SenterNovem

EOS Long Term

Energy Research Strategy

The Netherlands

November 2004

CONTENTS

Introduction

This report covers the research programmes for long-term energy research within the five research areas of the new EOS (energy research strategy). These programmes describe the research proposals thatcan be submitted within the framework of the 'Long-TermEnergy Research Subsidies Act'.

EOS

The Dutch Ministry of Economic Affairs (known as EZ)began reviewing its research policy in 2001. There were several reasons behind this, e.g. the upcomingliberalisation of the energy market, increased internationalisation and the changing role of thegovernment. This review led to a new Energy Research Strategy (known as EOS). The main focus of this strategy concerns:

1. Focusing publicly funded energy research on a limited number of themes;
2. More efficient use of the available resources;
3. Strengthening international collaboration.

These points were discussed and approved bypoliticians in the Dutch Lower House in December 2001[1]. The implementation of this decision began in 2002.

R&D portfolio

In 2002, the Ministry of Economic Affairs asked market parties and knowledge institutes which focal points they would choose for the energy research. The question was: how did the 60+ research areas (chosen bythose involved) score according to the criteria:

- Contribution to a sustainable energy economy (in 2010 and 2030);
- Knowledge level for this option in the Netherlands.

This market research generated data for differentiating between the 60+ energy research areas in the EOS matrix[2].

The R&D portfolio was drawn up once the information gathered from the market research had been processed. This consisted of focal points, knowledge import themes, knowledge expert themes and themes thatdid not require long-term R&D.

The publicly funded energy research is concentrated into focal points. These are research areas that, from a sustainable energy economy point of view, make a significant contribution, and in which the Netherlands has a good level of knowledge. With regard to the areas that are still important, but where there is insufficient knowledge (i.e. knowledge import themes), the import ofsuch knowledge is encouraged.

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[1] Nota Energie Onderzoek Strategie (Energy Research Strategy Act); (Kamerstukken (Parliamentary papers) II 2001/2002, 28 108, nr.1).

[2] Een geïnformeerd beleid. Consultatie van het veld over de waarde van het publiek gefinancierde energieonderzoek in Nederland (An informed policy. Consultation from the field over the value of publicly funded energy research in the Netherlands);Van de Bunt, October 2002.

	Contribution to Sustainable Energy Economy	
	High	*Low*
Knowledge Position NL *High*	Focal points	Knowledge-export themes
Low	Knowledge import-themes	R&D themes none

Fig. 1.1: The EOS matrix

In order to make the R&D portfolio more manageable, focal points and import themes have been grouped into five research areas:

- Energy efficiency in the industrial and agricultural sectors;
- Biomass;
- New gas/clean fossils;
- Built environment;
- Generation and networks.

A pre-survey was carried out in preparation for the research programming[1]. The final R&D portfolio has been presented to a wide range of market parties. Demarcation lines have been drawn up for each research area, an overview made of the stakeholders and initiatives within these research areas, and recommendations have been drawn up for the programming process.

Energy transition

Energy transition[2] aims to develop an energy economy that is both reliable and suitable (on a long-term basis). Above all, it must solve the climate problems caused by burning fossil fuels. There is considerable support among the government, industry, research world and social organisations for this transition to a sustainable energy economy. An optimum breeding ground has been created for sustainable system innovation. Visions of the future have been drawn up for these transition areas and their related transition paths, which will contain certain priorities (‘recognition’). It is expected that the first transition experiments from these recognised transition paths will be start in 2005. These mark the beginning of the ‘energy transition’ to a sustainable energy economy that, over the coming decades, will evolve into a more specific form. Because energy transition is so important, the research elements from the transition paths, together with theresults of the pre-survey and the aforementioned R&D portfolio, have been used as the starting points for defining the long-term research programmes. The transition pathways: Efficient Green Gas, Chain Efficiency, Green Raw materials, Alternative motor fuels and Sustainable Electricity all have something in common with thefive EOS research areas. The specificcommon denominators between a number of research areas and energy transition are described in the individual chapters.

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[1] Resulaten Voorverkenning EOS2 (Results pre-survey EOS2), SenterNovem, June 2003; www.energieonderzoek.ez.nl

[2] www.energietransitie.nl

Programming process

The Ministry of Economic Affairs appointed a chairperson for each of the five research areas. In consultation with EZ and SenterNovem, these chairpersons asked the relevant experts to participate in the programmepreparation committees (PVCs). EZ also appointed an observer to each PVC, and the PVCs were also supported by a coordinator from SenterNovem. The members of the five PVCs are listed in the introduction to each chapter. The five PVCs were asked to draw up the five research areas for long-term research programmes. Based on the aforementioned material, the PVCs specified long-term philosophies for the selected research areas. Research objectives were then formulated based on these visions, showing the way forward for the next few years in order to achieve the required future developments. These objectives were also illustrated via (non-depleting) long-term research items. The draft programmes were presented to a large number of relevant market stakeholders, who were asked to comment. The PVCs then submitted their programmes to the Minister for Economic Affairs, and these have now been accepted.

Long-term EOS programme

The programme is described in Chapters 1-5, and includes:

- A description of the research area, including an indication of the Dutch knowledge infrastructure and the international prospects;
- A long-term research vision aimed at the period 2020-2030;
- A description of the research objectives to which the project proposals must contribute;
- A summary of the non-technical aspects.

See the following chapters for the specific programmes.
All chapters begin by presenting the EOS R&D portfolio. Only the focal points and import themes are detailed with the programmes and may apply for subsidy for long-term energy research. Proposals for non-technological research may be submitted, provided theseform (a limited) part of a research proposal concerning the focal points or importthemes. It is clear thatsocioeconomic research undertaken within the framework offundamental research cannot be used for industrial or commercial purposes. If socioeconomic research is carried out under the framework of industrial research, then the relevant conditions for industrial research must apply. In both cases the results are far removed from the market and individual stakeholders may not gain any specific advantage from these results.

Subsidy scheme for long-term research and other instruments

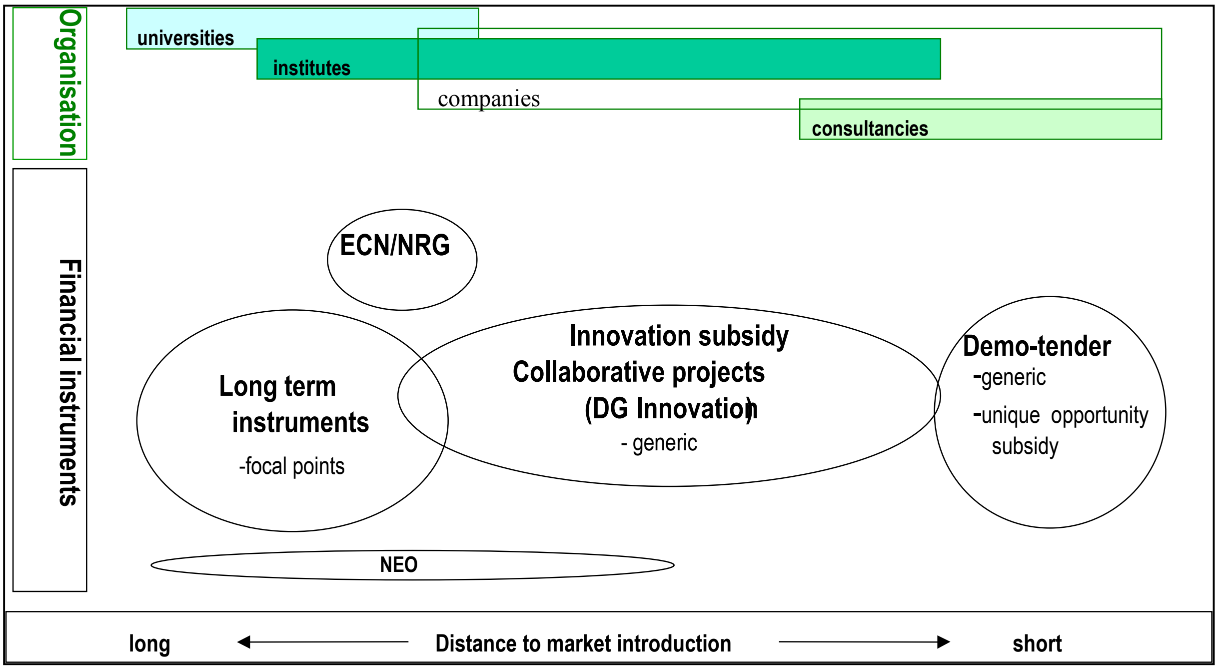
The programmes form an essential element for the formal and practical evaluation of projects that are submitted within the framework of the new subsidy scheme for long-term energy research. According to this scheme, research proposals must fit into the programmes. After a practical-technical evaluation, an advisory committee also prioritises the proposals according to theextent to which they contribute to theobjectives of the programmes. Since the programmes are set up based on the technology options, selected according to the aforementioned basic EOS criteria (sustainable energy economy and knowledge level), these basic criteria form the principles behind the prioritisation.

The priority list of proposals therefore initially depends on the extent to which the results of the research are expected to contribute to achieving a sustainable energy economy, and maintaining or improving the relative knowledge level.

More specifically, this concerns the extent to which the proposal contributes to achieving the objectives of the research areas of the various research programmes, per (cluster of) technology option(s).

In addition to thesubsidy scheme for long-term research, a new scheme will be set up to supportdemonstration projects. The scheme for transition experiments is included here (the unique opportunities scheme). This research, focusing on the short to medium term, comes under the Innovation Subsidy for Collaborative Projects at the Ministry of Economic Affairs. The existing New Energy Research (NEO) programmealso acts as a ‘ breeding ground’ for new ideas

The following figure shows the energy research instruments.



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[1] Nota Energie Onderzoek Strategie (Energy Research Strategy Act); (Kamerstukken (Parliamentary papers) II 2001/2002, 28 108, nr.1).

[2] Een geïnformeerd beleid. Consultatie van het veld over de waarde van het publiek gefinancierde energieonderzoek in Nederland (An informed policy. Consultation from the field over the value of publicly funded energy research in the Netherlands);Van de Bunt, October 2002.

[3] Resulaten Voorverkenning EOS2 (Results pre-survey EOS2), SenterNovem, June 2003; www.energieonderzoek.ez.nl

[4] www.energietransitie.nl

1 Energy efficiency in the industrial and agricultural sectors

Introduction

The R&D portfolio for this research area is defined below.

Focal points	- Thermal treatment processes - Anorganic membrane technology - Heat management in industry and agriculture - System approach in glass horticulture
Knowledge import themes	- System approach in industry - Multifunctional reactors - Cooling techniques, industry and built environment
Knowledge export themes	
No R&D themes	- End-use/reuse of residual heat in industry and built environment, heat pumps - Liquid separation, advanced destillation - Gas separation, organic membrane technology - Biocatalysis, organic membrane technology - Electrochemicals, chemical and galvanising industry

The PVC for this research area consisted of the following persons:

Dr. Ir. G.E.H. Joosten	Chair
Ir. P.T Alderliesten	ECN
Ing. W.J. Diekhuis	Siemens, NAP DACE
Ing. A. Jolman	Productschap Tuinbouw
Prof. Dr. Ir. J.A.M. Kuipers	Twente University
Ir. B. Ph. ter Meulen MSc.	MolaTech, NL GUTS
Ir. E.J. Postmus	Gasunie Trade and Supply
Dr. Ir. A.F.M. van Velsen MSc.	Royal Haskoning, NAP DACE
Drs. S.M. Koomen	Ministry of Economic Affairs, observer
Ir. J.W. Nijdam	SenterNovem, coordinator
Ir. M. Dieleman	SenterNovem, support

1.1 Description

1.1.1 The research area

The transition to a sustainable energy economy begins by reducing the demand for energy, thus using energy as efficiently as possible. The next step is to use renewable sources whenever possible, e.g. sun, wind, and biomass. Finally, until they can be avoided altogether, using fossil fuels as 'cleanly' as possible. This three-step approach to achieving a sustainable energy supply is commonly known as the *trias energetica.*

Efficiency improvement covers a wide range of aspects: not only producing energy more efficiently, but also using raw materials more sparingly, manufacturing in a more flexible and compact way, and producing less waste. Efficiency improvement is good for the environment, but can also reduce production costs and even lead to product innovation. Important motivations for efficiency improvement include:

- Energy costs. The increasing costs of energy carriers (e.g. fuel or feedstock) can make it financially interesting to make production processes more energy efficient;
- Environmental policy and legislation. It is not only the Kyoto Protocol that is resulting in an incentive to save energy, but waste residues are also resulting in environmental problems. The necessity for socially responsible business management can also form a motivation for efficiency improvement;
- International competition. Companies are competing in a global market: this competitiveness forces them to develop new and more efficient processes and process intensification.

