy consumption for more than a century; BP estimates the current (i.e. only the conventional) reserves at 40 years for oil and 60 years for gas.*

#### DEMATERIALISATION

Dematerialisation, the phenomenon that a developing economy uses steadily fewer materials per unit of added value, is partly the result of the previously mentioned shift towards a more service-oriented economy, but is also due in part to technological innovation: lighter products through improved material properties (for example, packaging), smaller appliances, the replacement of physical information with on-line information. The use of materials can also be reduced by life cycle optimisation, by using secondary rather than primary raw materials (recycling) and through the application of nano techno-logy. Dematerialisation occurs as the value per unit of material increases, for instance by adapting the product to the wishes of the user ('just in time'/service). In other words, the phenomenon incorporates both an efficiency effect and a structural effect.

#### CONCLUSION: THE DEMAND FOR ENERGY

In all Worlds the global demand for energy increases due to the growth of the population and prosperity, which is not sufficiently offset by a decline in energy-intensity (worldwide, average percentages per year 2000-2050): see table 3.

We conclude that the sensible course is to expect more than a doubling of the world demand for energy around 2050.

## 2. The supply of energy

The supply of energy is determined by the world's reserves of energy and the use of renewable energy, both in relation to the associated technology.

#### COMPOSITION OF THE ENERGY SUPPLY

Current world energy consumption amounts to around 400 EJ. Of this, some 355 EJ is 'commercial energy' (traded energy carriers) and the rest is energy for personal consumption (wood, harvest waste, manure). Of this 355 EJ, fossil fuels account for 90% (40% oil, 26% coal, 24% natural gas); the rest is electricity from hydro power and nuclear energy (BP/Amoco). The structural changes in the economy described in this annex (from agrarian, via industrial to the post-industrial service economy) has a counter-part in the energy supply. There has been a clear development through history from a period dominated by biomass (wood), via a coal, oil and gas era, to a future with low-carbon energy carriers: renewable sources and /or nuclear energy (see curve 3, Marchetti curve, IIASA 1978).

**TABEL 3**
*demand for energy*

| | Free trade | Ecology | Isolation | Solidarity |
|---|---|---|---|---|
| Economic growth | +3 | +2 | +2 | +3 |
| Energy-intensity | -1 | -1 | -1 | -1,5 |
| Energy demand | +2 | +1 | +1 | +1,5 |

**RESERVES OF FOSSIL ENERGY**

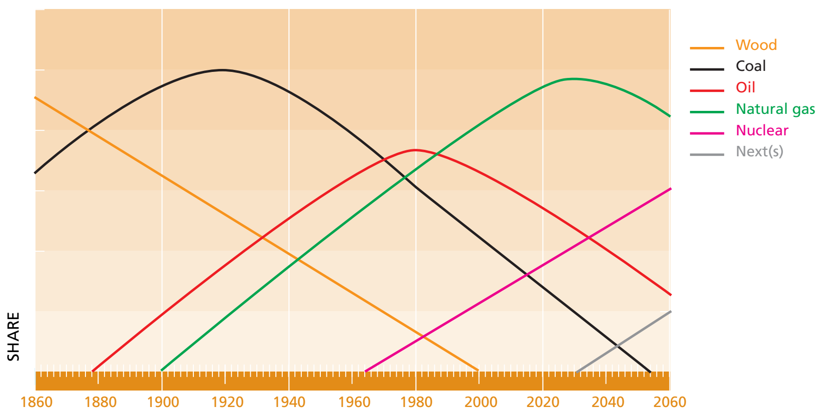
So the vast bulk of global energy consumption is based on fossil energy.
For the future energy situation it is therefore crucial to have some idea of what reserves there are in the world. There are two distinct dimensions at play here:
on the one hand, the geological likelihood that energy carriers will actually be found, and on the other hand, the technological/economic feasibility of recovering them.
The following estimates have been made (IIASA/WEC, 1998; in EJ): see table 4.

Non-conventional' means: low concentrations, the need for new recovery tech-niques and additional steps in conversion for use, and in most cases serious consequences for the environment from the recovery process. In its internal projections, BP does not include the heavy oil and tar sand because they are so demanding that the technology for refining and transporting them is similar to that for coal. In the estimate of reserves, 'incidental reserves' like methane hydrates (see box page 36) are also not included.

By contrast with these optimistic estimates are findings about the vulnerability of the world economy to disruptions in the supply of oil, for instance because of 'peaks' in oil production (see curve 4: the Hubbert peak). For instance, analyst C.J. Campbell argues that drilling for new oil reserves, despite improvements in methods of exploration, is occurring at a far slower pace than formerly ('we find 1 barrel for every 4 that we use'); that the demand for oil is still growing rapidly, at 1.8% per year from 71 million barrels per day now to 112 million barrels per day in 2020 (IEA); and that the world oil production will peak in the coming years and then (after 2008, when the OPEC countries have also passed their peak production) commence a steady decline. His conclusion is that the production of natural gas and non-conventional oil

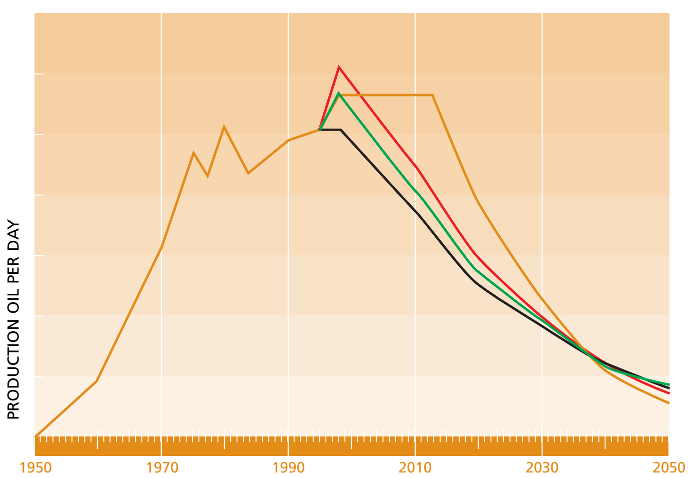
| **TABEL 4** *supply of energy* | Coal | Oil | Gas | **Total** |
|---|---|---|---|---|
| Conventional, commercially and technically recoverable | 26.000 | 6.300 | 5.900 | **38.000** |
| Non-conventional, commercially/technically recoverable | | 8.100 | 8.000 | **16.000** |
| (Not yet) commercially or technically recoverable | 117.000 | 20.000 | 22.000 | **160.000** |

**CURVE 3:** **MARCHETTI CURVE: GLOBAL SUBSTITUTION OF PRIMARY ENERGY**




[SOURCE: IIASA]

**CURVE 4:** **HUBBERT PEAK: PRODUCTION PEAK ACCORDING TO HUBBERT**




[SOURCE: CAMPBELL (1996)]

will have to increase quickly in order to meet the growing gap between oil supply and demand after 2015.

The figures for commercially and technically recoverable reserves incorporate expectations about the development of recovery and conversion technologies. Their development naturally depends on the World. Especially the direction of technological progress differs from World to World and will determine the supply in the coming 50 years. However, it is unlikely that totally unknown energy carriers or technologies will emerge.

#### COAL

Given its wide availability it is understandable that the share of coal (coal and lignite) in the world energy supply is relatively high. In countries like China (73%) and India (56%) it is the dominant source of energy, but the US is the major coal user (22 EJ, 25% of energy consumption) after China. The coal deposits in the earth's crust are more widespread than those of oil, so that countries can reduce their energy-dependence (particularly on the Middle East) by switching to coal. Development of national coal reserves also helps the balance of payments. Consequently, coal could play an important role in the world's energy future, especially in the Worlds 'Isolation' and 'Free Trade'. However, the use of coal could have quite serious environmental consequences, both locally (dust, waste), regionally (acidification) and globally (greenhouse effect).

#### CLEAN COAL

In the light of the potential drawbacks of using coal, the term 'clean coal' has been coined, covering a wide range of techniques designed to reduce the environmental pollution caused by the use of coal throughout the chain: see table 5.

In 'Ecology' (Nox and Sox free) and 'Solidarity' (also $CO_2$ free) these incineration technologies will be fully developed. In the other Worlds, attention will focus entirely on the easily avoidable damage to the immediate environment.

#### NUCLEAR ENERGY

Many energy scenarios incorporate a role for nuclear energy. An estimate of the world reserves of fissionable material is therefore important. There is a large quantity of uranium in the earth's crust; but the only fissionable isotope, Uranium-235, is only present in 0.7% of natural uranium. The 'proven economically recoverable reserves' amount to 4.3 million tonne of uranium (IAEA, OECD/NEA). With a light water reactor (LWR), approximately 37 GWh (130 TJe) can be generated from every tonne of natural uranium, so that this quantity represents electricity production of 18.3 TW years (580 EJe).

Beside these 'proven reserves' there is roughly another 7 million tonne available as a by-product of the production of phosphate and an estimated 'speculative economic reserve' of 13 million tonne.

With this additional 20 million tonne it would be possible to produce a total of 120 TW years (3700 EJ) of electricity, and that's not even counting the very poor-grade ores. IIASA/WEC estimates the available reserves of uranium for nuclear fission at around 2400 EJ; with current use of 24 EJ per year these reserves would be enough for 100 years.

The existing light water reactor (LWR) technology is, incidentally, not very efficient as regards the use of uranium, and is being used less and less. Although the NEA still sees prospects for (improved) LWRs, the IEA is already thinking of a new generation of reactors with a better fission economy and inherent safety.

Nuclear fusion is also mentioned as a possible source of energy for the long term. Nuclear fusion research in the last few decades has not yet produced a working, let alone commercially viable, fusion reactor. The EU does not expect one before 2060.