Policy
Policy instruments for energy conservation can be split into:

- Control (insulation standards, Environmental Management Act/licensing, etc.);
- Financial encouragement for purchasing (EIA, VAMIL, EPR, etc.);
- Financial encouragement for usage (MEP, etc.);
- Financial encouragement for development (EDI, IS, etc.);
- Voluntary agreements (MJA, Benchmarking covenant, the transition teams Modernising Energy Chains, MEK and Sustainable Rijnmond, R3);
- Future policy (trading CO_2 emission rights, etc.).

Target group
The target group for the energy efficiency research area covers a wide scope within the industrial and agricultural sectors. This target group can be further defined based on the energy consumption. Table 1.1 provides an overview of the consumption development achieved, in primary terms for end-users [11].

Industry
Table 1.1 shows an 11% increase in primary industrial energy consumption during the period 1990-2000. This is less than the increase in the total primary energy consumption (18%).

Within industry as a whole the chemical sector is responsible for around 44%, basic metals and the foodstuffs sector are each responsible for around 15%, and the paper/cardboard and equipment manufacturing sectors are each responsible for around 7% of the total industrial primary energy consumption [7]. The research area for the industry target group is primarily aimed at the aforementioned sectors.

Table 1.1: Consumption development achieved, recalculated into primary terms for end-users (in PJ).

	1990	1995	2000
Industry	1,167	1,243	1,298
Agriculture and horticulture	186	211	232
Household energy	518	569	604
Trade, services, government	418	443	542
Transport	414	464	510
Total	2,703	2,930	3,186

Agriculture
Within the agricultural and horticultural sectors, glass horticulture is responsible for 80% [7] of the energy consumption. The research area for agriculture is therefore also aimed at glass horticulture.

1.1.2 Knowledge infrastructure in the Netherlands

Various Dutch research organisations are conducting studies into this research area. These include universities (Twente University, TU Delft, TU Eindhoven, Utrecht University, Groningen State University, Wageningen University and Research Centre, etc.), research institutes (TNO, NIZO, ECN, etc.), plus (semi) private organisations such as Gasunie research, KEMA and Gastec, as well as the research departments of a number of (large) corporations.

In addition to EOS, there are also various other R&D programmes that are relevant to energy efficiency in the glass horticulture and industrial sectors.

- Advanced catalytic technologies for sustainability (ACTS, part of NWO). This programme focuses on knowledge development concerning catalysis – to make production processes more efficient, cleaner and faster;
- With regard to separation technologies, knowledge providers and clients are collectively working on a Separation Technology Roadmap. This process is supported by EZ (Dir. Gen. for Innovation). Within the theme ‘Upcoming Technologies’ NWO has set up a separation technology programme. IOP (an industrial research programme) also used to be active in separation technology (IOP membrane technology). This programme ran during the 1980s and achieved sustainable harmonisation between the knowledge infrastructure and the commercial sector;

- GLAMI (**Gla**stuinbouw en **Mi**lieu) Convenant (glass horticulture and the environment). The Ministry of LNV (Agriculture, Nature and Food Quality), together with the PT (horticultural products), finances research projects, informational activities and demonstration projects that contribute to achieving the GLAMI energy objectives in 2010.

1.1.3 International prospects

Considering the enormous diversity of research subjects in this programme, and the sometimes broad description of certain research areas, it is not possible to produce a definitive overview of international developments and leading knowledge centres. Appendix 1.1 therefore includes a non-definitive list of international references for a number of research options.

The IEA (International Energy Agency) encourages the transition to a sustainable energy economy, for example, by encouraging and coordinating energy research through Implementing Agreements (IAs). There are currently several IAs active in energy efficiency: energy conservation through energy storage, process integration, pulp and paper, etc.

1.1.4 Knowledge clients

Industry

Those involved in applying the innovations in the process industry include:

- End-users (process industry);
- Designers of new processes (engineering companies);
- Technology suppliers (process/equipment and operational knowledge suppliers);
- Equipment manufacturers (suppliers of equipment/components);
- (Utility) construction.

The entire chain (from end-users, suppliers, knowledge institutes) is represented in the Stichting NAP (Centre of Competence for the Process Industry) and DACE (Dutch Association of Cost Engineers). There are also a large number of separation technology end-users in the knowledge network NL GUTS (Group of Users of Technology for Separation in the Netherlands).

Dutch end-users are strongly represented in the oil/gas, (petro/fine-) chemicals, metal, water purification, waste incineration (AVIs) and foodstuff industries, although sectors such as paper/cardboard and carpets are also important. Various important, internationally operating engineering companies support the activities of these sectors.

With regard to the technology suppliers and equipment manufacturers, the Netherlands currently includes several important foreign parties and a number of smaller Dutch companies (e.g. for filtration), which all specialise in separation technology. When it comes to membrane technology in the Netherlands, a strong knowledge infrastructure has been built up with several important (international) stakeholders, partly through the IOP membranes. For very selective separations (e.g. for use in biotechnology), a number of extremely promising starters have now been established.

Glass horticulture
Those involved in innovative applications for the glass horticulture sector include:

- The horticulturalists (as end-users);
- Information providers, as intermediaries between the research world and the horticulturalists;
- Suppliers, such as greenhouse builders, climate computer suppliers, crop/greenhouse systems and installations.

1.1.5 Energy transition

Industry
The most relevant industrial projects for energy transition are MEK II (modernising energy chains) and R3 (Rotterdam harbour and industrial complex).

Modernising energy chains (MEK II) has selected a number of industrial energy chains for which a transition path has been drawn up. The following chains are relevant for this research area.

1. Heat transition. Over 70% of Dutch energy consumption is used for heating. At the same time, industry loses a huge amount of heat (approx. one-third of the primary energy consumption[1] is lost as residual heat, which in theory could be usefully reused. Substantiated estimates indicate that 50% input improvement is feasible in 2050. The plan's objective is to save many millions of tons of CO_2 - by the year 2020 - by reducing the heating demand at all temperature levels through efficiency improvements in production processes; encouraging the use of ambient and residual heat through heating the built environment; and generating heat (where necessary) using electricity as a residual product. This transition path has a clear relation to the focal points 'thermal treatment processes' and 'heat management', but also to the knowledge import theme 'system approach in industry'.
2. Energy transition of paper and cardboard. This industry is responsible for around 7% of the primary energy consumption in the Dutch process industry. The sector is a good example of a traditional industry but stands out through the desire to look further ahead. There is potential for a considerable reduction in energy consumption (up to 50%). This transition path has a clear relation to the focal points 'thermal treatment processes' (drying) and 'heat management', and to the knowledge import themes 'system approach in industry' and 'cooling techniques'.

The R3 project includes an inventory of sustainable system innovations around the relatively energy-intensive industry in Rijnmond. Companies in Rijnmond are prepared to take the necessary steps towards a sustainable energy economy, providing that the conditions fit in with their corporate objectives. A number of projects were started in 2003 concerning industrial heat and residues. This path complements the focal points 'heat management' and 'thermal treatment processes', and the knowledge import theme 'system approach in industry'.

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[1] Excluding feedstock

Glass horticulture
The objective is an energy-neutral, or even energy-supplying greenhouse; thus minimising the demand for energy and maximising use of captured solar energy. The Ministry of LNV and the PT programme, together with the LTO (Dutch organisation for agriculture and horticulture) form transition paths that should contribute to achieving the aforementioned objectives for a sustainable agricultural sector. Within this framework, researchers are working on the following transition paths: ‘greenhouse as energy source’, ‘natural heat’, ‘residual and waste heat’, ‘biomass and hydrogen’, ‘solar energy’, and ‘PV (photovoltaics) and light’.

1.2 Research areas and objectives

1.2.1 Vision

The National Environment Policy Plan (NEPP-4) states that a sustainable energy economy can be achieved by separating economic growth from energy consumption. Forcing a break in the trend requires a huge effort, both technologically (EOS) and supervisory (transition management). A large number of production processes need to be structurally revised.

The transition to a sustainable energy economy aims to develop an energy supply that is reliable (on a long-term basis) and efficient, and prevents the climate and environmental problems that are created through burning fossil fuels. In order to achieve this objective, it is clear that huge leaps need to be made in technological improvements.

The research vision for energy efficiency in agriculture and industry is that technological breakthroughs should be achieved in production processes to make them 2-5 times more efficient. These breakthroughs should be technically feasible on a large scale, economically viable and socially acceptable over a period of 10-20 years.

There is still a lot of R&D required in order to realise this objective.

Industry
Over the past decades considerable efforts have been made to improve efficiency. Statistics show that, despite these efforts, energy consumption in 2000 rose by 11% compared to 1990 levels. Physical growth also rose during this period by approximately 12%, which proves that the aforementioned separation has not yet been achieved. This separation forms the main challenge for the future. Energy saving techniques that are part of the generic technique have usually already been implemented. However, in order to force a break in the trend, it is necessary to conduct research into new technologies that lead to huge leaps in technological improvements, that offer good potential for considerable energy savings, and where these are expected to be implemented in the longer term (> 10 years).

Glass horticulture
The energy efficiency index (EEI, the amount of energy per unit of product) for the glass horticultural sector has developed as follows during the period 1995-2002 (source: LEI).
(1980 = 100).

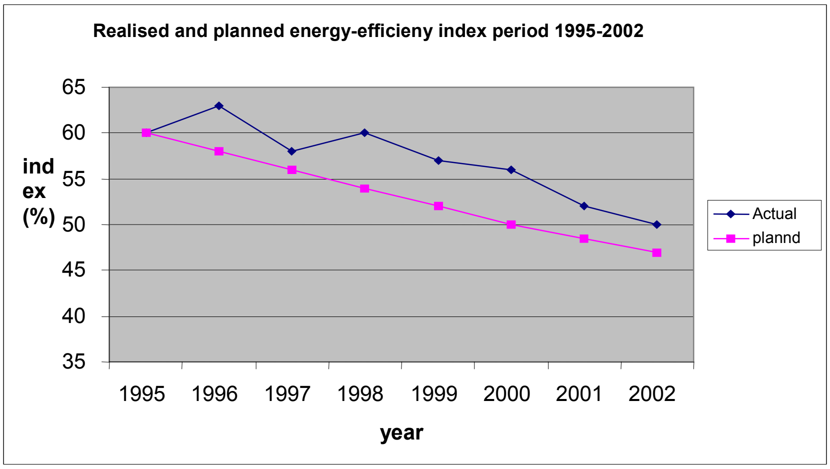

Figure 1.1: EEI development for glass horticulture.

Under the framework of the GLAMI Covenant, the EEI efficiency improvement target for 2020 is a 65% improvement on 1980 levels. For 2002 the EEI result was 50% (see Figure 1.1). During this period the physical production rose from around 36 euro (1980)/m² to around 39 euro (1980)/m². Glass horticulture is therefore one of the few industrial sectors to achieve an absolute reduction in CO_2 emissions (5% compared to 1990). By 2010 a further EEI-reduction needs to be achieved, from 50% to 35%. Glass horticulture policy focuses on 100% sustainability by constructing new greenhouses in 2020. In order to achieve this objective, huge leaps in technological improvement are clearly needed. Potential research areas include ‘system approach’, ‘greenhouse construction’, ‘climatisation’, and ‘optimal energy conversion’.

1.2.2 Demarcation

Figure 1.2 shows the focal points and import themes, grouped into four research areas.

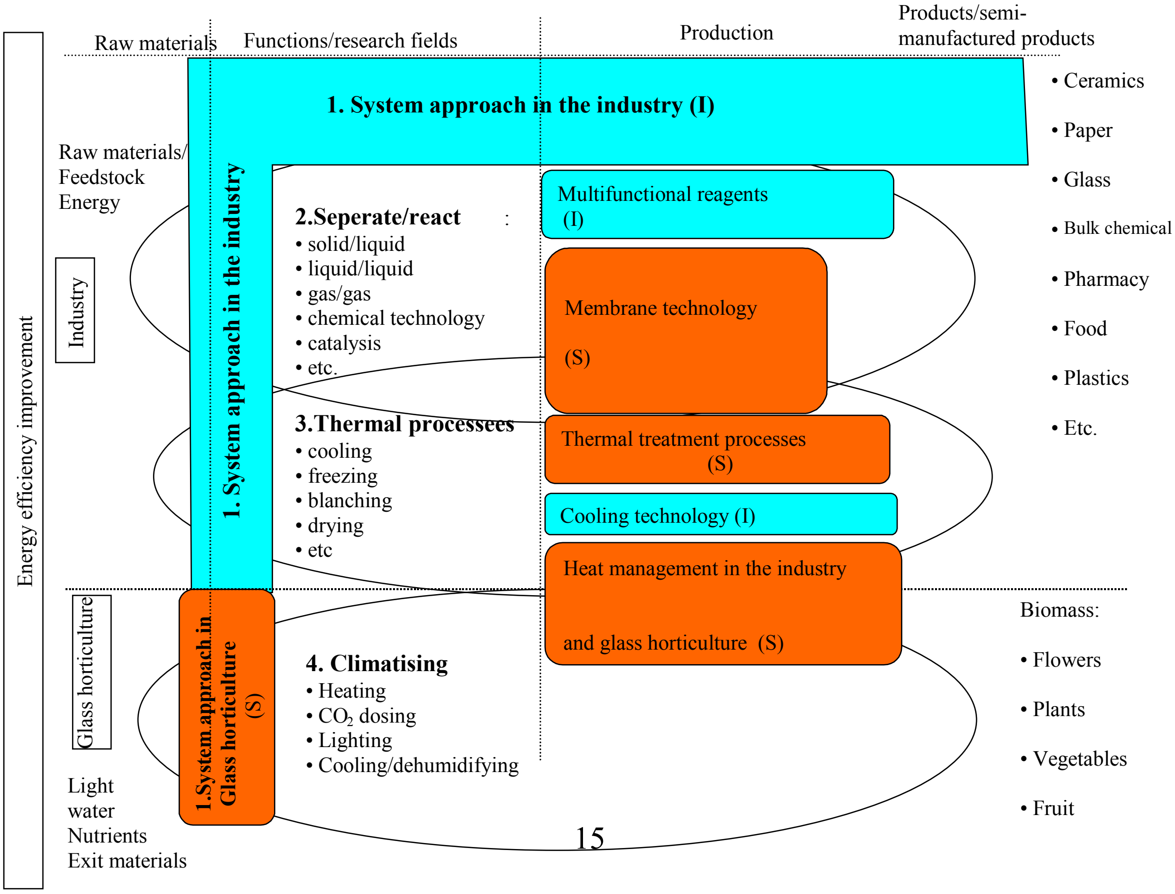

Figure 1.2: Research subjects for this research area (S: focal point; I: import theme).

Research area 1: System approach

The system approach concerns the analysis of production and energy chains. This research area covers all production processes and chains in the industrial and agricultural sectors, on three levels:

a) System approach at corporate level, within a single process;
b) System approach for several processes at one or more locations;
c) System approach at macro level covering production chains (from raw materials to finished product): the so-called ‘chain’ approach.

These three points collectively form the system approach research area. The system analysis results act as starting point for the research undertaken in the individual process steps, such as thermal treatment, heat, (membrane) separation and climatisation in glass horticulture. This helps to make the entire process more energy efficient. A result of this analysis, for example, is process intensification by using multifunctional reagents, where various process steps (separation, reaction and heat exchange) are combined. System analysis is very important for the process industry in order to achieve a greatly improved redesign of existing processes in the short term, and long-term development of new (integrated) processes. The relevant Dutch knowledge of the system approach to industry is currently fragmented, sometimes out of date, and new approach methods are not yet operationally available. In order to achieve a durable approach to energy conservation in the Netherlands, the PVC feels that this research needs to develop from a knowledge import theme to a focal point.

This knowledge is better developed in the glass horticulture sector and therefore system approach is a focal point in this sector. The system approach is used to analyse the cohesion between construction strategies, combinations of functions, regulations, capturing sunlight and system integration. The result is an identification of extremely promising research areas that should lead to minimising the energy demand. Two examples of system approach results are studies into heat storage for decoupling energy supply and demand (based on time and place) and developing energy-optimum and growth-spectrum specific assimilation lighting.

Research area 2: Reaction and separation

This research area covers the focal point ‘membrane technology’ (liquid separation, gas separation, anorganic membrane technology) and the import theme ‘multifunctional reactors’. The two areas have a number of points in common. Substantial energy saving in the process industry is theoretically possible through two main aspects: huge leaps in improving conventional separation technology plus the combination of reactor/separation technology, which makes use of the synergy between reaction and separation.

Research area 3: Thermal processes

This research area covers the focal points ‘thermal treatment’, ‘heat economy in industry and glass horticulture’ as well as the knowledge import theme ‘cooling technique’. Thermal processes are also closely related to the transition path for ‘heat transition’ under the MEK transition team.

Industry often has a large excess of heat available at a temperature that can initially be used for glass horticulture, industry or commercial and/or residential buildings. However, the potential for reusing (residual) heat is not being developed further. A large number of factors are to blame, e.g. demand and supply occurring at different times, the (often considerable) distance between the release and reuse of heat, temperature variations between release (low temperatures) and reuse (medium temperatures), differences in investment horizons in the coupled processes etc. Long-term research can achieve a breakthrough in a number of these factors.

Within this research area, technology is being developed whereby thermal processes (both heating and cooling) can be implemented more efficiently, including technologies for converting low-temperature residual heat into more useful higher temperatures, huge (short-term) capacity for heat storage, and then transporting this heat using a high-energy intensity for reuse elsewhere.

Cooling techniques concern the generation, transport and use of cold air, and is a common energy-intensive technique that is used everywhere in the process industry and the agricultural food chain. This option focuses on developing more efficient cooling systems, optimising process control, defrosting and, for example, covers the entire cooling chain for the food sector.

Research area 4: Climatisation in glass horticulture
Starting points for long-term research in the glass horticulture sector include the growth factors (functions): temperature, humidity, light, and CO_2. The climate control systems required are therefore based on energy-based functions: heating, cooling/humidity, CO_2 dosing, and lighting. Energy accounts for 15-25% of the production costs in the glass horticulture sector. Research into these energy functions can provide a significant improvement in energy efficiency. The research itself is described in research area 1: System approach in the glass horticulture, and research area 3: Heat economy in industry and glass horticulture. The final objective is to (largely) close the energy cycles within the greenhouses, under commercially economic conditions. The biomass that is released as a by-product can be used for sustainable energy production. This aspect is further detailed in the section on biomass.

1.2.3 Research area 1A: System approach in industry

Import theme: system approach in industry

Objective: To develop and use knowledge concerning system studies and technology surveys for selecting/evaluating possible research areas aimed at substantial energy and emissions reduction in the industrial sector.

Long-term research (process redesign) should focus on:

- Further defining the chain approach for processes and process chains, and quantifying the savings potential;
- Further defining specific programme directions and realisation paths (road maps) for long-term timeframes and indicating the size up to and including implementation. Aspects such as national and international acceptance/partners, early market introduction etc. should also be included;

- Using the system approach concept to redesign processes;
- Government use of the system approach for eventual revaluation of the focal points and import themes from long-term research programmes.

In general, the system approach can include information on potential opportunities of new technology, e.g. in terms of possible energy saving, efficiencies etc. Apart from the potential involved, other information is also generated (e.g. expected costs, development phase, social effects, technological barriers, and other factors that affect the chances of a new technology succeeding).

This information also provides an insight into the worldwide development status, the competitiveness of Dutch knowledge in this area, and the potential support for further R&D. This can also be important for future assessments and eventual revaluation of the focal points and import themes of long-term energy research programmes.

This research area is particularly important and needs to develop into a focal point as soon as possible. The following short-term activities are proposed:

(gathering knowledge):
- Identifying the international status quo regarding system studies and technology surveys aimed at substantial energy and emissions reduction in the industrial sector;
- Anchoring this knowledge into one or two knowledge centres in the Netherlands;
- Applying this knowledge as soon as possible, in order to gain better insight into the energy consumption of the most important processes in the Netherlands, thus identifying the most important process phases and unit operations. Comparing this to the international situation.

Medium-term activities consist of:
(applying knowledge):
- Developing further into an international top centre for system analysis;
- Developing an evaluation system for selecting the best options within the EOS programme. Criteria such as energy saving, exergetic efficiency, reducing environmental impact, innovation potential, relative/feasible position compared to international developments, support, size and type of barriers, strategy relevance, etc. should be specified in detail;
- Development and implementation of proposals for strategic (programme-based) national and international cooperation.

1.2.4 Research area 1B: System approach in glass horticulture

Focal point: System approach in glass horticulture

Objective: To achieve a cost-effective energy-neutral greenhouse, or one that supplies energy rather than consuming it.
Timeframe: 2020: (developed market-ripe technology).

The glass horticulture sector uses 90% of its energy consumption (in 2004) for greenhouse climate systems (heating, cooling/humidifying, CO_2 dosing, and lighting). In order to achieve the aforementioned objective, an intensive system approach will be required towards the processes within the greenhouse (and between greenhouses).

This will need to identify opportunities for achieving results with minimum energy demand and maximum use of sustainable energy sources.

An essential condition here is that the new (to be developed) technologies contribute to the desired corporate developments, crop intensification per m^2 and increased harvest.

The first step has already been taken on the road towards energy-supplying greenhouses. In order to achieve the aforementioned objectives, further breakthroughs are needed because:

- The energy supplied by the greenhouses is often of inferior quality and cannot be supplied to third parties;
- Currently (in 2004) around 25% of the natural light is lost through transmission losses;
- Not all the incoming solar energy can be used effectively for the production process in the greenhouse and to produce renewable energy.

Research will generally need to focus on maximum capture (and storage) of solar energy, energy-optimum and growth-spectrum specific assimilation lighting, insulation, construction strategies, control and integration with other systems. This primarily concerns combining functions that involve all factors of climate systems (heating, CO_2 dosing, lighting and cooling/humidifying).

Breakthroughs:
- Maximising the useful application of incoming solar energy for use, both within the greenhouse, and by third parties;
- Cost-effective energy exchange with third parties.

1.2.5 Research area 2: Reaction and separation, anorganic membrane technology
Focal point: Anorganic membrane technology

Objective:	An 80% reduction (compared to 2004) of the energy consumption for specific separation processes (at equal costs).
Timeframe:	2015: market-ripe technology. 2025: large-scale application.

The energy consumption of the Dutch chemical industry is estimated at around 580 PJ/year. Separation processes are responsible for an estimated 200 PJ/year. These are primarily processes that separate process streams that are mixed at molecular level. Using membranes, sometimes in combination with reagents (e.g. together with destillation and for certain applications to replace this), allow substantial energy savings to be achieved. The target for the aforementioned specific processes is an 80% reduction in energy consumption in 2025, through using membrane technology, at equal or lower costs (investment + operational) for the new technology.

As most separations and combinations of reactions/separations in the process industry are conducted in circumstances involving high pressures (> 20 bar) and temperatures (> 120°C) together with (aggressive) organic media, using membrane technology requires the use of special materials that are operationally resistant to such circumstances. Anorganic membranes currently seem the best choice for these applications.

However, organic materials are continuing to be developed, and cannot be entirely excluded. It is important to concentrate evaluations on the functional aspects of the technology to be developed.

Specific applications of membrane technology focus on more energy-efficient molecular separation:

- *Nanofiltration (NF) of organic solvents*: e.g. extracting homogenous catalysts, extracting solvents, separating reagents;
- *Pervaporation (PV) and vapour permeation (VP):* e.g. draining organic solvents, separating azeotropics, shifting the balance in esterification, for optimalisation/improvement of destillated separations;
- *Gas separations:* primarily in combination with reagents, for removing or dosing reagents, and for extracting components from process gas streams.