**TABLE 5:** *different techniques of clean coal*

| Position in the chain | Technique | Envisaged environmental effect |
|---|---|---|
| Recovery | Improved exploitation of field | Less wastage, larger reserves |
| Recovery | Less dust, waste | Improved local living conditions |
| Pre-treatment | Quality management | Constant quality (for incineration) |
| Incineration | Low NOx incinerators | Lower $NO_x$ emissions, less acidification |
| Incineration | Flue gas desulphurisation | Lower $SO_x$ emissions, less acidification |
| Incineration | Optimal incineration | Lower $CO_2$ emissions |
| Incineration | Coal gasification | Lower $CO_2$ emissions |
| Incineration | $CO_2$ storage | Lower $CO_2$ emissions |

**TABLE 6:** *radioactive waste*

Radioactive waste from the nuclear fuel cycle during production of 1 GWyear with a light water reactor:

| | |
|---|---|
| Mining waste | = 50.000 m3 grit of 1,85 TBq |
| Remains after enriching | = 200 tonne (with approx. 0.3 % U-235, which can possibly be enriched later). |
| Industrial waste | = 500 m3. After a year the activity is still 3700 TBq. |
| Nuclear fuel waste | = 5 m3. |

#### RADIOACTIVE WASTE

All Worlds envisage a role for nuclear energy for different reasons. Besides the (residual) risks during the operation of nuclear plants, the waste from the nuclear fuel cycle forms a barrier to social acceptance of this energy strategy. (table 6)

The major problem lies in the nuclear fuel waste. The radioactivity is so high that the waste has to be cooled. Around 10 years after discharge the radioactivity measures 370,000 TBq, after 300 years 370 TBq, but even then it remains radioactive for millions of years. The longest-surviving fraction in the nuclear fuel waste consists of plutonium and other actinides.
All nuclear plants on earth together now produce approximately 1 million kg of plutonium, not counting plutonium for military purposes. New techniques are needed to solve this problem. The effective life of nuclear fuel waste can be shortened to around 250 years (source: NRG) by fragmenting it in a new type of nuclear reactor, but this technique has not yet been fully developed.

#### RENEWABLE ENERGY

Besides the finite reserves of fossil fuels and uranium, there are in principle infinite supplies of 'renewable energy' such as solar rays, wind, sea and tidal flows, stored or otherwise in plant material (biomass). Annual solar radiation on earth amounts to 5,500,000 EJ. But the energy density of these streams is small. In practice, therefore, the supply of renewable energy is limited by the required and available land surface area. The future availability of renewable energy is also determined to a large extent by the expected progress with conversion technology. The current situation is as follows.

- ***Solar electricity (PV):*** Still in development. The most successful technique is with silicon cells; the development goes from mono, via polycrystalline cells to amorphous silicon cells with a corresponding fall in price. A lot of research is being conducted into so-called organic cells. A significant role is assigned to solar PV in many scenarios, especially where the emphasis is on autonomous or decentralised generation.
- ***Wind energy:*** Reasonably advanced technology; wind turbines are already used on a large scale in California, Denmark and Germany, for instance. Development is dedicated to further cost reduction and towards steadily larger units (from hundreds of kW now to a few MW per turbine soon) and offshore installation.
- ***Hydropower.*** Fully developed technology, with large-scale application, a cost price far below that of fossil energy. According to the available sources, there is only limited opportunity to expand current potential (in part because of environmental consequences).
- ***Wave and tidal energy.*** Up to now technology is only available to recover tidal energy in areas where the tidal difference is very large (Normandy). Recovery of wave energy is still at the stage of practical experiments (Portugal).
- ***Solar heat.*** Collector technology is now fully developed. Efficiency can still be improved through integration with other technologies, such as the heat pump. It is expected that this technology can assume part of the supply of hot tap water in buildings in temperate climatic zones, as is the case already in southern Europe.
- ***Biomass.*** Biomass is already widely used for heating and food preparation (ovens, stoves), although with a low yield. More advanced applications are electricity production (sometimes with simultaneous generation of heat in combined heat and power generators) and gasification. The latter is primarily suitable in regions that have a gas infrastructure or are building one. Most natural gas technology is also suitable for biogas, while biogas can also be converted to liquid fuels.
- ***Geothermal heat:*** Technologies are already available and in use (France, Italy); the applicability depends upon having a suitable source and appropriate drilling techniques.
- ***Ambient heat.*** Ambient heat can be used with heat pumps. The technology has been available for a long time; electric heat pumps are widely used in countries where electricity is cheap and fossil energy is relatively expensive.

With respect to the availability and use of renewable energy there are optimistic and pessimistic camps. In the pessimistic scenarios there is only room for biomass, 'traditional' and improved, and wind and solar energy are not competitive.
The optimists include, for example, the Renewables Intensive Global Energy Scenario (RIGES), developed in preparation for the UN Conference on Environment and Development (UNCED, Rio 1992) to investigate whether a sharp reduction of $CO_2$ emission by around 2050 would be feasible (see box).

Some long-term scenarios (Shell and BP/Amoco) also say that in 2050 half of the world energy supply will be based on renewable sources. But in other scenarios these companies are less convinced of a breakthrough by renewable energy. Similarly, the role of renewable energy also differs from World to World, according to the level of technological development (high in 'Free Trade' and 'Solidarity') and the willingness to pay more for energy self-sufficiency ('Isolation') or for environmental protection ('Ecology').

***Biomass and innovation***

*The project Renewable Technology Development (DTO'97) was very positive not only about the further development of biomass as an energy source, but also as a raw material for the chemical industry. By 2050, two billion hectares of agricultural land will be needed for food-production, which will leave 0.8 billion hectares over for production of non-food biomass. With a yield of 50 tonne per hectare per year, this would produce 40 Gtonne of biomass per year (plus roughly a further 10 Gtonne from forests and waste). DTO reserves 5 billion tonne per year as raw material for a 'renewable chemical industry'; this leaves 44 billion tonne for energy purposes. That is 200 EJ, or 20 to 25% of the world's energy requirement in 2040.*

**END USE OF ENERGY**

Energy is not sold to users in its primary form. For the energy user it is ultimately about performing a function such as preparing food, heating, lighting, power, movement. People's surroundings also impose requirements on the form in which energy can be available. To fulfil the energy functions in the manner that users desire, energy must be supplied in a practical form, as secondary energy carrier.
The greater the increase in prosperity, the more customers will demand more flexible, cleaner energy carriers which are easy to use. There are a number of trends to be seen in this development.

**ELECTRICITY**

Electricity is a secondary fuel of very high quality and hence has a high degree of efficiency in final use. It has the advantage that it is very clean to use and the electrical processes can be easily regulated, which makes it easier to use and more flexible.
In the digital society, the demands on the reliability of supply and the quality of the product will become even higher.
Disadvantages of electricity are that it cannot be stored and that relatively large losses are incurred when it is transported over longer distances. But convenience of use is decisive, which is the reason why electricity's share in growing energy consumption is expected to increase in most future scenarios.
Total electricity consumption is likely to treble in each World. An institution like the EPRI in fact argues that further electrification is an ideal development in itself ('every inhabitant of the world 1000 kWh or more').

The conversion of primary energy into electricity currently has a yield ('best practice') of around 55%. A conversion yield of 70% is feasible with fuel cells. Breakthroughs are also expected in the transport of electricity: by combining advanced drilling technology and the use of high-voltage direct current (HVDC), high-voltage lines can be laid underground, which could enormously improve the reliability of the system. In the longer term, super-conductive cables could mark the end of transport losses, which could be a step towards a worldwide electricity grid, encompassing all the optimal production locations for electricity (hydropower from Iceland, solar electricity from the Sahara).

**HYDROGEN**

Besides electricity, energy users in a developed energy economy also have oil products and often (natural) gas.
Both have a relatively high energy density and the associated technology for their use is widely available. Oil products have the further advantage that they are easy to store and that the distribution network is highly developed and relatively low-tech.
The drawback of natural gas is that it requires a distribution network. Both have the disadvantage that the emissions during combustion are discharged close to the end user. Acidifying emissions, dust and noise can be eliminated with end-of-pipe measures, but the diffusion of $CO_2$ only at high cost and with a great deal of

**TABLE 7:** *Renewables Intensive Global Energy Scenario (1993)*

| | 1985 | 2025 | 2050 | |
|---|---|---|---|---|
| Electricity | 9.200 | 22.300 | 33.850 | TWh per year |
| • of which renewable | 1.500 | 12.300 | 20.400 (=60%) | |
| Direct energy consumption | 220 | 290 | 300 | EJ |
| • of which renewable | | 88 | 130 (=40%) | |
| $CO_2$-emissions | 6,0 | 5,0 | 3,2 | GtC |

energy loss. So the search is on for technologies and energy carriers that combine the advantages of gas and oil with the possibility of capturing $CO_2$.

The conversion of hydrocarbons into a blend of hydrogen and $CO_2$ is one such option: the $CO_2$ is captured and users receive pure hydrogen.
Hydrogen can also be produced through electrolysis of water, for example where a lot of cheap electricity is available from hydropower or nuclear energy.

The first use of hydrogen seems likely to be in cars, given the enormous research budgets that have already been spent on it. Hydrogen would then be converted into electricity in a fuel cell.
This option fits in particularly well with the Worlds 'Solidarity' and 'Ecology'.
For stationary applications, a strategic choice is involved as to which fuel and hence which type of transport and distribution network best meets the wishes of customers: generate electricity centrally and then bring it to customers ('Solidarity') or bring hydrogen to the customers and allow them to produce their own electricity ('Ecology').

#### ENERGY STORAGE

Matching the supply of energy, such as the volatile supply of solar and wind energy, to the no less volatile pattern of demand usually calls for a form of storage.
But storage can also be necessary to guarantee the reliability of electricity supply.
In this context, the EPRI thinks in terms of both central storage systems (as is now the case with reservoirs) and storage systems for the users themselves.
But in the case of energy storage the cycle yield is relevant: energy is lost at each stage of storage and discharge.

#### CONCLUSION: THE SUPPLY OF ENERGY

There are sufficient reserves of energy even to meet a rising energy demand during this century. The supply of renewable energy can meet a substantial portion of the energy demand. The only question is what demands society will place on the energy supply, what energy carriers society will find acceptable, and at what price. This depends on the World. For all Worlds it is reasonable to assume that the next 50 years will see an end to the era of cheap oil. Further electrification of the world energy supply is also likely.

### 3. Matching of demand and supply: global

Future energy consumers will demand a reliable, affordable and clean energy supply. Socio-cultural factors, as they have been translated in the different Worlds, will determine the relative importance of these factors. What is certain is that $CO_2$ emissions from the use of fossil fuels will remain a burning issue for the coming period. These preconditions will now be reviewed for each World.

#### RELIABLE ENERGY SUPPLY

The formation or otherwise of global institutions will determine how and to what extent preconditions are imposed on particular aspects of the energy supply. In the 1970s and 1980s the IEA was founded and expanded to formulate common policy to guarantee the supply of oil to Western industrial countries.
The WTO is currently engaged in removing the existing barriers to world trade and will then act as an appeal body.
The UN organisation, the IPCC, is drawing up a common global policy to reverse the greenhouse effect. However, this is not a logical development in all Worlds.