When developing and implementing new membrane technology for the process industry, it is not just the separation performance that is important, but also flexibility, reliability, robustness, safety and maintenance. When it comes to large-scale implementation, both the technology and the supplier need to have 'proven' status.

Research should focus on:

- Basic research into new membrane materials and membranes for the aforementioned separations, plus research into new carrier structures;
- Developing new modules for specific applications, possibly in combination with catalysts;
- Developing upscaling and manufacturing technologies for the new membranes/modules;
- Developing application opportunities of specific membranes and modules in the (chemical) process industry and food industry, using the system approach to determine the essential role of the process operation.

Breakthroughs:
Membrane technology that works under high pressure (> 20 bar), at high temperatures (>120ºC), can resist aggressive environments and where the tool life of the membrane meets current industrial standards.

1.2.6 Research area 2: Reaction and separation, multifunctional reactors
Import theme: Multifunctional reactors

Objective: To develop process equipment that combines several functions and/or intensifies existing functions.
Timeframe: 2015: knowledge development through international cooperation.
2025: applications.

The term 'multifunctional reactors' is used when several functions are combined into a single reactor, or when primary functions are intensified. This includes using:

- Membranes in combination with chemical conversion, where products are selectively separated, and/or where reactors are selectively, or in a controlled manner, added to the reaction mixture.

- Structured reactors to achieve a more effective contact between the phases (gas-liquid, gas-solid, and gas-liquid-catalyst);
- Dynamically or cyclically operating reactors that allow compression, expansion and heat exchange to be integrated and/or operated at optimum catalyst conditions.

Research must make maximum use of the knowledge available in other countries, and should focus on:

- Experimental basic research into the technical possibilities and the feasibility of embryonic process intensification technologies;
- Making models, including experimental validation of the models at laboratory scale in order to evaluate industrial viability;
- Developing and upscaling new technologies.

Breakthroughs: Development and upscaling new reactor concepts.

1.2.7 Research area 3: Thermal processes, heat management
Focal point: Heat economy in industry and glass horticulture

Objective: To develop cost-effective technologies to achieve large-scale and large-capacity heat storage and transport, plus technologies allowing technical upgrading of heat.
Timeframe: 2015: technology development completed.
2025: implementation on a medium scale.

In the Netherlands over 70% of the industrial energy consumption is used for heat. Eventually this heat is largely lost as industrial residual heat cools upon exit to the environment. Storage, upgrading and transport of this thermal energy could, in principle, help to better match the demand and supply of heat. Substantiated estimates show that a 50% saving should be feasible in 2050.

Transporting heat currently has a limited action radius (max. 15 km) and flexibility. It is also very expensive, due to insulation, maintenance and heat losses. Reusing this heat somewhere else is often less effective (costs and energy losses) than using it at source. Allowing two end-users to utilise the same heat source is also organisationally and legally complex. Allowing residual heat to be used at source requires systems to be developed that can upgrade residual heat with a sufficient temperature lift so that it becomes warmer than the pinch temperature of the location.

Heat storage can be split into long-term and short-term storage, and in active or passive systems. The working principles can be split into tangible heat, latent heat and chemical heat. With the accessibility of a technology for high-temperature heat storage, this increases the opportunities for the useful reuse of residual heat. Researchers also expect to be able to use heat storage technology, based on latent heat or even reaction heat, not only to store heat at high temperatures, but also to increase the storage density and timeframe of the heat storage.

Considering the local restrictions regarding aquifers, above-ground heat storage requires a breakthrough to allow high storage capacity per volume unit with minimum heat losses. The investment and operational costs form an important bottleneck to this introduction.

Research should focus on:

- New storage and transport systems;
- Upgrading heat to above the pinch temperature (at the client) or converting heat into other forms of energy carriers;
- High-temperature storage (60-150ºC);
- Large storage capacity/density;
- Cost reductions.

Breakthroughs:

- Reducing costs sufficiently so that the system is technically and economically viable;
- Storage with high capacity per volume unit, with minimum heat losses.

1.2.8 Research area 3: Thermal processes, treatment processes

Focal point: Thermal treatment processes

Objective: To develop new thermal treatment processes that achieve a huge leap in energy savings.
Timeframe: 2015: development of new concepts.
2025: implementation on a medium scale.

Thermal treatment processes cover a wide range of applications whereby heat is added in order to achieve certain separations, physical (possibly biological and/or chemical) changes to products. This means processes where the heat is often generated and applied using natural gas, though other heat sources, fuels or electricity may be used. Energy consumption by Dutch industry is considerable. Within the thermal processes, the following functions can be listed: drying, blanching, sterilising, melting etc. These functions are now common throughout the industrial sector.

Research should focus on technologies that can achieve substantial, ‘huge leap’ energy savings, possibly using the following techniques:

- Focused heating;
- Pulsed heating;
- Sonoluminescence;
- Using high pressures;
- Pulsed electrical fields;
- High-intensive lighting;

Breakthroughs:
Developing new concepts for thermal treatment processes that are more efficient by a factor of 2-3.

1.2.9 Research area 3: Thermal processes, cooling techniques

Import theme: Cooling techniques

Objective: To develop new cooling concepts and cooling agents that are 30% more efficient than their current 2004 counterparts.
Timeframe: 2015: development of new cooling concepts and cooling agents.
2025: implementation.

The energy demand for cooling, as required by the processes themselves, consists of approximately 28 PJ per year, split into 12 PJ for the foodstuff industry, and 16 PJ for the (petro-)chemical and natural gas sector. As a main 'distribution country' the Netherlands has a relatively high cooling and freezing capacity. The Dutch animal husbandry and agricultural/horticultural sector also requires a considerable capacity. The trend shows that this demand is increasing. System analysis is required for the cooling chain, just as for the other processes. This should identify several interesting research areas.

Research should make maximum use of the knowledge that is available outside Dutch national borders, and focus on:

- Developing new cooling-technical concepts. System approach: the entire installation should be optimised, rather than just optimising individual components;
- Developing new/better freezing methods, rather than freezing air as transport medium for the cooling;
- Using other cooling concepts rather than just compression cooling;
- A more specific application of cooling: at the moment entire rooms are cooled in order to freeze products. Local cooling would mean a breakthrough in energy-efficient freezing;
- Control engineering: optimising installations according to their specific impact behaviour;
- Thawing: building up knowledge regarding ice, developing thawing methods and strategies (this may also mean preventing the growth of rime ice).

Breakthroughs:
Developing and introducing 30% more energy efficient (compared to 2004) cooling/freezing climate-neutral concepts.

1.3 Non-technological aspects

The large-scale technical practicality and economic feasibility are essential conditions for the successful implementation of the knowledge and techniques developed. However, social acceptance is also important. This often focuses on (internal and external) safety and environment-technical aspects of industrial processes. These aspects need to be incorporated into the research path in a timely fashion. Proposals for non-technical research may be submitted provided these form a (limited) part of a larger research proposal for focal points or import themes.

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2 Biomass

Introduction

The R&D portfolio for biomass consists of the following:

Focal points	- Biomass, gas cleaning and conditioning (incl. syngas production from gas fuel) - Biorefineries - Biomass conversion, co- and auxiliary incineration in E-plants
Knowledge import themes	- Biomass conversion, pre-treatment/ feeding - Biofuels, application in the transport sector
Knowledge export themes	- Biochemical conversion - Biomass (primary conversion) Thermochemical conversion
No R&D themes	- Biomass extraction - Biomass conversion, energy from residues - Biomass, process control and supervision

The PVC for 'Biomass' consisted of the following people:

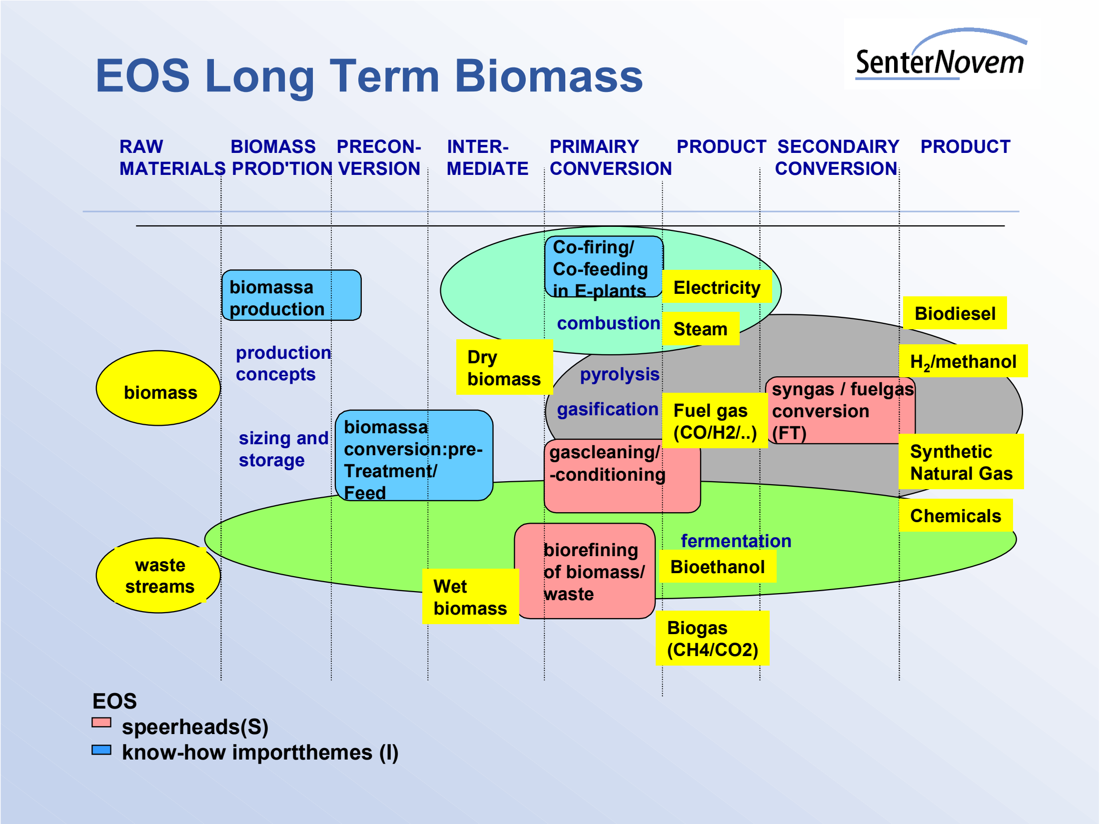
Dr. Ir. T. van Herwijnen	ETC Energy Technology, Chair
Dr. K.D. van der Linde	Waste Energy Company, Amsterdam
Dr. J. Sanders	A&F, WUR
Dr. Ir. M. Steijns	DOW
Prof. Dr. Ir. W.P.M. van Swaaij	Twente University
Prof. Dr. H. Veringa	ECN
Dr. W. Willeboer	Essent
Ir. G.C. van Uitert	Min. of Economic Affairs, observer
Ir. K.W. Kwant	SenterNovem, coordinator
Ir. J. Reijnders, Ir. R. de Reu	SenterNovem, support

2.1 Description

2.1.1 Focus on biomass

Biomass covers a wide range of aspects, due to the large number of different types of biomass (crops, wood, waste, etc.), the many technologies used for the conversion process and the huge number of applications as an energy source: heating, electricity, transport fuel and as an intermediate gas product. In order to achieve a sustainable system, biomass should always be considered as part of a chain, from biomass production, transport, and conversion through to application, plus the residues and emissions that accompany this process.

Fig. 2.1. EOS Biomass



The chain approach
Biomass covers the entire energy chain, from ‘extraction’ to end-use. The ‘extraction’ of biomass refers to the collection process, harvesting crops or import. Even the responsible use of residues or organic-based waste products comes under the heading of ‘biomass’. Household waste and co-/auxiliary incineration in coal-fired power plants forms a good example, as well as pre-treatments such as drying, reducing and separating materials.

The further detailing of the Biomass Programme will also take account of other EOS (energy research strategy) focal points, such as the built environment, generation and networks, and new gas/clean fossils. The first two overlap slightly with biomass where they concern (de)centralised energy supplies to the built environment and decentralised electricity generation. There is also a clear overlap with new gas/clean fossils, where green-gas or biogas is concerned, adding SNG (synthesis gas) to the existing natural gas network, or CO_2 capture and storage.

2.1.2 Biomass programmes in the Netherlands

Overview (as per 2003)
Since 1990 biomass has been increasingly seen as a sustainable raw material, and the government has started initiatives and programmes to support this development. Biomass research in the Netherlands has a long history within a wide range of universities and industries. Since the beginning of the 1990s the emphasis has primarily been on energy from waste via the EWAB (energy from waste and biomass) programme.

In 2000 this was merged into a more generic programme: DEN (sustainable energy in the Netherlands), and other generic programmes were also started. The EET (economy, ecology and technology) programme was implemented between 1997 and 2003, the SDE (collaborative agreement on renewable energy) programme ran from 1998, and the NEO (new energy research) programme began in 2002. Specifically for the CO_2 neutral fuels, the GAVE (climate-neutral gaseous and liquid fuels) programme was set up in 1997, the NWO/ACTS (Advanced Catalytic Technology for Sustainability) programme for catalysis began in 2001. The BSIK/ B-BASIC (Bio-BAsed Sustainable Industrial Chemistry) project was initiated in 2004, and is more focused towards biotechnology. In 2002 and 2004 the Biomass Transition Project concentrated on determining the direction for biomass via transition paths. Appendix 2.1 contains more information on the aforementioned programmes.

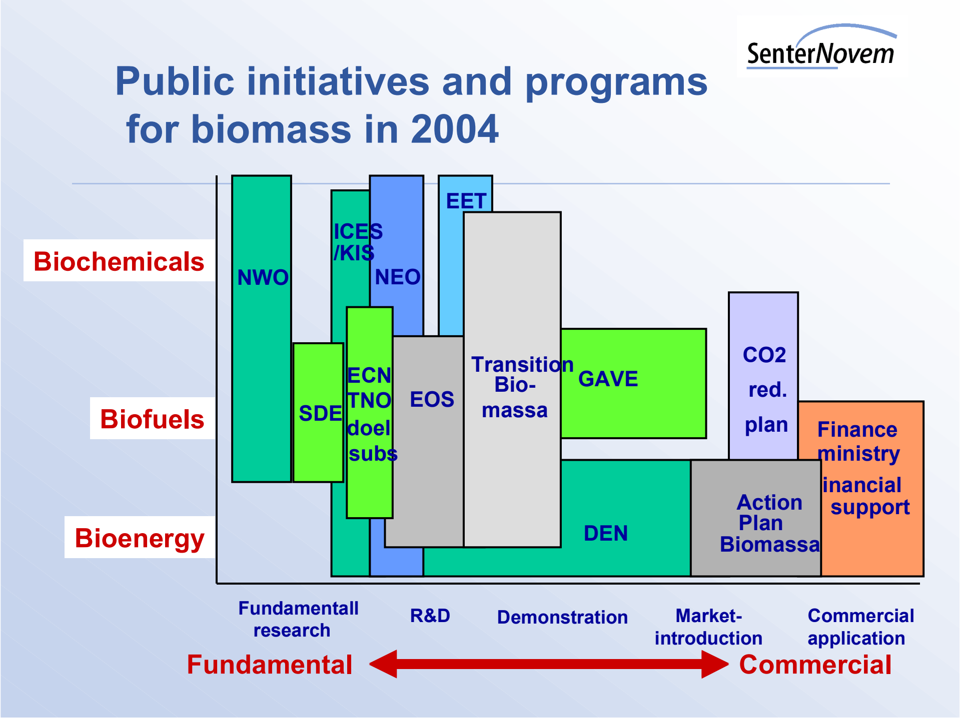


Fig 2.2 Government initiatives and programmes for biomass

Harmonisation

Harmonisation is required due to the large number of national programmes in which biomass plays a role. On the one hand because the existing programmes (DEN, SDE and EET) are still managing projects that are expected to show results over the next few years (up to 2006) that could be important in the longer term. On the other hand, this programme focuses on long-term biomass research and should be referred to the IS (innovative collaboration) scheme for projects where market introduction is less than 10 years away.

Finally, there are a number of adjacent programmes where the EOS biomass programme should seek harmonisation in order to ensure efficient implementation. For the immediate future this is mainly the NWO (Netherlands organisation for scientific research) funded research that is managed by ACTS, such as the B-BASIC programme.

2.1.3 Knowledge infrastructure in the Netherlands

Government
Various government ministries are concerned with bioenergy and biomass research and development. Firstly, the Ministry of Economic Affairs is involved in the DEN, BSIK (subsidy investment in knowledge infrastructure) and NEO programmes. The Ministry of VROM (Spatial Planning, Housing and the Environment) is also involved in climate and environmental research, and the Ministry of LNV (Agriculture, Nature and Food Quality) is concerned with agricultural technology research. Fundamental research is also financed via NWO through the Ministry of Education, Culture and Science (OC&W) and there are a number of collaborative programmes, such as BSIK and ACTS.

Knowledge institutes
Knowledge institutes play an important role in the knowledge position of the Netherlands. This knowledge can be brought onto both the national and international markets. TNO-MEP in Apeldoorn, ECN in Petten and A&F in Wageningen are undertaking a large number of biomass research projects. TNO concentrates on energy from waste, while ECN focuses on developing new technologies, and A&F works primarily on biorefining aspects. In addition to these three research institutes, Dutch universities also play an important role. All technical universities (Delft, Twente, Eindhoven, and even Groningen and Utrecht) have large departments conducting research into biomass and bioenergy.

Consultancies
Consultancies and designers form the catalysts, and thus an important link in the entire process, from ambition to implementation. Consultancies generally do not conduct long-term research, but focus more on application-oriented R&D. These companies have separate departments where specific bioenergy and biomass knowledge is gained and further developed.

Industry
Knowledge is also gained within the industrial sector – not only in the manufacturing industry but also companies applying this knowledge. The Netherlands has no specific manufacturing industry for biomass and bioenergy, although there are special sub-segments, such as anaerobic water purification. As far as applications are concerned, it is primarily the energy suppliers and waste companies that play a leading role, where new technologies are used for waste incineration and co-/auxiliary incineration.

2.1.4 International prospects

Biomass research in the Netherlands currently holds a qualitative high-grade position, compared to other countries. This has increased significantly, both in quality and quantity, over the past decade, and is supported by an increasing number of publications by Dutch graduates. At the 2nd World Biomass Congress (held in Rome, May 2004), around 10% of the papers and presentations were given by Dutch representatives, thus ensuring that the Netherlands contributed the greatest input.

Within the total biomass research sector, the Netherlands is selectively working on a number of specific subjects, while ignoring several other subjects. In wood-rich countries such as Finland, Sweden and Austria, forestry products and the use of wood for heat production in large boilers or small pellet stoves, are important research aspects.

However, the Netherlands focuses on the useful application of residues from industry, the agricultural sector or household waste, and on generating electricity. Over the past four years the production of transport fuels has also been added to this list. With regard to applications, waste incineration, co-/auxiliary incineration in coal-fired power plants and fermenting wastewater and compostable waste (GFT) are all strongly represented in the Netherlands.

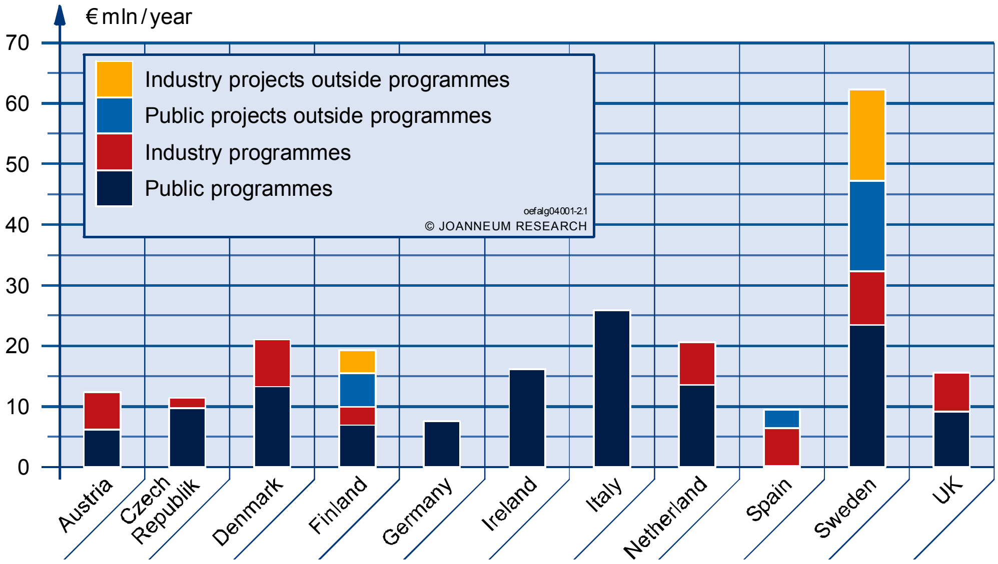


Fig 2.3: Research budgets for bioenergy in various EU countries (source: ERA Bioenergy)

Within the EU 'ERA Bioenergy' (European Research Area) project (ENK5-CT-2001-80526), Novem assisted in producing an overview of European research into bioenergy[1]. Six EU countries, including the Netherlands, have significant biomass R&D activities. Research institutes and universities in all countries are working (to some extent) on the entire range of bioenergy research activities.

A number of important movements are currently being instigated to improve international collaboration. Via the ERA, the EU is using a number of important new instruments to improve collaboration. This occurs via large integrated projects, in which various industries and research institutes work together, and through Networks of Excellence (NoE) with virtual integrated research institutes. In the Bioenergy NoE, which started on 1 January 2004, ECN represents the Netherlands, alongside institutes from Sweden, Finland, Poland, France, Austria and the UK.

One of the instruments that focuses on governments is the ERANET, which tries to achieve harmonisation and integration of national programmes.

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[1] The final report is available from www.joanneum.at/ief/erabioenergy.

A consortium that includes SenterNovem has drawn up a proposal for a Bioenergy ERANET, which began on 1 October 2004. In addition to the Netherlands, other initial participating countries include: Finland, Sweden, UK, Austria and Germany.

But bioenergy research is not restricted to Europe; collaboration is continuing worldwide. Since 1978, around 20 countries have taken part in the IEA Bioenergy Implementing Agreement. In addition to a number of EU nations, countries such as the USA, Canada, Brazil, Japan, Australia and New Zealand also participate. Within a number of three-year Tasks, researchers and programme managers from a number of countries collaborate and exchange knowledge on progress and priorities, and work together on various specific activities. The Tasks in which the Netherlands participates (from 2004) include:

- Task 32: Combustion and Co-firing;
- Task 33: Gasification;
- Task 36: Anaerobic Digestion;
- Task 38: Greenhouse Gases;
- Task 39: Liquid Biofuels; and
- Task 40: Biomass Trade.[1]

With regard to bioenergy research, there is a bilateral collaboration with Japan, organised by the NWO, which primarily focuses on thermal catalytic conversions.

In the aforementioned countries, as well as in the programme presented by the Netherlands in this document, there is a clear transition from the more technologically oriented programmes such as Biomass Gasification or Pyrolysis, to more integrated programmes under the umbrella of Biorefining. This is occurring in Austria, but also in the USA[2], where this type of programme has been running since 2002. Collaboration with the USA on these aspects would be extremely useful.

2.1.5 Energy transition

Biomass Transition is a sub-project under the transition to a sustainable energy supply. From this philosophy, the various stakeholders (industry, knowledge institutes and governmental bodies) have defined transition paths for biomass, within which the definition of experiments and the required programming of energy research are developed. The tangible result of the Biomass Transition process is a communal vision for 2020 and the selection of around 10 specific transition paths[3]. Biomass is also included in other energy transition sub-projects, e.g. the New Gas and MEK (modernising energy chain) projects.

The research philosophy of the EOS focus area is based on the Biomass Transition vision, whereby the research fields chosen form a seamless connection between the long-term research within EOS and the Biomass Transition path.

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[1] For a complete overview, see: www.ieabioenergy.com .