In its recent global scenarios (1998) Shell gives its reaction to the, according to Shell, inevitable ('There Is No Alternative'), trends of globalisation, liberalisation and creation of an information society.
According to Shell, these trends manifest themselves on two levels:

- institutional ('TINA above'): globalisation of world culture and economy, liberalisation of world trade, reliance on information in relationship between customer and supplier;
- human relations ('TINA below'): globalisation of taste, liberalisation of ideas, multiplication of knowledge.
  With a strong 'TINA above' international institutions ('The New Game') have a powerful role; in the other case ('TINA below'), the future rests with flexible, less structured network relationships ('People Power').
- The New Game - companies and institutions are 'learning systems'; there is a lot to be gained by adopting the 'best practice'. Enlightened self-interest leads to strengthening of international economic, monetary and social institutions, as well as a global system of environmental rules ('Kyoto works').
- People Power - a non-conformist, prosperous world centred on the local community. Innovation and improvement of quality, also of the environment, are brought about by the actions of critical consumers rather than by regulation.

#### AFFORDABLE ENERGY SUPPLY

In all Worlds (except 'Ecology'), energy carriers are chosen on the basis of economic considerations: the 'basic price', possibly with the addition of the costs of curbing $CO_2$ emissions. In price studies (although they do not extend further than 2020) the world energy price is dominated by the oil price. The market is 'cost driven': the cost of production of oil is the decisive factor (besides specific market conditions such as the power of the OPEC cartel). From these medium-term studies (e.g. IEA, 2000) it is possible to identify

***Example: Equitable allocation***

*In 1995 each Dutch person, large or small, was responsible for $CO_2$ discharges of 11.6 tonne. An emission limit of 3.5 Gtonne of carbon (13 Gtonne $CO_2$) in 2050 for 9 billion world citizens represents no more than 1.4 tonne of $CO_2$ emissions per year for each world citizen. The average Dutch person would therefore have to cut emissions by 90%.*

a trajectory for the oil price that lies between $10 and $25 per barrel.
The reasoning is: with a structurally lower price than $10 the demand for oil would increase to such an extent that the price would quickly rise again; at an oil price structurally higher than $25, the more expensive, unconventional oil sources would be exploited, which would push down the market price.

Beyond 2020 the oil reserves which are now regarded as 'cheaply recoverable' will be exhausted. It is likely that by then a lot of substitution will already have occurred or be underway, for instance from oil to gas and nuclear energy in electricity production and from oil to hydrogen in transport. Once gas is the most important energy carrier, the world energy price will be determined by the costs of producing and transporting natural gas.
In some cases the costs of curbing $CO_2$ emissions have to be added ('environment in the prices'), if that fits in with the World in question.

Finally, even a world energy market dominated by renewable energy is 'cost driven', given the capital intensity of the technology required. Even in this market there are sufficient alternatives (such as solar PV) that will come onto the market as soon as the world market price of energy rises above their cost price.
This price mechanism assumes an open world market, as in 'Free Trade' and 'Solidarity'. In the other Worlds markets will be more fragmented.

**CLEAN ENERGY SUPPLY**

**THE $CO_2$ DEBATE**

The evidence that the climate is changing is increasingly strong. This change is being caused, among other things, by an increased concentration of 'greenhouse gases' in the atmosphere, of which $CO_2$ is the most important. In 1996 the IPCC commissioned a new series of possible scenarios, each of them presenting a single characteristic emission scenario. The $CO_2$ emissions in Gtonne of carbon per year is as follows (1995 = 7.4 Gtonne). (See table 8).
The 'characteristic scenario' B1 is normative: the IPCC sought an option for limiting the global $CO_2$ emissions to 3.5 Gtonne of carbon.

The reduction target is a translation of the agreements at the UNCED conference in Rio (1992). To prevent irreversible climate effects, the reasoning goes, the increase in temperature on earth must be restricted to 2 degrees compared with the pre-industrial revolution level. This means that the concentration of $CO_2$ in the atmosphere, which was 280 ppm, must not be higher than 450 ppm. The present concentration is already 360 ppm.
To achieve this, the emissions of greenhouse gases, especially $CO_2$, must fall. An emission level of 3.5 Gtonne of carbon per year is the maximum, according to this reasoning. That means that global emissions must be reduced by half, regardless of the development of population and prosperity. In Rio it was also agreed that

**TABLE 8:** *$CO_2$ emissions (Gtonne) IPCC*

| | 2050 | 2100 | trend after 2100 |
|---|---|---|---|
| A1 | 16 | 13 | decline |
| B2 | 11 | 13 | slight increase |
| A2 | 17 | 29 | sharp increase |
| B1 | 11 | 3,5 | stabilising |

the industrialised countries would take the lead in order to allow some leeway for the development of the 'South'. This is where disagreement arose, since it is then a question of an allocation of commitments and what is historically just. Rio will only be effectively followed-up in 'Solidarity'.

#### TRADE IN EMISSIONS

Emission trading could play an important role in the optimal allocation of the costs of reducing $CO_2$ emissions. The idea is that a country that reduces emissions by more than it is obliged to can sell this 'surplus' to countries that fail to meet their obligations. This means that there has to be a system of obligations to start with. Under the current Kyoto protocol emission trading is permitted between industrial countries themselves ('trading'), with Eastern Europe ('Joint Implementation') and with developing countries ('Clean Development Mechanism'). There are two basic variants to this emission trading:

- Tradeable emission rights: this refers to shares in an absolute emission ceiling. An advantage is that an absolute environmental target will also be met (subject to effective control and enforcement).
- Tradeable emission reductions: this refers to previously agreed emission reductions without the imposition of an ultimate target for the level of emissions.

The emission trade can take place between countries, but also within countries. The US already has experience with trade in acidification rights, in the United Kingdom an emission trading system will commence in 2001 and Denmark started such a system in 2000. In North America two transactions totalling 5 Mtonne in $CO_2$ emission rights have already been concluded.

An interesting development is that multinational companies are also experimenting with emission trading between production locations in different countries (Shell, BP/Amoco).

A system of tradeable emissions assumes the existence of a regulatory body, to ensure that the ceilings and control mechanisms work. After all, early a djustment of the environmental target disrupts the operation of the market by influencing price expectations etc.
On the other hand, the regulatory body can influence the size of the market and hence the total volume of permitted emissions by acting as buyer within the trading system. There will be no such powerful institution in any of the Worlds except 'Solidarity'.

#### TECHNOLOGY

In addition to efficiency improvement and the application of carbon-free fuels (renewable energy and nuclear energy), global $CO_2$ emissions can also be curbed by treating the exhaust gases from energy processes. It could well be that $CO_2$ is reduced even in the worlds without global collaboration because, for instance, major efficiency improvements partially resolve the problem.

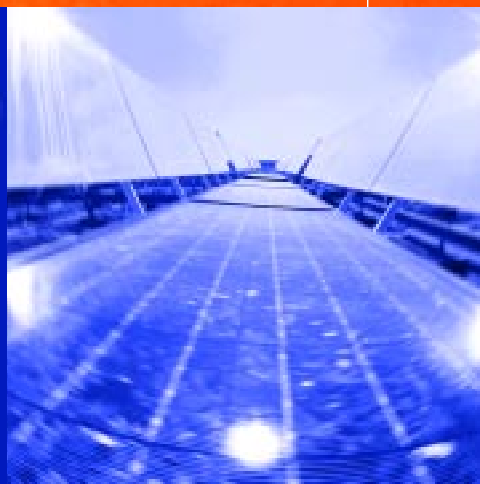
One idea is to capture and concentrate $CO_2$ before injecting it into empty natural gas fields, in aquifers or discharging it into deep seas, where it would remain sealed by the prevailing temperature and pressure (like methane hydrates). There are also a number of interesting catalytic conversion processes in development with which $CO_2$ can be bound, although these are still only at the laboratory stage.

#### OTHER ENVIRONMENTAL THEMES

#### LOCAL ENVIRONMENT

The use of energy in all its forms has not only environmental effects at a global level. In the coming decades it will be at least as important to know whether, and if so how, local and regional environmental consequences of energy consumption can be dealt with. In the World of 'Ecology' sustainability at the level of the local community is in fact the driving force, while they help to control global environmental problems like the greenhouse effect.

The coming decades will be marked by growing urbanisation. The combination of poor spatial planning, the lack of investment in mass transport systems and growing personal prosperity will lead to an enormous increase in road traffic, with all the environmental consequences (dust, acidification, noise) this will bring in its wake. Where the car has only arrived relatively recently or replaces unmechanised transport, it will also represent a significant share of the expected increase in world energy consumption. If car makers succeed in finding a solution for these local environmental problems, it will have a knock-on effect on the energy-efficiency of traffic and hence on $CO_2$ emissions.



**We can’t solve problems by using the same kind of thinking we used when we created them.**

**Albert Einstein**

*Annex*

II

*Demand for and supply of energy:*

# Western Europe and Netherlands

## 1. The demand for energy

***Composition of the energy demand***

**WESTERN EUROPE**

The use of energy is expected to rise, but to do so at a slower pace than the growth of national income ('decoupling').
In the Engel curve (part 1) we see a steady rise in the share of energy consumption for transport from a per capita income of around $22,000, the current level in the euro-zone. Energy consumption for transport and the accompanying environmental problems are therefore crucial in the coming decades.
Estimates of the development of the demand for energy are described in table 9.

These figures support the claim of WEA (2000): a more far-reaching cost-effective improvement in energy efficiency by 20-25% can already be achieved in the Western countries within 25 years.

All scenarios of the Netherlands Bureau for Economic Policy Analysis (CPB) include a sizeable share for 'industry' in the GDP: apparently the economy's shift to services comes to an end. In other words, industry will not disappear in this part of the world, but become more specialised. The degree and manner differ according to the World.

**THE NETHERLANDS**

The Netherlands currently has a high energy-intensity compared with other industrial countries. This is the net effect of a number of discrepancies both below and above the OECD average: the substantial share of basic industry, horticulture, car density and the level of comfort of Dutch homes all increase the energy-intensity; a downward effect comes from industry's relatively small share in the GDP, the small distances for transport, the widespread use of bicycles and the relatively low degree of electrification.

In the short term energy-intensity is not expected to decline and may even increase. The Netherlands is still a favourable location for the establishment of heavy industry thanks to the presence of ports for the import of raw materials and additives, good connections to the economically booming hinterland, a reasonably high level of know-how and cheap energy. These advantages could be built on in the coming years in those Worlds in which industrial activity remains welcome. Benchmarking, optimal energy-efficiency and responsible business practice contribute to preserving this public support.