[2] Visit: www.bioproducts-bioenergy.gov

[3] ‘Biomass: the green tool for transition’, December 2003, Ministry of Economic Affairs. The report is available from www.energietransitie.nl

2.2 Research areas and objectives

2.2.1 Vision

The philosophy behind the EOS research into biomass is based on the vision formulated by the Biomass Transition project. The main characteristic of this vision is the broad, large-scale application of biomass for energy, fuels and products, primarily based on imported biomass. As a raw material for sustainable energy, biomass is also a robust element in the LTVE (Long-Term Vision of Energy Supply).

This research philosophy is based on the fact that biomass has wide application possibilities. Various processing routes will produce a rich assortment of biomass raw materials that can be converted into final products for various market segments. Clear choices have been made in order to ensure that research funds are utilised correctly within this wide range of opportunities.

2.2.2 Motivation for biomass energy research

There is a huge potential for using biomass as raw material for sustainable energy.

- Biomass forms the basis for renewable energy carriers and contributes to greenhouse gas reduction. Compared to the other renewable energy sources, such as wind and sun, biomass has the advantage that stored solar energy can be used at any time.
- In the long term, using biomass in the energy sector within the EU will result in an important contribution to security of energy supply through reduced dependence on geopolitically sensitive regions, and forms an alternative to the increasingly scarce fossil fuels.
- The swing towards large-scale use of biomass, in all its facets, is an important boost for the knowledge economy and innovation. There are significant opportunities, depending on the position in trade, economy (energy, chemicals, the agricultural industry), science and development. The Netherlands already has a good knowledge position in many sections of the biomass sector
- Biomass-based production processes broaden the spectrum of raw materials thus achieving significantly more flexibility.
- Biomass production generates new opportunities for rural development, particularly in developing countries, but also within the EU (see also Section 2.3).

2.2.3 Objectives for 2040

The Biomass Transition predicts that, in 2040, bioenergy will make up 30% of the total energy consumption in the Netherlands, i.e. 600-1000 PJ[1], in a scenario with considerable energy conservation. This target is seen as a good balance between trying to achieve a fundamental change in energy supply (transition) and setting feasible goals.

Biomass supply

By 2040 biomass will be available from many different sources. Residual biomass will be usefully recycled for energy applications, and biomass crops will be harvested (generally outside Dutch borders). The Netherlands will need to meet its demand for biomass by purchasing on the international market. From a sustainability point of view, there are a number of prerequisites concerning biomass crops, e.g. food, preserving nature, biodiversity and respect for local conditions in developing countries. Where possible, these processes will be achieved through closed cycles.

The production chains for bioproducts are set up such that they exemplify very low emissions and maximum use of all components. The supply of residues has increased significantly and there is a market for semi-manufactured biomass products, where biomass is converted into a concentrated form (usually for logistical reasons).

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[1] Clarification: 30% is seen as a feasible, but very ambitious, target. Depending on the reduction in energy consumption achieved in 2040, 30% of the national energy requirements will equal 1000 PJ or perhaps even 600 PJ: in any case, a very significant reduction. This not only means making more efficient use of energy, but also taking energy-efficient alternative routes, e.g. for mobility or chemical products.

These semi-manufactured products are converted (fairly close to the market) into final products, e.g. electricity, transport fuel, gas or other products that are produced through fossil-based energy. Producing semi-manufactured items (for further processing) can also reduce the wide variety of biomass characteristics.

Products and markets

In 2040 biomass products will be marketed in a recognisable and certified manner, and will have a positive image with the consumer and social parties, who will have no doubts about the sustainability of such products. Electricity and heat, gas, transport fuels and chemicals will be efficiently produced and used and, to the consumer, form valued alternatives to products manufactured using fossil fuels.

Biomass energy research

Long-term research is extremely important in achieving the aforementioned objectives. The broad input of biomass is translated into the biorefining concept, whereby the highest possible added value can be achieved, both environment-technically and economically. This concerns structural changes in the energy sector and chemical industry, resulting in economically competitive processes with, for example, minimum turnover losses and very low emissions. Biological conversion processes at low temperatures are just as important as converting at high temperatures, such as incineration and gasification combined with gas cleaning, e.g. to produce syngas. In the energy sector, the long-term demand for electricity, heating and fuels remain crucial to a stable society, and biomass will play an important role here.

Biomass research can be divided into three main areas:

1 **Biorefining:**
The focus here lies in unravelling biomass and using it in the production of transport fuels and chemicals.

2 **Electricity and heating:**
This concerns the sustainable production of electricity and heat – possibly, but not necessarily, in combination with fossil fuels.

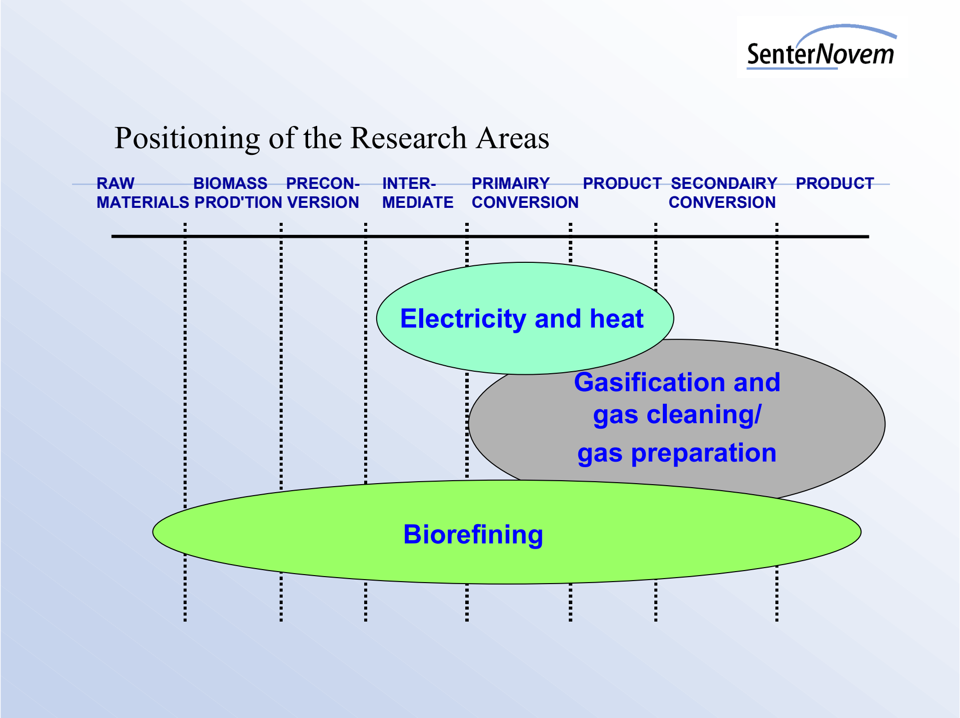
3 **Gasification, gas cleaning, conditioning and syngas production:**
The main focus here concerns developing technologies to manufacture gaseous semi-manufactured products, whereby electricity and heat, transport fuels and ‘new gases’ (such as SNG and hydrogen) can be produced efficiently. The product gases can also be used as raw material for chemical applications.

2.2.4 Demarcation

The biomass research programme is described from three research aspects:

- Biorefining;
- Power and heat;
- Gasification, gas cleaning, conditioning and syngas production.

Schematically, these three points can be placed in the generic biomass chain as follows:



Characteristic for biomass is the considerable cohesion between various elements. Even restricting the energy applications still provides a broad range of routes and (alternative) process steps. This results in a chain with a clear growth of biomass, collection (harvest), transport and logistics, conversion to semi-manufactured products or end products. This process creates residues and by-products, as well as waste products that can be reused (cascading and biorefining).

This is why research proposals cannot be presented in isolation, but should be considered as one element in a chain covering the entire process – from raw material to market product. The demand for chain cohesion does not imply that the chain, in its entirety, needs to be detailed or evaluated. But it is important that the research proposal in question, as part of the biomass chain, can provide an important contribution to the success of the chain.

Developing and evaluating chains is a speciality in its own right. For thermal routes, a great deal of national and international literature has already been published. However, for biorefining routes, sound and innovative research may well have taken place but has been published under the Biorefining research point 1: Integral aspects.

It is also important to emphasise that EOS biomass also encourages long-term research, provided that commercial exploitation of research results can reasonably be expected within 10 years.

2.2.5 Biorefining

Demarcation
Biorefining includes the entire series of processes to fractionate the biomass raw materials into sub-components via biological, (bio)chemical, physical and/or thermo-chemical means. This is a broad area and includes processes that take place in the chemicals, biotechnological and food technologies. Using biorefining techniques, existing production processes can improve energetically, allow new products to be made, and permit products to act as energy carriers.

Biorefining also plays a role on the energy conservation side of industry, and in the production of new sustainable energy carriers. Biorefining offers the opportunity (with minimum loss in mass and energy) to replace fossil-based raw materials and fuels, and to use entirely new marketable 'products' that have an immediate biomass functionality. Only projects that focus on a more sustainable energy management system can be included in this section of the EOS.

Definition:
Biorefining refers to fractionating biomass into various separated 'products' that possibly undergo a further biological, (bio)chemical, physical and/or thermal-chemical processing and separation.

Research objectives
The objective is to fractionate biomass raw materials into high-grade sub-components for use in the chemical and energy sectors, thus minimising the number of conversion steps and loss between the raw material and the final product while being exergetically optimised. The research aims to offer more energy-efficient biorefining alternatives to existing production processes, while also making biofuels more efficient and less expensive to produce.

Targets

- Pilot plant demonstrations showing the replacement of a chemical production process by a biorefining process, for products with well-founded market prospects and a potential of 100 PJ energy reduction in 2020.
- Producing biofuels as a cost price of 400 euro/ton (15-20 euro/GJ) around 2010, and 250 euro/ton (8-10 euro/GJ) around 2020.
- Commercial production of ethanol from woody crops.

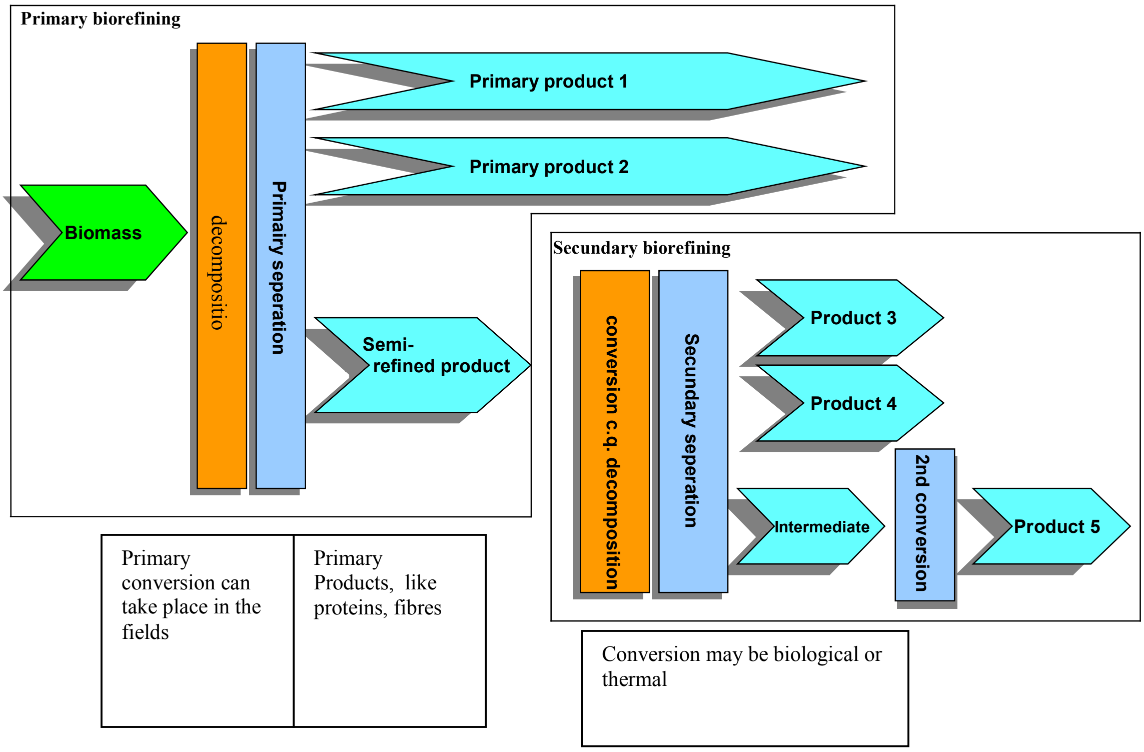
Focal points and import themes
The following main points and knowledge import themes are included in this research area:

Focal points: Biorefining, raw materials from biomass and residues

Import themes: Biomass conversion, pre-treatment/feeding
Biofuels, application in the transport sector

The following aspects are important when formulating the studies in this research area:

- The research should provide an indication of the long-term technological developments required with regard to the related non-technical aspects concerning public acceptance and implementation;
- This research area is split into primary biorefining (unravelling biomass) and secondary biorefining (manufacturing the product), also in both the biological and thermal routes.



Primary conversion can take place in the fields

Primary Products, like proteins, fibres

Conversion may be biological or thermal

Biorefinery (into A&F, Wageningen and Biomass Transition)

Long-term research

The following research points should be solved within the long-term research.

1. Integral aspects

In view of the wide range of the biorefining studies, researchers should try to find ways to optimally integrate the results into current chemical and energy production processes. They should also work towards a maximum valorisation of biomass across the entire chain, including worldwide usage. Analysing existing processes and future chains allow focal aspects to be traced plus evaluation of the choices made. Technologies should be used to develop systems that can also be placed in a social context, so that bottlenecks can be identified and addressed, while providing feedback to the technological research. Important points to remember concern the non-technical aspects such as competition with food production, biodiversity, water, nutrient depletion and erosion.

Therefore research into integral aspects forms the core of the long-term EOS biomass research programme, and acts as a reference for choices made – both in the past and the future. See Section 2.3.

Research items

Developing advanced, integrated (biochemical and thermochemical) refining concepts, including:

- Process analysis: research should be focused on exergetic analyses of industrial processes in order to identify ‘opportunities’ where biomass-related ‘products’ can best be used. This means fossil-based raw materials or fuel substitutes whereby maximum energy conservation and CO_2 reduction can be achieved. The logistics chain is part of this, including supply and accessibility. The focus lies on optimising the future industrial biomass infrastructure across the entire chain, with its worldwide subdivisions;
- Chain analysis: research should work towards optimalisation of exergy and energy, plus CO_2 reduction and the environment (Life-Cycle Analysis, LCA) within the chain. A maximum valorisation of all biomass components should be achieved throughout the chain, and every residue should be usefully utilised.

2. Primary biorefining

Although primary biomass refining partially concerns current techniques, additional research should search for substantial efficiency improvements (factor 2) and cost-price-reducing sales at current technical risk levels. This research is necessary in order to make secondary refining possible.

Research items

- Pre-treatment and separating ‘raw’ biomass into components. This concerns double output processes that allow conversion processes and/or secondary biorefining processes to produce more specific products.

3. Secondary thermo-chemical refining

Thermochemical refining, whether or not it is preceded by primary biorefining, can be implemented relatively simply (biomass – torrefaction – chemicals) or in a very advanced manner (biomass – torrefaction – gasification – gas cleaning – synthesis – useful residues), whereby the required ‘products’ are separated at various stages. However, only the thermochemical refining is discussed here, as part of the biorefining process. Thermochemical refining in itself has already qualified as export theme and is not included in the long-term programme. It is therefore not the conversion step that is the determinant, but the refining process that leads to the required products within which this conversion can play a role.

Research items

- The process and chain analyses with thermochemical refining falls under the integral approach (see point 1 above);
- Technological research into thermochemical conversion should attempt to achieve substantial improvements in production and economic efficiency. For gasification, see Section 2.2.7.

4. Secondary biological refining

The research items can be split into the development of specific conversions and the optimalisation of the process conditions under which conversion takes place. Only biological refining is discussed here, as part of the biorefining process. It is therefore not the conversion step that matters, but the refining process, which leads to the required products, within which this conversion can play a role.

Research items

- Conversion from biomass fractions (hemicellulose, cellulose, protein and/or sugars) into energy carriers and bulk chemicals, providing that at least 50% energy is saved (fossil and biomass) across the entire chain, compared to the alternative.
- Biological production of hydrogen (with/without photosynthesis) with an energy return of 40%;
- Reactor and process technology: Optimalisation of conversion processes and conditions (including reducing end-product constraints, increasing reaction speed, process integration etc.).

5. Using biofuels in the transport sector (import theme)

Research into the production of biofuels in an integral part of this research area, whereby both the biological production of biofuels (ethanol from cellulose-based crops) and thermochemical production (syngas -> methanol or FT (Fischer Tropsch) diesel) will become an important route. Harmonisation with the international transport sector is required in order to achieve a successful application, and research should focus on exchanging knowledge with foreign researchers and/or collaboration with European and American biorefinery programmes, whereby the application side of biofuels is included.

2.2.6 Power and heat from biomass

Demarcation

Research into power and heat from biomass covers all processes whereby biomass and related substances (including biological residues) are converted into electricity and heat. This is a wide area and covers processes such as incineration, gasification, pyrolysis and other thermal processes, including gas cleaning. The total research area includes co/-auxiliary incineration plants, waste incineration plants (AVIs), installations specifically focusing on converting biomass into electricity and ‘multifuel’ plants that can efficiently convert combinations of biomass, coal and residues.

Heat is automatically created when generating electricity. In order to achieve a high chain efficiency, researchers try to achieve maximum useful application of the heat generated, as well as a high electrical return. Future small-scale decentralised power plants will also emphasise a high-efficiency chain as well as just a high electricity output.

‘CO_2 capture and storage’ is not discussed here as this falls under the research into new gas/clean fossil.

However, in many cases, a combination of ‘clean fossil’ and ‘electricity from biomass’ is certainly possible.

Sustainable production of electricity and heat through biomass will, in the run-up to a completely renewable energy supply, often be combined with fossil fuels. Using biomass can thus ‘profit’ from the high-efficiency techniques that have been developed for fossil fuels and from the stable corporate circumstances that have been achieved with fossil fuels. There is also an overlap with ‘biorefining’, because part of the biorefinery residues can eventually be used (decentrally) to produce electricity and heat.

General research objective

The general research objective is to increase the amount of biomass used to generate electricity and heat, thus achieving the highest possible efficiency and lowest possible emissions.

Specific research objectives

Leading on from this, specific process-related objectives can be formulated. For co-/auxiliary incineration in coal-fired plants, the objective is a 40% mix percentage of biomass and an electrical return of over 50% in 2040. The target for AVIs is a 40% electrical return. A mix percentage is difficult to define as a target; currently half of our waste from residues has biological origins. ‘Multifuel’ installations are aiming for an electrical return of above 50%, whereby the return using a high percentage of biomass is only a few percentage points lower than for 100% fossil fuels. Small-scale decentralised plants are aiming for a return from electricity and heat of over 85%.

In addition to the efficiency (return), there is also a high level of corporate security and flexibility, because large-scale use of biomass must also be economically viable.

Residues should preferably be used in processes that gain the maximum return from these residues (see also Section 2.2.7). Finally these conversions should be achieved with minimum emissions and maximum reuse of residues.

Targets

2020:

- Co/auxiliary mix percentage is 25% (on an energy basis);
- Completion of the technology for construction a 100 MW_{th} gasification plant, whereby the gas in a STEG (steam and gas turbine) is used for maximum electricity production;
- All wastes can be reused;
- 20% electricity generated from biomass and wastes; first use of residual heat at decentralised units.

2040:

- 40% electricity generated from biomass and wastes;
- Co-/auxiliary mix percentage is 40% on an energy basis;
- Conversion return for coal + biomass into electricity is over 50%, complete use of residual heat at decentralised units;
- Several biomass-STEG plants operational.

'Biomass 2040' includes a target for 2040 that 30% of the total energy supply will come from biomass. Because the conversion to electricity is proceeding faster than the total energy supply, and this is expected to remain the case, decision-makers have chosen a higher percentage than the 30% listed in the Biomass 2040 objectives. Coal-fired power plants and AVIs have the potential to achieve this objective.

This also implies that heat input is indispensable if the 30% target for the total energy supply is to be reached. The output of residual heat is not studied within this research area. Readers are referred to the research areas for ‘Built Environment’ and ‘Energy efficiency in the Industrial and Agricultural Sectors’.

Focal points and import themes
The following focal points and import themes are included in this research area.

Focal points:	Biomass, gas cleaning and reconditioning (incl. syngas production from heating gas) Biomass conversion, co-/auxiliary incineration in E-plants
Import theme:	Biomass conversion, pre-treatment and feeding

Gas cleaning and conditioning (focal point)
For research on this subject, please see the relevant research area (Section 2.2.7).

Biomass conversion, co-/auxiliary incineration in E-plants (focal point) and pre-treatment and feeding (import theme)
The Netherlands is a forerunner when it comes to co-/auxiliary incineration of biomass and waste to produce electricity and heat. When considering the contribution that co-/auxiliary and waste incineration in AVIs make to the amount of sustainable energy, then these technologies are very important: almost 75% of our sustainable energy has been generated in this way for many years. AVIs are among the most leading-edge technologies in the world when it comes to efficiency and emissions. The Netherlands has built up a great deal of knowledge on this subject. Various research institutes have ongoing projects where fundamental research is carried out into finding new ways of using biomass and waste flows, and reducing emissions even further. An expert group on this subject was set up last year and a test boiler has been constructed.

Significant progress has also been made on implementation, partly through the Coal Covenant. Using this technology biomass can make a significant contribution to the security of energy supply. With power plants such as the 250 MW_e gasification plant in Buggenum, the Netherlands will soon have a unique opportunity to find new highly efficient ways of converting residues into electricity. In the longer term, biomass can replace natural gas in modern STEG plants and will be very efficient.

Knowledge of pre-treatment and feeding of wastes is not available in other countries because this often concerns product combinations that are specific to the Netherlands.

The Netherlands can learn from the experience gained in the Scandinavian countries, particularly on the subject of pre-treatment/feeding of wood. The research may include the following knowledge import themes:

- Inventory of knowledge import sub-areas;

- Inventory of expertise;
- Attend relevant conferences;
- Visit foreign knowledge institutes and build up external knowledge network;
- Determine the 'knowledge importer' in the Netherlands and the relevant associated stakeholders;
- Specific purchasing knowledge (licences/patents/…);
- Collaboration with foreign partner.

Long-term research
The following research points should be resolved within the long-term research programme.

1. Pre-treatment of specific mixtures

Pre-treatment of waste or fuel is required for the Dutch processing conditions. Research includes both thermal and mechanical pre-treatments such as those mentioned under the 'gasification' section. Pre-treatment is a knowledge import theme requiring harmonisation with other countries. However, AVIs impose specific criteria with regard to mixture and structure. In particular, when using wastes, separating the inert substances and managing the structure and moisture content (when mixing with coal, for example) should be included in this research.

2. Research to improve the price/performance ratio

Large-scale use of biomass requires an innovative approach to both existing and new installations. Research to improve the price/performance ratio, particularly of AVIs, can include proposals to improve efficiency, reduce costs or make better use of residues such as fly ash. Clever combinations of processes and the useful reuse of heat can increase output. In addition, managing the slag formation and deposits (slagging and fouling) and limiting emissions through 'in-line' measures, all fall within this research area because they integrally influence both the price and the performance.

3. New multifuel plants

High-efficiency installations are currently being developed that can burn variable combinations of coal and biomass. Specific research is required for the Netherlands, to see how wastes can also be incinerated in these plants. Research is required into a variable mixture ratio in order to allow a varying supply of fuels and wastes, and also to keep the electricity price constant. Auxiliary incineration of heating gas in natural-gas-STEG installations should also be part of this research area.

4. Small decentralised units with high total efficiency

Research into new decentralised units that allow the industry to meet the changing demand for electricity and heating in urban areas, and where the residual heat can be usefully reused for space heating. This research focuses on the ability to vary the capacity and to input heat, rather than on just a high electrical efficiency.

5. Emissions/reuse/residues

Research should initially focus on 'in-process' measures to reduce emissions and residues to an absolute minimum.

Reusing residues (e.g. fly-ash for the cement and road-building industry) can be part of the research, alongside ‘end of pipe’ measures and post-separation techniques.