Another energy-intensive sector, horticulture, is currently going through a period of reorientation. Its future very much depends on the development of the sector's export markets. Should they be lost, as in 'Isolation', a major restructuring of the sector cannot be ruled out.
Of the factors that currently still lead to a reduction in energy-intensity, the Nether-lands is rapidly making up its leeway on the OECD average in car density and electricity consumption.

**TABLE 9:** *growth of economy and energy in Western Europe*

| source | region | period | average growth per year | average growth energy demand |
|---|---|---|---|---|
| S&P-forecast | Western-Europe | 2020 | 2,3% | 0,9% |
| EU-DGXVII | EU-15 | 2020 | 1,6% - 2,3% | 0,8% - 1,3% |
| CPB | Western-Europe | 2050 | 0,2% - 1,6% | -0,1% - 1,2% |
| AIM96 | Western-Europe | 2050 | 1,8% | 0,5% - 1,2% |
| IIASA/WEC | Western-Europe | 2050 | 1,3% - 1,8% | -0,8% - 0,8% |

***Project perspective: Less energy consumption by changing a lifestyle?***

*In the period 1995-98 the Ministry of Housing, Spatial Planning and the Environment (VROM) conducted a major study into the relationship between lifestyle and energy consumption. Twelve families were challenged to reduce their direct and indirect energy consumption while their incomes were simultaneously rising. The result was that they used a third less energy than before the project, with the majority saved on 'indirect energy consumption'. The lifestyle of the participants seemed to change significantly ('selective consumption', 'choosing for quality') but it later emerged that their conduct reverted after the trial period.*

### *User groups of energy*

#### CONSUMERS

The Dutch population in 2000 is 16 million; according to the most recent estimates (CBS, 1998). by 2050 the figure will be between 15.7 and 18.9 million. In other words, in the former case a decline in the population compared with 2000; in the latter case the population will stabilise at a higher level around 2050.

The energy consumption of Dutch consumers has risen by a quarter in the last 15 years, due mainly to an increase in the use of electricity and the car. Efficiency gains in these areas have on balance been cancelled out by greater use. No distinct environment-friendly lifestyle can be discerned among Dutch consumers (SCP, 1999): Dutch consumers are consistently environmentally friendly- or otherwise- within a single domain of behaviour, but can display totally different conduct in another domain, for instance going in the car to the recycling centre. If doing something that is good for the environment costs time or money, or if people have to sacrifice freedom of movement or comfort for it, people will not do it. It is fair to assume that as Dutch consumers' prosperity increases they will opt for greater comfort ('enjoying life's luxuries'). The associated World is 'Free Trade'. This attitude is reflected in the desire for maximum ease of use in energy-consuming appliances, further electrification and the subcontracting of energy or 'comfort services'. At the same time, there are opportunities to sell a 'green' image.

#### DWELLINGS AND BUILDINGS

The number of dwellings and buildings depends on the size of the population, the average size of families and economic development (utilities, industry). The housing stock is expected to be between 7.5 and 8.5 million in 2030 (RPD, 1997); less is known about the development of offices and commercial premises. Apart from their number and their volume, the future energy consumption of the buildings also depends on the net effect of the trends towards energy-efficient building and towards increased comfort and greater intensity of use.

- ***Energy-efficient building:*** Buildings are a rewarding object for energy conservation measures: the techniques are known and can be easily applied, especially in new buildings.
  New buildings will therefore be more energy-efficient than existing ones; so through demolition and new building the average energy-efficiency of buildings will increase until building - related energy consumption stabilises at a low level due to the sharp decline in the marginal return. In other words, by 2050 it will not be the building or the installation, but consumer behaviour that dictates energy consumption.
  A feature of the World 'Solidarity' is a relatively large share of urban heating. In 'Free Trade' it is small-scale combined heat and power generation.
- ***Comfort:*** Consumers and employees demand more comfort in the home and at work, which can lead to a greater energy demand, for example for climate control (cooling). Greater comfort can a lso mean: larger and less compact building, larger windows - which directly conflicts with the trend towards energy-efficient building.
  Because these large comfortable buildings are more expensive to build and to use, continuation of this trend depends greatly on the development of prosperity.
- ***Intensification of use:*** flexible work-places lead to a higher effective utilisation of capacity of buildings, the 24-hour economy leads to a higher utilisation rate of the infrastructure. Dwellings will be used more often as

a second office, but at the same time individualisation and greater participation in the labour force may lead to less use of the home. Unless of course teleworking becomes popular. Spatial planning is becoming increasingly important for the level and type of energy supply. Compact building is relatively energy-efficient and offers possibilities for construction and exploitation of (residual) heating networks. This development is particularly likely if 'Solidarity' becomes reality. In this way, even more energy-efficiency can be achieved on scales larger than the home (see table 10).

**INDUSTRY**

Of the primary energy in the Netherlands (excluding feedstocks) 20% is presently used by industry. This share will remain the same until 2020 (S&P, European Outlook), as will the distribution between sectors (34% chemical industry, 13% base metal, 50% other). In this period the previously mentioned advantages for the establishment of companies will be enough to retain heavy industry and the chemical industry in the Netherlands, as for example in the World 'Solidarity'.
A large portion of the industrial energy consumption is used for the generation of processing heat (40% heat, 40% steam). The future lies in even more efficient techniques, especially processes without thermal, but with catalytic or physical, conversion (US DoE).

Energy is also saved by integrating the energy requirements of the various stages in a process through cascading of energy streams. Because of the nature of demand for industrial heat (60% of industrial energy consumption is low temperature heat) the heat pump will be widely used, sometimes in combination with its use for cooling. The remaining residual heat will be sold locally as far as possible.
Electrification is also increasing in industry. Electricity is increasingly used for drives, process control, conditioning, separation and recycling purposes, drying, baking, smelting, evaporation, and to initiate or maintain chemical reactions.
This situation corresponds closely with the World 'Free Trade'. In the more traditional

***Cutting edge technology in manufacturing industry***

*Application of a 'cutting edge technology' produces an abrupt improvement in energy-efficiency through a drastic change in the manufacturing process.*
*The payback period is 5 to 20 years.*
*Six technology groups are distinguished (ADL, 1997):*

- *Redesign of processes*
- *Advanced catalytic processes*
- *Process integration and inter-sector residual heat use*
- *Advanced process control and sensors*
- *Separation and drying technologies (e.g. membranes, impulse drying)*
- *Biotechnology*

*Blok et al (VCE 1996) concluded that applying this sort of system could lead to efficiency-improvement of from 60 to 90% in industry.*

**TABLE 10:** *Land use planning in the Netherlands in 2030 (RPD, 1997)*

*To get an idea of the claims on space and investment in the coming decades, in 1997 the RPD compared a number of development paths for the Netherlands:*

| NAME | VALUE ORIENTATION | SPATIL PATTERNS | CHOICE OF TRANSPORT |
|---|---|---|---|
| **Pallet** ***(See: Free Trade)*** | Freedom of establishment and movement | Combintions of living, working and recreation | Individual between, collective within cities |
| **Park landscape** ***(See: Solidarity)*** | Relaxation | City and country interwoven, green space is residential | Individual, regional, electronic superhighway |
| **Country of flows** ***(See: Ecology)*** | Trade and transport | Water and transport dictate | Collective, bundled and adapted |
| **Country of towns** ***(See: Isolation)*** | Separation of town and country | Concentration of living and working in urban network | Collective |

***Food and food production in 2040 (DTO 1997)***

*Trends in demand*

- *Greater variety, multiculturalism on the plate*
- *Convenience foods, several snacks throughout the day*
- *Health and quality: food is information*
- *'Green' and 'natural' products*

*Trends in supply*

- *Back to mixed, regional farms with closed bio-cycles*
- *High-tech crop production in greenhouses on solar energy*
- *Combination with raw material and energy production*
- *Combination with nature management and recreation*
- *Crop modification and vegetable 'meat' (novel protein food)*

electricity applications (drives) there are even greater efficiency gains to be achieved, forinstance through improved control technology.

Special attention has to be given to the use of energy carriers as raw material (feedstock), especially in the fertiliser and chemical industries. In the Netherlands this currently accounts for 40% of the final energy consumption in industry; world-wide it accounts for 6 to 8% of the total consumption of fossil fuels. The people in the DTO programme feel that the future raw material for the chemical industry will not be fossil fuels but biomass. See 'Free Trade'. They say that this will proceed via synthesis gas (the use of CO, $CO_2$ or $CH_4$, also know as $C_1$ chemistry), initially still on the basis of oil and natural gas, and later on the basis of vegetable matter.

#### AGRICULTURE AND LIVESTOCK

Agriculture currently takes up 70% of the surface area of the Netherlands, but in the future will take up less land than housing, work, recreation and nature areas.
In the next 30 years around a quarter of the existing agricultural land will disappear: "the total area devoted to agriculture declined by 55,000 hectares between 1980 and 1995, a surface area greater than the Noordoostpolder (....) and this process will probably continue" (RPD).
The future direction of the remaining agricultural sector depends greatly on which World one chooses: intensification and even industrialisation is possible, but extensification in the direction of nature and recreation-oriented enterprises is equally possible.
The greenhouse horticulture sector still has good opportunities in the event of strong economic growth and open markets, but with lower growth the current area devoted to greenhouse cultivation would decline by half (RPD).

#### TRAFFIC AND TRANSPORT

The energy consumption for traffic is dominant in the development of energy from a certain level of per capita income. In most Worlds there is a great demand for physical mobility, despite the increasing use of ICT. How this growing energy demand for traffic can be met differs widely; the technologies are there, but switching over to a different energy system takes a long time. The transition calls for a certain flexibility, so that the former system and the new one can function alongside each other.

**TABLE 11:** *lead time new systems*

| | SHIPPING | AVIATION | ROAD TRAFFIC |
|---|---|---|---|
| Scale | global | global/ continental | continental/ regional |
| technical concept - prototype | 5 -100 | 5 -100 | 5 -100** |
| prototype - demonstration version | 10 | 8 | 5 |
| demonstration version - 1st series production | 10 | 10 | 8 |
| phasing out of excisting production | 15 | 7 | 15 |
| last 'old' vehicle delivered * | 40 | 25 | 12 |
| **total lead time required** | **75** | **50** | **40** |
| in case of different feul: period with double energy-infrastructure | 55 | 32 | 27 |
| * possibilities for modification | yes | limited | no |

** for example, the Sterling engine: designed in the 19th century, still no prototype built.

Table 11 shows that a complete transition to a new propulsion system is unlikely even in a period of half a century: in 2050 the process is still proceeding.
A shorter transition phase is possible in the road traffic sector; shortening the transition period always means a certain capital destruction. Whether society will accept this depends on the World.
In principle, there are four conceivable technology paths for future mobility.

**a. Free trade: Further development ofexisting technology (internal combustion engines and gas turbines)**

- *Road traffic:* with the application of new motor control, better transmission and lighter materials, passenger cars could use half the fuel they use now. The potential for trucks is smaller. The nature of the transport demanded will also have an influence: a larger truck means lower energy consumption per tonne, but also requires the transport of large units and improved logistics.
- *Aviation:* In the aviation sector, the gas turbine is dominant (turboprop, turbofan and 'ordinary' jet); efficiency is an absolute requirement for carrying larger cargoes. Reliability and low weight are so important that they are delaying the introduction of new technology - new engines will have a very long experimental phase.
- *Shipping:* ships can adopt new technology more easily, but it will only be introduced if the costs fall to the current very low level. Ocean-going shipping requires that the engines can easily be repaired on board; even in this respect the simple internal combustion engine is difficult to replace.

The existing infrastructure of the car industry (production lines, suppliers) plays an important role. A lot of capital is invested in the automotive factories and car production represents a lot of jobs. Consequently, the interests of the car industry are often reflected in political positions.

**b. Isolation and/or Ecology: Transition to fuel cell on fossil fuel**

Forced by the government (especially in California), the automotive industry is focusing on the fuel cell to greatly reduce emissions of CO, $NO_x$ and VOS. These cars use oil products or biofuels as fuel.
An incidental benefit is that the drive line naphtha - reformer - fuel cell - electric engine gives a higher yield than the internal combustion engine; a reduction of around. 60% of energy consumption is possible. This technology is also attractive for heavy transport by road and on water as a means of meeting the emission standards. For shipping, the price of drive line and fuel is decisive.
Successful market penetration depends on the mass production of reliable fuel cells in various power classes at a price that is comparable to that of the current internal combustion engine. This means that the production price of the fuel cell still has to decline by a factor of 10 from today's price.

**c. Solidarity: Transition to fuel cell on hydrogen**

Another possibility is to feed the fuel cell directly with hydrogen, without the intervention of a reformer in the vehicle. Liquid motor fuels (oil or biofuel) will then be completely replaced by hydrogen.
The benefit of producing hydrogen centrally as opposed to in the vehicle (in the reformer) still has to be demonstrated. The technological development of hydrogen storage (metal hydrides, nanotubes etc.) will have to progress far enough to facilitate the transition, but this is not expected to happen before 2020 (Shell).

***From the petrol engine to the bio-engine***

*As an alternative to the dominant, because proven, automobile concept in the year 2000 (Otto or diesel engine, energy storage in the vehicle, oil products) the first thing people think of is the electric car. Advantages: simpler engine concept (constant revolution etc.), higher efficiency (the electric engine converts 90% of the electricity into purposeful movement, the combustion engine just 15%).*
*Disadvantage: electricity is difficult to store, recharging a battery takes hours, and the energy density is 80 time smaller than a petrol tank. Ideas are therefore moving away from the electric car to the electric car with fuel cell on hydrogen. Advantage: the fuel can simply be carried, is still 2 to 3 times more efficient the combustion engine.*
*Disadvantage: the low energy density of hydrogen. At normal T(emperature) and P(ressure) 36,000 litres of hydrogen are need to drive 500 km, so cryogen tanks and robotic filling stations are needed.*
*Another disadvantage: cooling hydrogen under pressure costs a third of its energy. So thoughts are turning to the fuel cell car on methanol, with a reformer to produce hydrogen while moving.*
*Advantage: the yield of the reformer, fuel cell and electric engine is 38%.*
*Disadvantage: steam reforming of methanol requires 280 degrees Celsius.*
*A second disadvantage is the $CO_2$ emission. So we finally arrive at a fuel cell car on methanol from biomass.*

Given the long production times in the automotive world this transition - if it is made - will certainly not be completed before 2050.Moreover, an entirely new fuel supply structure will have to be created. For aviation and shipping, developments are too slow to be of real significance in 2050.

### d. Ecology: Further development of electric vehicles

Important components of the car with fuel cell are also a part of electric vehicles. Practical storage in batteries will become available and there is certainly potential for electric transport in cities and for other shorter distances. But the question is whether electric transport over longer distances has advantages over vehicles driven by fuel cell or the internal combustion engine. Storage technology will have to be taken a few steps further for wider application.

An important factor is that the transition to electric vehicles can start soon and could proceed gradually or quickly: the infrastructure already exists.

## 2. The supply of energy

### Composition of the supply of energy

More than 80% of the primary energy consumption in Europe - at 75 EJ approximately 20 % of the world total - consists of fossil energy. The situation in terms of (Use (U), Production (P), and Reserves (R) is as follows: all figures in EJ, R/P and R/U in years (see table 12 BP/Amoco). These figures relate to the whole of Europe; Western Europe's own energy reserves are smaller still. The EU currently has 2% of the world's reserves of oil, 3.6% of gas, 12.4% of coal and 3% of uranium. Only Japan is in a worse position with regard to reserves. The oil and gas dependency of the EU will increase from 65% in 1995 to 80% in 2020 (Appert et al.); so Europe's primary energy demand is made up for 46% of oil and for 41% of gas. Matsuoka et al. (AIM96) see very little changing in the coming decades in the energy supply for Europe as a whole (including Central and Eastern Europe), except in the use and production of coal. According to them, this variation depends very much on whether a common $CO_2$ policy is pursued and therefore on the World. If the policy is aimed at stabilising $CO_2$ emissions, use and production of coal could stabilise at 8.5 to 17 EJ in 2050 (now: 10.5 EJ) Failure to reach agreement on reduction could lead to European coal consumption rising five-fold to 50 EJ in 2050. The consumption of oil and gas increases slightly and their production declines slightly in all scenarios. IIASA/WEC give the following projections (see table 13).

**TABLE 12:** *figures Europe (BP/Amoco, USGS)*

| Europe | Use | Production | P/U | Reserves | R/P | R/U | still undiscovered (USGS) |
|---|---|---|---|---|---|---|---|
| Oil | 31,8 | 13,6 | 0,43 | 113 | 8 | 3 | 125 |
| Gas | 16 | 10,3 | 0,64 | 196 | 19 | 12 | 330 |
| Coal | 14,7 | 10,9 | 0,74 | 2280 | 209 | 155 | |

**TABLE 13:** *projections for Europa*

| Europa | | IIASA/WEC 2000 | IIASA/WEC 2050 |
|---|---|---|---|
| coil | consumption of primary energy | 11 - 16 | 1,5 - 24,5 |
| | production | 8,5 - 10,5 | 1,25 - 12,5 |
| gas | final energy consumption | 9 - 11 | 8,5 - 22 |
| | consumption of primary energy | 12,5 - 14 | 10 - 30,5 |
| | productie | 8 - 9 | 6 - 7,5 |
| nuclear energy | consumption of primary energy | 8 | 5 - 41 |
| | production | 8 | 5 - 41 |
| oil | final energy consumption | 19,5 - 21,5 | 1,5 - 18 |
| | consumption of primary energy | 23,5 - 25,5 | 4 - 29,5 |
| | productie | 9 - 11,5 | 1,5 - 17 |
| final energy consumption | industry | 14 - 15 | 6,5 - 12 |
| | services | 15,5 - 17,5 | 14,5 - 28,5 |
| | transport | 13 - 15 | 8 - 23,5 |

A common feature of all scenarios is the growing demand for flexible, comfortable and clean fuel: electricity and gas.
This also applies for all Worlds, although the demand for clean energy does differ: in 'Free Trade' this demand is smaller, in 'Isolation' and 'Ecology' the demand only applies for the immediate environment.
In 'Ecology', the emphasis is also still on renewable energy and energy conservation.

While the non-OECD countries, especially in Asia, account for more than 50% of the worldwide energy demand, in the future natural gas will have to come mainly from the former Soviet Union (40% of the proven reserves), the Middle East and North Africa (together 30% of the proven reserves). If this gas is not exported, Asia will still depend on coal and Western Europe will face shortages.

### *Fossil fuels*

#### OIL

The Netherlands is an important link in Western Europe's oil supply chain: of the nearly 150 million tonnes of oil and oil products that are imported, each year 25 million tonnes are used in this country while a further 15 million tonnes are bunkered; the rest is held in the 5 refineries, with or without processing, for transhipment. At the moment 2/3 of this oil comes from the Middle East and 1/3 from elsewhere. Given the exhaustion of European sources, Europe's dependency on the Middle East is increasing again.
This oil dependency of Europe will increase in the next 20 years from 50 to 75%.
In and around Europe the oil situation is as follows: see table 14.

As reserves of good quality and cheap oil run out (see chapter 2) the price of crude oil will rise. Because the price of end products, such as petrol, is largely dictated by processing, duties and taxes, it will only be affected to a limited extent by this price increase. And given the low price elasticity it will do little to slow the demand for oil products for transport.
Apart from transport, the petrochemical industry, refining and bunkering will remain dominant users in the Netherlands.

Their mutual dependence, the proximity of markets, a favourable infrastructure and the 'lock-in-effects' of the huge investments needed mean that this industrial activity will remain in the Netherlands for the time being. A greater distance to the sources of oil and stricter environmental requirements could force these activities out of the Netherlands in the longer term.

#### NATURAL GAS

The European gas market has a more regional structure than the oil market because of the limited transport capacity. Western Europe's gas (from Norway, Germany, the Netherlands and the United Kingdom) will run out after 2020, particularly in 'Free Trade' and 'Solidarity'. The production will not be able to keep pace with the sharp rise in demand and more will have to be imported.
The dependence on imports is now 1/3, will be 2/3 in 20 years and almost total in 50 years. At the moment 3/4 of these imports come from Russia via pipelines, but in 2050 they will come from all the neighbouring gas fields (see table), along pipelines or in the form of LNG. The gas situation in the regions around Europe is as follows (BP 1999 and USGS 2000) See table 15.

Gas will be the most heavily traded fuel in 2050. Russia will then export 100 to 500 billion $m^3$ gas per year (which is 4 - 19 EJ; IIASA/WEC); in certain scenarios technological progress will mean that unconventional fossil and renewable energy will be possible sooner, in others there is strong growth in energy demand, but there are no alternatives available.

Whether the necessary pipelines and LNG transhipment infrastructure will be built in the next 50 years depends on the World: in 'Isolation' Western Europe is cut off from the gas sources in Central Asia and the Middle East; in 'Ecology' large-scale LNG imports are unwanted. The necessary infrastructure will also cost a lot, which raises the question (depending on the World) of whether there is a willingness to pay for it. For instance, the planned Yamal

**TABLE 14:** *oil production*

| Country/region | Crude oil production 1998 (PJ per day) | Proven oil reserves (EJ) |
|---|---|---|
| Norway and United Kingdom | 34,5 | 92 |
| Middle East | 132 | 3870 |
| Algeria and Libya | 17,25 | 230 |
| Nigeria | 11,5 | 132 |
| Russia | 40 | 373 |

**TABLE 15:** *natural gas production*

| Country/region | Crude natural gas production 1998 (EJ) | Proven natural gas reserves (EJ) |
|---|---|---|
| Europe | 11,5 | 190 |
| Middle East | 7,5 | 1900 |
| North-Africa | 3,75 | 225 |
| Nigeria | 0,2 | 150 |
| Russia | 27 | 2150 |

***Iran***

*With more than 20 trillion m³ of gas (750 EJ) in the ground, Iran has the second largest proven reserves of gas. Less and less of this is burnt off, more and more is consumed domestically and increasing volumes are exported. The exports have to be transported mainly by pipeline because Iran has no LNG factories. Iran has major plans for the construction of networks in the direction of India, Pakistan, Turkey, Ukraine and Central and Eastern Europe. In its long-term plans (up to 2020) Iran anticipates the end of its oil reserves and makes proposals to invest the last of its oil revenues in gas infrastructure (IEA, Middle East Oil and Gas, 1995).*

***Windy Europe?***

*Greenpeace has calculated what it would mean if 10% of the world's electricity requirements were met by wind energy in 2020: an installed capacity of 1200 GWe (now: 10 GWe) and output of 3000 TWh (now: 20).*

*In 1998, European wind power was 6.5 GWe. Germany was European champion with 3 GWe. The Greenpeace scenario for Western Europe is 220 GWe wind power in 2020 (of which 70 offshore) with annual production of 540 TWh: a thirty-fold increase. Why should Europe move in this direction?*

*Reason 1: wind energy produces annual savings of 3500 PJ in primary fuel, or 110 billion m³ of natural gas (at a STEG return of 55%).*

*Reason 2: this would mean a reduction of 215 Mtonne in $CO_2$ emissions in 2020, or 5% of the emission in that year.*

pipeline (capacity 60 - 80 billion m³ per year over 4000 km) will cost 25 - 30 billion $ (Energy Charter 1998). Other major pipelines to Europe are (Cedigaz, 1995): table 16

Within Western Europe the Netherlands still occupies a special position thanks to its extensive gas infrastructure and national reserves. According to the most recent data, there is still 800 billion m³ in known fields and a further 325 billion m³ is expected ('futures'). If production proceeds at the same pace as at present (75 billion m³ per year, Gasunie) the gas, including the futures, will run out in 28 years.

**OTHER GAS**

There are a number of gases that can be used as fuel. Besides natural gas (in various compositions), these are synthetic natural gas (SNG), biogas (a gas compound from waste or biomass), synthesis gas (a compound of carbon monoxide and hydrogen, similar to gas used in the past (coal gas) and hydrogen. Except for natural gas and biogas, the gases have to be produced. This can be done from renewable energy and from fossil energy, as is shown in the table below (Novem/GAVE, 1999). (table 17).

A far-reaching example of the use of 'another gas' is the 'hydrogen economy', which is based on the assumption of a gradual transition from natural gas to the use of hydrogen. The hydrogen needed would initially be produced from coal gas, natural gas or biomass and mixed with existing gas flows (admixture up to 17% hydrogen is no problem in the Netherlands' existing natural gas structure); the $CO_2$ that is released is captured and stored. In the longer term pure hydrogen would be used, produced

**TABLE 16:** *major pipelines to europe*

| Source | Destination | Capacity billion m³ /year / (EJ/year) |
|---|---|---|
| Russia | Europe | 60 - 80 (2,25 - 3) |
| Barents sea | Finland | 10 - 12 (0,38 - 0,45) |
| Turkmenistan | Turkey | 31 (1,17) |
| Libya | Italy | 8 - 10 (0,30 - 0,38) |
| Qatar | Europe | 30 (1,13) |
| Iran | Europe | 32 (1,20) |
| Russia | Turkey | 17 (0,64) |

**TABLE 17:** *types of gases*

| Source/raw material | Technique | Hydrogen | Synthesis gas | SNG |
|---|---|---|---|---|
| Biomass/coal | Gasification | X | X | X |
| Biomass | Pyrolyse | X | | |
| Biomass/natural gas | Plasma separation | X | | |
| Biomass | Fermentation | | | X |
| Electricity | Electrolysis | X | | |
| Direct sunlight | Various | X | | |
| Natural gas/oil | Steam reforming<br>Partial oxidation | X | X | |

by electrolysis of water with energy from sunlight or other energy sources with no $CO_2$ emission. In this theory, there would be hydrogen networks similar to the natural gas networks now; the hydrogen will be used in fuel cells (small-scale combined heat and power generation or cars). The development of the technology needed for this and the willingness to use it is most evident in 'Solidarity'.

**COAL**

Coal is and will remain the energy source of last resort for Western Europe, as in 'Isolation': there is enough, even in Europe itself (in Germany and Poland) and the prices are stable. Coal is used for the base load production of electricity and as feedstock; there is also proven technology for producing SNG and a liquid motor fuel from it. For some decades there has been a worldwide development towards the use of hydrocarbons with a lower carbon content (from coal to oil to natural gas). This trend will continue, especially if the fuel cell technology takes off (BP/Amoco). Even in Europe production and consumption of coal declines further each year under pressure from social and climate objectives. This trend may be reversed if it becomes possible to use 'clean coal' (annex 1) and carbon-free coal ($CO_2$ storage), or if imports of oil and gas are interrupted for any length of time.

***Non-fossil energy: renewable energy and nuclear energy***

**RENEWABLE ENERGY**

It is expected that renewable energy sources will be most popular for the production of electricity. In 2050 the cost price of power from wind energy will undoubtedly be competitive with other electricity.

In the Netherlands the capacity on land is limited because of competition with other potential uses; the maximum capacity from locations on land is
estimated at 2000 to 3000 MW.
The offshore potential is greater (larger capacities, more favourable wind), although this is offset by the costs of laying electricity cables. ECN estimates that the European offshore potential could be 15,000 MW by 2020; in 2050 it could be significantly larger if the North Sea countries make a clear choice in favour of it. In three of the four Worlds offshore wind energy is an attractive option: in 'Isolation' because of its contribution to energy self-sufficiency; in 'Solidarity' because of its contribution to reducing greenhouse gas emissions and in 'Free Trade' because it will eventually be a cheap source of electricity. 'Ecology' is the only World where its development is more modest because the large-scale nature of the technology is less welcome.

Production of electricity and heat from waste and biomass is expected to be normal practice by 2050, although the scale depends on which World materialises. In 'Ecology' and 'Isolation' the use of biomass is local, but in 'Free Trade' and 'Soldarity' it is internationally oriented. Energy production with PV is possible, so long as the assumed trend towards lower production costs and kWh prices through further R&D and progressive advantages of scale in the production actually come about. Depending on which World materialises, the roofs of the Netherlands and unused infrastructure (sound barriers, the Afsluitdijk) could be fitted with PV materials in 2050; large-scale PV stations at ground level are unlikely because of pressure of space.

***Integrated plant conversion***

*Green plants convert sunlight into chemical energy with an efficiency of 6.7% (Hall et al., Renewable Energy, 1993). Plants use only 50% of the sunlight they receive and only 80% of that for photosynthesis; and part of it is also used for respiration at night. So it would seem worthwhile to 'recreate' the photochemical process of green plants without these drawbacks. Conversion of sunlight into chemical energy with an efficiency of more than 15% is certainly feasible with such an 'artificial leaf'.*

***New renewable energy***

*Wave energy*

*various 'wave power generators' (0.1-1 MW) have been developed in the United Kingdom and Ireland since the first oil crisis. A Dutch invention is the Archimedes Water Swing [Schommel] (2 MW pilot, 8 MW operational version).*

*Tidal energy*

*in Europe there are more than 100 places that are suitable (potential 50 TWh per year) for tidal power stations. A new development is the 'underwater mills' (Seaflow, prototype 300 kW); a trial project in the Netherlands involves an 800 kW power plant in Vliestroom.*

*Geothermal heat*

*the temperature gradient in the earth's crust is approximately 3 degrees per 100 metres. Warm water with a low temperature is available at shallow depths; at deeper levels (2 to 3 km) there is 'hot dry rock' at 100 to 200 degrees.*

***Accelerator Driven Systems***

*At the European research centre CERN, a team including Professor Rubbia has developed an entirely new type of reactor. This Accelerator Driven System (ADS) consists of a high-energy proton accelerator and sub-critical (breeder) reactor. The former uses a lot of energy, but fission in the breeder reactor produces many time as much. This method also provides a solution for the problem of the radioactive waste: the most dangerous, longest-surviving isotopes are transmuted. The entire system is passively safe, but the costs of electricity production will probably be substantial.*

***Nuclear Europe ?***

*The European Commission has looked into what is needed in the coming decades to preserve the share of nuclear energy. Given the growth of electricity consumption, this would signify 40 GWe in extra nuclear power stations in 2025 and replacement of a further 60 GWe (the total nuclear capacity would then be 164 GWe).*
*A consequence of this is the production, up to 2025, of 975 tonnes of plutonium and 2655 tHM of spent nuclear fuel per year.*
*Why should Europe follow this course?*
*Reason 1: nuclear generation saves 7000 PJ in primary fuel each year, or 220 billion m$^3$ of natural gas (as a STEG yield of 55%).*
*Reason 2: nuclear generation means 423 Mtonne less $CO_2$ in 2025, or 11% of the $CO_2$ emissions in that year (3650 Mtonne in the Conventional Wisdom scenario).*
*Each Mtonne $CO_2$ emission reduction per year represents 6.2 tHM extra spent nuclear fuel.*

The manner in which renewable electricity is delivered to customers very much depends on the available infrastructure and the World. Especially in ‘Ecology’ and ‘Isolation’ PV is ideal for decentralised energy supply; biomass can be processed in large centralised units but also in small, decentralised installations for particular customers. Matching the demand to supply calls for storage systems. These can be central (at European level reservoirs in Switzerland and Scandinavia, as in ‘Free Trade’, or at national level a reservoir in the North Sea or via central hydrogen production, as in ‘Isolation’) or local (batteries, hydrogen production).
Renewable energy sources can also be used to produce heat (solar boilers, ambient heat, bio-combined heat and power, terrestrial heat). The drawbacks of heat transport (energy loss, cost) mean that this heat will generally be used locally; in other words at the level of dwelling or district. These options will probably be included as standard in the design of buildings. Heat pumps can be generally used in non-residential building (combined cold and heat supply).

#### NUCLEAR ENERGY

Western Europe currently depends for one-third of its electricity supply on nuclear energy. However, if built new the most common type of reactor, the LWR, is not economically competitive with gas-fired steam and gas turbine plants (STEGs). Dutch public opinion is massively opposed to the use of nuclear energy because of the (small) risk of a major accident.
There is also the question of radioactive waste, which is reduced but not resolved with LWR-technology.
Research is underway into nuclear technologies without these drawbacks.

In any case, the new nuclear reactors will have to be inherently safe: the High Temperature Reactor (HTR) meets this criterion. Secondly, the waste problem has to be resolved in a socially acceptable way: techniques are being developed to significantly shorten the life of radioactive isotopes (from tens of thousands to hundreds of years). Finally, the investment costs can be reduced further: through greater simplicity, modular construction and serial production the costs of power from HTRs can probably be half those of STEGs. In principle, as is expected in ‘Solidarity’, in a few decades inherently safe nuclear power stations will be able to meet a large proportion of the Netherlands’ electricity needs.

### 3. The route to the user

Western Europe and the Netherlands have a highly developed network structure for energy. In the Netherlands everyone who wants to be is connected to the electricity grid and gas network. For a long time the supply on this network (production capacity, product quality, balancing of technological and economic factors) was centrally directed, but now the network managers are only responsible for a minimum of quality and maintenance requirements.

Some improvements in the quality of the energy supply, such as greater energy-efficiency, are still feasible within the existing frameworks, but more extensive innovations will require a new infrastructure. For instance, the 'clean fossil' option will require technologies and an organisation for capturing, collecting and storing $CO_2$; this option will also require a distribution channel for hydrogen. The use of renewable energy involving substantial input from intermittent sources (sun, wind) will probably call for a new measurement and control system in the electricity grid as well as energy storage to match supply to demand. On the other hand, it is debatable whether large-scale networks will still be needed if consumers switch to autonomous systems. Such a small-scale energy supply, connected to consumers, fits in with 'Ecology' and 'Isolation', which are based on far-reaching individualisation or the primacy of local communities. Moreover, it represents a reversal of the trend in energy technology: whereas until recently up-scaling (coal, nuclear, wind energy, energy transport) was a benefit, technologies are now emerging (fuel cell, small-scale combined heat and power, heat pump, solar PV) which actually offer advantages for consumers when applied on a small scale.

#### INFRASTRUCTURE FOR GAS

Gaseous energy carriers have the advantage that losses are small during transport, so that they are highly suitable for energy transport over long distances. Other advantages are security of supply, flexibility in terms of capacity and the possibility of storing them to cater for fluctuations in demand. There are a number of conceivable scenarios for the use of gaseous energy carriers:

- Central conversion of natural gas (from the pipeline or LNG) into hydrogen, $CO_2$ capture and storage, distribution of hydrogen as energy carrier
- Use of a compound of natural gas and (locally produced) hydrogen
- Use of natural gas and SNG in transport and distribution network
- Transport network for natural gas/ SNG and distribution network for hydrogen

The gaseous energy carrier is then converted by consumers into electricity and heat. The scale on which this happens determines the method of conversion, as well as the flexibility in final energy carriers.

The Netherlands occupies a special position in Europe as regards the size of the share of natural gas (50%) in primary energy consumption.
The Netherlands consequently has a substantial gas transport and distribution network (12,000 km high pressure gas transport network, 110,000 km distribution networks).
The bulk of this network was laid in the 60s, although parts of the local network date from the earlier period of urban gas. Estimates of the useful life of a gas network range from 50 to 80 years.
The estimated cost of replacing just the distribution networks of the energy companies is around 15 billion guilders.
A large part of the current network will, unless drastic uneconomic measures are taken, still be useful in 2050.
In principle, all gaseous energy carriers can be transported along the Dutch pipeline network, although modifications will be needed for gases of a very different type.

The quality of the natural gas for small consumers in the Netherlands is presently very consistent (narrow Wobbe bandwidth). If manufactured gases and mixes of gases are used, it will be more difficult to maintain this constant quality. A wider margin will probably be needed if a number of gases and gas mixes are used.
Appliances will have to be adjusted accordingly. Since the economic life of appliances is not usually longer than 20 years, this choice does not have to be made yet. A great variation in gas quality means that the appliances will be slightly less energy-efficient, but the yield across the entire gas chain could increase. In the worlds 'Free Trade' and 'Solidarity' by 2050 natural gas or SNG is expected to form the basis of the gas supply, possibly mixed with hydrogen. A transition to hydrogen only occurs if that option is explicitly chosen (as in 'Solidarity') or if the circumstances dictate it (as in 'Isolation': European hydrogen production with electricity from large-scale wind parks or nuclear power plants. In 'Ecology' local or regional use of hydrogen-rich gas mixtures is a realistic option.

Depending on the necessary flexibility in demand and the variation in the supply, storage of gas will be necessary. At the moment, by comparison with other European countries the Netherlands invests little in storage capacity for natural gas. Storage is now primarily intended to meet peak demand for gas, for instance on very cold days; storage is also needed because the capacity of existing gas fields will be inadequate. Natural gas is currently stored

***Direct current***

*Improved power electronics will in the long term make it possible to use HVDC (high voltage direct current). Electricity can then be transported by underground cables so that the above-ground high-voltage network will become redundant. Despite the higher costs the advantages in densely populated areas are evident. With this new technique electricity can also be transported over long distances with minor losses, which opens up unprecedented possibilities for energy transport: it is not the primary energy carrier that is transported but the electricity that has been produced. HVDC is therefore an alternative for long distance gas transport, for example: Norway and Russia then evolve from natural gas exporters to electricity exporters. Finally, this technique offers the possibility of providing the optimal scale and location for renewable energy systems (large wind turbines far out at sea, PV in thinly populated remote areas) and of exploiting in marginal offshore oil and gas fields by converting the fossil fuel into electricity on the spot.*

in empty gas fields, in the form of LNG and in the form of linepack in the pipeline system. In future energy may need to be stored to cope with day/night variations, week/ weekend variations or seasonal variations in demand. The choice as to the form of gas storage depends on energy requirements and the system:

- Central conversion of natural gas (from the pipeline or LNG) into hydrogen, $CO_2$ (or C) capture and storage, distribution of hydrogen as energy carrier: central storage of hydrogen needed for seasonal variations. Smaller variations can probably be accommodated within this.
- Use of a mix of natural gas and (locally produced) hydrogen: seasonal storage for natural and local storage at hydrogen production points (day/week).
- Use of natural gas and SNG in transport and distribution network: seasonal storage at production points SNG Transport network natural gas/ SNG and hydrogen distribution network: see above.
- the seasonal peak could pose a problem particularly where gas production is decentralised.

#### INFRASTRUCTURE FOR ELECTRICITY

The existing electricity grid consists of high, medium and low-voltage sections. The (above-ground) high-voltage section is 8,500 km long, the length of the underground section is 100,000 km.
The installations in the electricity infrastructure are so robust that they last longer than 35 years. The average lifetime of the components in the Netherlands' electricity network is 25 years, but there are electricity cables that have lasted 100 years.

The function of the electricity network is changing in a number of respects.
The high-voltage network, once constructed to increase the security of supply to energy consumers by connecting ('linking network') the various power plants, is increasingly a medium for electricity trading. This new function also calls for new techniques, such as FACTS (Flexible AC Transmission), which enables electricity flows to be managed.
The medium and low-voltage networks are also suitable for transporting information, so that they can in principle assume the function of telephone and tv cables.
Electricity trading, a wide range of producers (including some small-scale, local) and consumer demands (such as differentiation of charges and the possibility of changing suppliers) and the permanent requirement of network stability all present a major challenge for measurement and control technology.
The development of the electricity grid depends to a certain extent on the World being considered. In 'Free Trade' and in 'Solidarity' we expect a strong link to the European high-voltage infrastructure.
In 'Ecology' and 'Isolation' that link is far weaker and local weakly linked sub-netw-orks are used at national level, which fits in with the highly decentralised electricity production.

Because of renewable energy's growing share in electricity generation, in future electricity will be stored on both a large and a small scale. Small-scale electricity storage will be mainly in hybrid vehicles. Due to the large numbers their total capacity can be regarded as large-scale sto-rage for the day/night cycle.
Other forms of large-scale electricity storage for the day/night cycle (for instance in a storage basin in the North Sea) remain expensive, although forms of electricity storage are developed for much shorter periods. Consequently it is easier to meet peak demand and energy from bra-king and/or falling, for instance of lifts, can be recovered.

#### INFRASTRUCTURE FOR HEAT

For energy and economic reasons there will also be no transport of heat over large distances in 2050. There will be heat distribution in some residential areas, especially when natural gas is no longer automatically used to heat spaces. In many cases it will involve distribution of heat at a low temperature (for instance, industrial residual heat) which can only be used to heat spaces. Existing heat distribution networks will use cascades: the heat returned from existing distribution would be input for new heat networks at a low temperature. A special form is the use of heat pumps with source distribution, in which there is scarcely any loss of heat and distribution of cold is also possible.

Heat distribution will be linked to various sources. With industrial (residual) heat the problem remains that it becomes available too far away from areas where it is used and the collection of different heat flows is relatively expensive. Heat is also released from large-scale electricity generation, (biomass) combined heat and power and geothermal heat. Other possibilities are collective heat pumps using industrial residual heat as a source, but also surface and ground water. The most extensive heat infrastructure is likely in Isolation, where the greatest emphasis is placed on the extremely efficient use of the remaining indigenous energy sources ('The Netherlands as a CHP country').

#### LOCAL ENERGY SUPPLY

In a 'local energy supply' energy consumers produce as much as possible of the fuel they need themselves. It is generally assumed that the share of local supply will increase in the Netherlands. The ultimate size of this share depends on the World and the weight attached to the advantages and disadvantages. Advantages of local systems are consumers' independence, the greater flexibility and hence the better manageability; in addition people with their 'own' supply may tend to be more energy-efficient. A disadvantage is that the systems are often over-dimensioned for a completely autonomous supply (in other words: always able to meet any demand, 'island company') and if not, a large network of back-up, transport and control systems will still have to be maintained involving very many actors. An advantage of an archipelago of island companies would be the relative insensitivity to breakdowns: if one breaks down it does not automatically lead to a reaction in the rest of the system.

Techniques for local energy supply include solar PV, solar thermal, small-scale combined heat and power and heat pumps. These are largely techniques which are only starting to be developed.
With their successful introduction wind and coal will become less important as primary energy sources and sun, gas and maybe biomass will become more important. Storage systems will be needed, local or otherwise, because generation and use do not occur simultaneously, and in order to increase reliability. A local supply will in any case call for further technological development, of the systems themselves and of the (local) storage systems.
A local supply also requires close collaboration or co-ordination between the various actors and between demand and supply; this might involve partnerships, co-operatives or other institutions at local and regional level. Given these prior assumptions a local supply will flourish mainly in a social/political climate where independence, self-sufficiency and a clean environment are nurtured.

***100% local - how would that look?***

*Dwellings and buildings:*

- *every building has a solar collector and PV roof, and*
- *either all buildings have their own small-scale combined heat and power plant, heat pump or fuel cell*
- *or there are heat pumps or small-scale combined heat and power plants at district level*

*Industry and agriculture:*

- *every industry has its own combined heat and power plant, for instance STEG or small-scale combined heat and power plant*
- *as many solar collectors, PV and/or local wind energy as possible*

*Traffic and transport:*

- *either local production of hydrogen for the car on fuel cells*
- *or electric cars that are charged at local PV or combined heat and power installations*

*The heat pumps run on locally produced electricity; the combined heat and power plants and fuel cells on locally produced biogas or hydrogen.*

***More of the same - how does that look?***

*Energy production:*

- *Electricity from wind or imported;*
- *Solar panel on the roofs*
- *Maximum possible combined heat and power production*
- *Coal consumption, coal gasification and gas consumption with $CO_2$ storage*

*Dwellings and buildings:*

- *Heat pumps*
- *High efficiency boilers and/or small-scale combined heat and power generation on natural gas, biogas or SNG*

*Traffic and transport:*

- *Hybrid cars with biofuel*
- *Cars with fuel cells*

**'MORE OF THE SAME'**

In its publication 'Energytechnologie in het spanningsveld tussen liberalisering en klimaatbeleid' [Energy Technology in the conflict between liberalisation and climate policy] ECN refers to the risk of a dead-end: as a result of further but not spectacular improvements to existing energy systems and the absence of a driving force behind long-term projects, there will be no system innovations, let alone a transition to a totally new energy supply.

There is always the temptation to take the easiest option which involves the least possible change. This attitude could mean that the energy supply continues in the old way for as long as that is possible.
An example of this mindset is using the existing infrastructure as much as possible because building a new infrastructure is expensive, difficult and risky. If this happens, it is legitimate to forecast that the final energy carriers in 2050 will be practically the same as today's: electricity, liquid and gaseous hydrocarbons.

If finding a solution to the $CO_2$ problem remains urgent, which is expected to be the case in the worlds 'Ecology' and 'Solidarity', the electricity has to come from non-fossil generation and the liquid and gaseous energy carriers will have to be replaced by more renewable energy forms, for which only biomass is suitable at the moment.
Because the Netherlands cannot produce the necessary quantities the energy supply will be heavily dependent on the biomass exporting countries. Such a scenario implies, among other things, $CO_2$ storage, hydrogasification of biomass for the production of SNG and production of bio-petrol and diesel.

Although the greatest possible use is made of the existing infrastructure, modifications will also be necessary in this case.
For instance, in the event of the large-scale use of SNG it will have to be stored to cope with the variation in demand and production, space and technology will be needed for $CO_2$ storage, and large quantities of solar, wind and nuclear power will be imported to meet the electricity demand.

Such a development requires that global environmental problems, such as $CO_2$ emissions, are not regarded as predominant. Confidence in technological progress is also required. If it is later decided to switch to innovation in the energy supply after all, but then on the basis of the existing infrastructure, imported electricity and biomass will be the main energy sources. But this will call for a properly functioning (world) market.

# List of acronyms

| | |
|---|---|
| ADL | Arthur D. Little |
| AER | National Energy Council |
| AIM | American Institute of Mining |
| CERN | Conseil Européen pour la Recherche Nucléaire |
| CPB | Netherlands Bureau of Policy Analysis |
| DTO | Renewable Technological Development |
| ECN | Netherlands Energy Research Centre |
| EPRI | Elektric Power Research Institute |
| IAEA | International Atomic Energy Agency |
| IEA | International Energy Agency |
| IIASA | International Institute for Applied Systems Analysis |
| IPCC | Intergovernmental Panel on Climate Change |
| NEA | Nuclear Energy Agency |
| NRG | Nuclear Research and Consultancy Group (joint venture ECN/KEMA) |
| OECD | Organisation for Economic Co-operation and Development |
| RPD | National Land Use Planning Agency |
| SCP | Social and Cultural Planning Office |
| S&P | Standard and Poor's |
| STT | Netherlands Study Center for Technology Trends |
| TNO | Netherlands Organization for Applied Scientific Research |
| UN | United Nations |
| UNCED | United Nations Conference on Environment and Development |
| USBoC | United States Bureau of Census |
| USDoE | United States Department of Energy |
| USGS | United States Geological Survey |
| WB | World Bank |
| WEC | World Energy Council |
| WTO | World Trade Organisation |

| | | | |
|---|---|---|---|
| kilo | k | 1000 | $10^3$ |
| Mega | M | 1000 kilo | $10^6$ |
| Giga | G | 1000 Mega | $10^9$ |
| Tera | T | 1000 Giga | $10^{12}$ |
| Peta | P | 1000 Tera | $10^{15}$ |
| Exa | E | 1000 Peta | $10^{18}$ |

| | |
|---|---|
| J | Joule |
| $CH_4$ | methane |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| $H_2$ | hydrogen |
| $H_2O$ | water |
| $H_2S$ | hydrogen sulphide |
| $NO_x$ | nitrogen oxide |
| $SO_2$ | sulphr dioxide |

# Index of literature and sources


| | |
|---|---|
| AER | Government policy on the long-term energy supply, 1999 |
| BP/Amoco | Statistical review of world energy, 1999 |
| Cal-Tech | http://mars3.gps.caltech.edu/whichworld/index.html |
| CPB | Working paper, no 110, Globalization, International Transport and the Global environment: four quantitative scenarios, 1999 |
| CPB | Worldscan, the core version, 1999 |
| Cedigaz | Planned gas pipelines around the world, 1995 |
| Cedigaz | The european gas market players, 1997 |
| Cedigaz | Natural gas in the World: 1998 survey, 1999 |
| ECN | High Temperature Gas Cooled Reactor Applications and Future Prospects, 1997 |
| ECN | Levensduurverkorting Radioactief Afval [Reducing the life of radioactive waste], 1998 |
| ECN | Nationale Energy Verkenningen [National Energy Outlook]1995-2020, 1998 |
| ECN | 'Energytechnologie in het spanningsveld tussen liberalisering en klimaatbeleid' [Energy Technology in the conflict between liberalisation and climate policy] |
| Economist | www.economist.com |
| Ecosystems | www.hubbertpeak.com |
| Edesign News | http://fcn.state.us/fdi/edesign/news/ |
| Energy Charter | Energy transit, the multilateral challenge, 1998 |
| EPRI | Technology roadmap, 1999 |
| ETF | http://www.nrcan.gc.ca/es/etf/default.html |
| European Commission | European Union Energy Outlook to 2020, 1999 |
| European Commission | Economic Foundations for Energy Policy, 1999 |
| Gashydraten | www.sciam.com/explorations/1999/122099hydrate/ |
| Greenpeace International | Windforce 10, 1999 |
| Hammond, A, | Which World? Scenarios for the 21st century, 1998 |
| IIASA | The dynamics of energy systems and the logistic substitution model, 1979 |
| IIASA/WEC | Global Energy Perspectives to 2050 and beyond, 1997 |
| IIASA | Towards New Infrastructures in Eurasia: a background paper, 1999 |
| IEA | Natural Gas Transportation, 1994 |
| IEA | Middle East Oil and Gas, 1995 |
| IEA | Energy technologies for the 21st century, 1997 |
| IEA | Energy and climate change, 1997 |
| IEA | World Energy Outlook, 1998 |
| IEA | Mapping the energy future, 1999 |
| IPPC | Emissions Scenarios, 2000 |
| Maisonnier et al, Cedigaz | World LNG outlook: a new market?, 1996 |
| Ministry of Economic Affairs | Energy Report, 1999 |
| MIT | Economic development and the Structure of the Demand for Commercial Energy, 1998 |
| Novem | Een energie klimaat voor neutrale dragers, eindadvies van de inventarisatie van het GAVE-programma [An energy climate for neutral carriers, Final report on the inventory of the GAVE programme] December 1999 |
| NRG | High Temperature Reactor Research at NRG, 1999 |
| OECD | China in the 21st century, 1996 |
| OECD | The Kyoto protocol, action of climate change |
| OECD | Framework to measure sustainable development |
| OECD | Energy The next 50 Years, 1999 |
| OECD | Future Program, Future Trends 5 cd-rom Database, 1999 |
| OECD | The future of the global economy: Towards a long boom?, 1999 |
| OECD | 21st century technologies: a future of promise? 1999 |
| Scientific American | www.sciam.com |
| Standard & Poor's | Oil market outlook, long-term focus, 1999 |
| Standard & Poor's | World energy service, European outlook volume II, 1999 |
| STT | Electriciteit in perspectief [Electricity in perspective], 1992 |
| STT | Stroomversnelling [Power on the move], 1999 |
| UN | World population prospects |
| Wolters, prof.dr.ir. M. | Renewable Gastechnologie voor de 21e eeuw, [ Renewable gas technology for the 21st century], Oration 11 May 2000, University of Twente |
| World Energy Assessment | Energy and the challenge of sustainability, 2000 |
| World Energy Council | www.worldenergy.org |
| World Future Society | http://www.wfs.org/ <http://www.wfs.org/> |
| World Watch Institute, Washington DC | www.worldwatch.org |
| USGS | |


**COLOPHON**

This discussion paper was written by the Energy Supply Long-Term Vision project group at the Ministry of Economic Affairs, Directorate-General for Energy for the Conference Energy and Society in 2050: The Netherlands in Different Worlds.

Text editor - BMT, Jan Noordhoek
Design - Looije Vormgevers, Adwin Looije
Translation - Wordsmiths Translations

**This is a publication of the Ministry of Economic Affairs**

The Hague, December 2000