2.2.7 Gasification, gas cleaning, conditioning and syngas production

Demarcation
This research area covers the processes whereby biomass is converted into a gaseous product that can be used for direct energy production (through incineration), or can be reprocessed into a high-grade intermediary fuel to replace fossil-based fuels, or used in advanced systems for electricity generation (such as fuel cells). The basic process is a thermal dissection of biomass at high temperatures, through a reaction to oxygen and other reagents.

The gas obtained is generally converted on-site, or after transporting a short distance, into a market-ready energy carrier. For stationary applications these include heat, electricity, hydrogen or synthetic natural gas (SNG). For mobile applications the gas can be converted to FT diesel, methanol, ethanol, hydrogen, SNG, as well as to heavier oxygen-based compounds. Considering the fact that the latter products are also basic ingredients for the chemical industry, there are clear opportunities for synergy between sustainable energy and sustainable chemicals.

However, the chemical applications are not included in the EOS scope. In fact all three of these energy market segments can be served by gasification:

- Gaseous fuels;
- Electricity and heat; and
- Transport fuels.

General research objective
The general research objective is to achieve efficient conversion of biomass into high-grade product gas that, in composition, meets the criteria for the sequential energy generation and/or the synthesis process to produce high-grade liquid or gaseous energy products. This conversion should meet high environmental criteria.

Specific research objectives
Gasification means that biomass can be widely used as a source of sustainable energy in the various market segments. EOS Biomass has the following objectives.

Application objectives

- Production of clean heating gas (‘product gas’) that is efficiently converted into heat and/or electricity, e.g. in an integrated cogeneration plant;
- Preparation of clean synthesis gas with a CO/H_2 ratio that makes it suitable for catalytic conversion to fuels, for both stationary and mobile applications;
- Preparation of SNG and/or hydrogen based on biomass.

Other objectives

- Development of efficient, reliable gasification systems that can be left unmanned.

- Development of large-scale gasifiers (hundreds of tons per day, or more);
- Development of small-scale gasifiers (several tens of tons per day);
- Development of suitable technologies to cool the gas produced, to clean components that restrict gas application, as well as bringing the gas combination up to specification, depending on the required application;
- Research into improving the quality and broadening the application opportunities of the residues produced.

Targets
The gasification should be developed to the most energetically efficient and environment-technical highest standard.

- Efficiency: the application should (be able to) produce an energy efficiency for combined heat and power production of over 85%; the energy efficiency for product gas or synthesis gas should be (able to achieve) over 75%;
- The mineral cycle can be closed;
- At some point the application should potentially be competitive with fossil energy sources.

Timeframe targets:

- 2015: demonstration of biosynthesis gas production at a scale of 10 tons of dry biomass material intake per day;
- 2020: commercial application of gasification in transport fuel production plants;
- 2010: commercial availability of small-scale gasifiers.

Focal points and import themes
The following focal points and import themes are included in this research area.

Focal points: Biomass, gas cleaning and conditioning (incl. syngas production from heating gas)
Import themes: Biomass conversion, pre-treatment and input
Biofuels, application in transport sector

Long-term research
The following research points should be resolved within the long-term research.

1. Pre-treatment of the biomass
Depending on the gasification technology used, the biomass should be pre-treated to some extent. This includes:

- Thermal pre-treatment of biomass for gasification, i.e. thermal: drying, torrefraction, carbonising, pyrolysis etc.;
- Thermomechanical pre-treatment of biomass, i.e. reducing, making into pellets or briquettes, mixing etc.;
- Developing new, more uniform, feeding components for gasification from a wide range of feeding specifications.

These steps are designated as a knowledge import theme because solid fuel handling is extensively developed in well-forested countries.

Where this offers harmonisation via knowledge import, there is actually plenty of room for original research, in collaboration with gasification.

2. Gasification and gas cleaning

Based on the objective of improving product gas composition and quality, researchers can choose from a broad range of technologies: from processes that are already commercial, to technologies that only exist on paper. An overview is made of all possible routes, and these are compared, based on development status and required product gas composition. With a view to the ambitious, long-term objectives, the EOS gasification research area is limited to the following categories, where long-term research is necessary.

(a) Gasification in a fluid bed using air, enriched air or oxygen to produce medium to high-caloric gas and biosyngas, preferably under pressure. Using in-situ catalysis can further support this concept. Gas cleaning and modifications in gas composition make the gas suitable for downstream gas applications, which can vary from electricity and heat generation to catalytic synthesis processes.

(b) Gasification in a reactor system consists of one unit for gasification and one unit for heat generation through incineration, whereby these units are physically separated. Various configurations and reactor types are possible for both units. This technology, provided it is carried out under pressure (min. 5 bar, preferably 20 bar), can be used to produce synthesis gas. In-situ catalysis can contribute to this technology. Gas cleaning and changes to gas composition make the gas suitable for downstream gas applications, which can vary from electricity and heat generation to catalytic synthesis processes.

(c) Entrained flow gasification under pressure from pre-processed biomass material using oxygen to produce synthesis gas. Cleaning the gas and modifying the gas composition for the downstream process are essential elements in this technology.

(d) Liquid phase high-pressure gasification (sub/supercritical) to produce methane and/or hydrogen-rich gas. Catalysis here offers opportunities for steering and intensifying the process. The product gas should be cleaned and further processed. Coproduction of hydrogen and SNG is an option, as well as complete conversion to hydrogen or SNG are also possible applications.

2.3 Non-technological aspects

Gamma aspects play an important role in the transition to a sustainable energy supply. The Biomass Transition project, which was implemented (2002-2004) as part of the Energy Transition programme, have also experienced this, and researchers have noted the necessity for interaction between technology development and social acceptance. Research proposals can be submitted, provided these are a (limited) part of a proposal concerning focal points or import themes.

1. Insight into motives and the attractiveness of the various options

Under which circumstances is this new technology attractive to market stakeholders? Gamma research can contribute to the required insight at two points:

- Prior to and during the bèta research. Gamma research can generate insight into the motivation behind market stakeholders to develop and implement new techniques and to ‘give’ these to the technical research as preconditions. An inventory of the requirements and criteria (before development) helps to ensure that (after development) the technology has sufficient support and will be implemented.

- After development, once the results of the bèta research are available. Gamma research can assist in selecting between the various options; offering insight into the most attractive option, given the criteria of the stakeholders. Assume, for example, that corporate economic considerations are vital: in this case a cost-benefit analysis can help in choosing between two options – which is the most advantageous?

2. The economy of scale of a biomass energy installation

Biomass-processing plants can have varying scale sizes, whereby the economy of scale can be controlled by the supply area of the biomass. Installations based on import will be ‘world scale’ (how large is that?), but how large should a biomass plant be that processes biomass from the immediate surroundings? Raw biomass has a low caloric content and therefore has an unfavourable logistic economy. Where are the break-even points and, based on this result, what are the guiding concepts?

3. Start-up economy of biomass technologies

Introducing new technologies generally means that these ‘first generation’ installations cannot compete against mature technologies. However, once the learning curve has been started then the new technology can become competitive. How can you guide the introduction of new technologies, economically and strategically, through the ‘nursery’, and what are the most suitable policy instruments for the government to use?

4. Designing trade systems for sustainable biomass

International trading systems need to be developed for the large-scale import of biomass. This means developing clear sustainability prerequisites, possibly through certification. What are the prerequisites within which these systems can be developed?

5. Market

Chains need to be designed that offer solutions to bottlenecks (such as supply, market analysis and limitations) and their related social aspects.
Product analysis: which biomass-related products/intermediaries offer the best prospects as fossil substitute, or as a new product with its own functionality?

6. Social aspects

Research into the social acceptance of new biomass-based raw materials or product chains. Systems should be developed per technology, but also need to be placed in a social context, whereby the bottlenecks are identified and addressed, so that feedback can be given to the technological research. Specific points include competing with food production, biodiversity, water, nutrient depletion and erosion.

3 New Gas/ Clean Fossils

Introduction

The R&D portfolio for 'New Gas/Clean Fossils' consists of the following:

Focal points	- CO_2 storage (underground) - CO_2 separation technology (membranes, solvents, sorbents) - Fuel cell (PEMFC and SOFC) - Reforming hydrocarbons into H_2 (excl. LPG) - Advanced coal conversion with CO_2 separation
Knowledge import themes	- Natural gas conversion, gas turbine technology
Knowledge export themes	- Reforming natural gas into H_2 (large installations)
No R&D themes	- CO_2 storage using mineral recording - Natural gas, conversion to end-use, emissions-reduction technologies - Natural gas conversion, production of H_2 with CO_2 capture

The PVC for this research area consisted of the following persons :

Dr. E.A. Breunesse	Shell Nederland, Chair
Dr. N. Bolt	KEMA
Dr. F.A. de Bruijn	ECN
Ir. O. Florisson	Gasunie Research
Dr. W.K. Heidug	Shell International Exploration
Dr. I. Ritsema	TNO-NITG
Drs. S.M. Koomen	Ministry of Economic Affairs, observer
Ir. F.J.R. Denys	SenterNovem, coordinator
Ir. P.J. Stollwerk	SenterNovem, support

3.1 Description

3.1.1 Research area

This research area consists of two sections, but these have been merged due to the huge overlap in subject matter. Clean Fossils focuses on the lowest possible (CO_2) emissions and making (climate-neutral) fossil energy carriers (facility chain). New Gas works towards a sustainable gas economy. In the long term this may mean switching to other sustainable fuels and a hydrogen economy.

Demarcation: Clean Fossils

In defining the demarcation for Clean Fossils, this report uses the definition as specified in the Clean Fossil Policy Document [3]. The term Clean Fossils includes: 'the extraction, transport and conversion from carbon-retaining substances into energy and/or other substances, such that they release as little CO_2 into the atmosphere as possible'.

The term Clean Fossils has an unambiguous definition, both nationally and internationally, which usually refers to turning fossil-based energy carriers into climate-neutral equivalents. Some people emphasise the fact that clean fossils also include other emissions, e.g. acid and toxic substances. However, there are very good reasons why these other environmentally disturbing substances are not included here. The development of both policies and techniques is currently undergoing huge variations between the prevention of 'conventional' emissions and the emission reduction of greenhouse gases, particularly CO_2. Techniques to prevent 'conventional' emissions are generally fully developed, reliable and fairly affordable.

In general this concerns fossil-based, although other carbon-based materials (such as biomass) are also included because, from a climate/environmental point of view, the CO_2 source is irrelevant. This usually concerns energy carriers but, from an environmental perspective, there is no reason to exclude other sources or processes. There are a number of chemical processes in the Netherlands that are responsible for releasing considerable and concentrated CO_2 emissions.

Finally, it is important to view Clean Fossils from a chain perspective. For energy carriers this means looking at the effect of these measures, from extraction up to and including CO_2 storage. The Clean Fossils chain consists of:

- **Extraction**: ideally, fossil fuels would be 'decarbonised' when they are extracted from their underground reservoirs. In addition to the previously applied technology of CO_2 separation when extracting oil and gas, this application is not yet feasible. The concepts that come closest to this ideal are those that, in the end, put just as much carbon back into the reservoir. This is possible in the Netherlands, by storing carbon dioxide in gas fields or aquifers, or extracting methane from coal layers during simultaneous CO_2 injection.
- **Pre-conversion**: carbon can be removed from fossil fuels before the final conversion into usable energy. This involves producing hydrogen, which is then offered to end-users as transport fuel, for chemical use and for stationary applications. The extra CO_2 that is created through CO_2 separation is then put back into storage in order to ensure a climate-neutral situation.
- **Conversion**: clean fossil supply chains require renewed conversion systems. In order to convert fossil sources into electricity without CO_2 emissions, various concepts are currently being developed, e.g. zero-emission coal-fired power plants.
- **Post-conversion**: with/without integration into the conversion system, CO_2 separation from flue gases can take place, even after the energy conversion. This can then be stored.
- **Infrastructure**: the infrastructure, i.e. the energy distribution system (including pipelines and storage) is very important in the clean fossil supply chain. This must be modified for new energy carriers such as hydrogen, and an infrastructure for CO_2 return flows may also be necessary.

Use: the use of final energy carriers, such as gas, electricity and transport fuels are found at the end of the chain. Users are confronted with new energy carriers (hydrogen) and new end-conversion techniques (fuel cells).

Whenever the CO_2 is separated from the supply chain, it will always need to be stored or reused.

Demarcation: New Gas

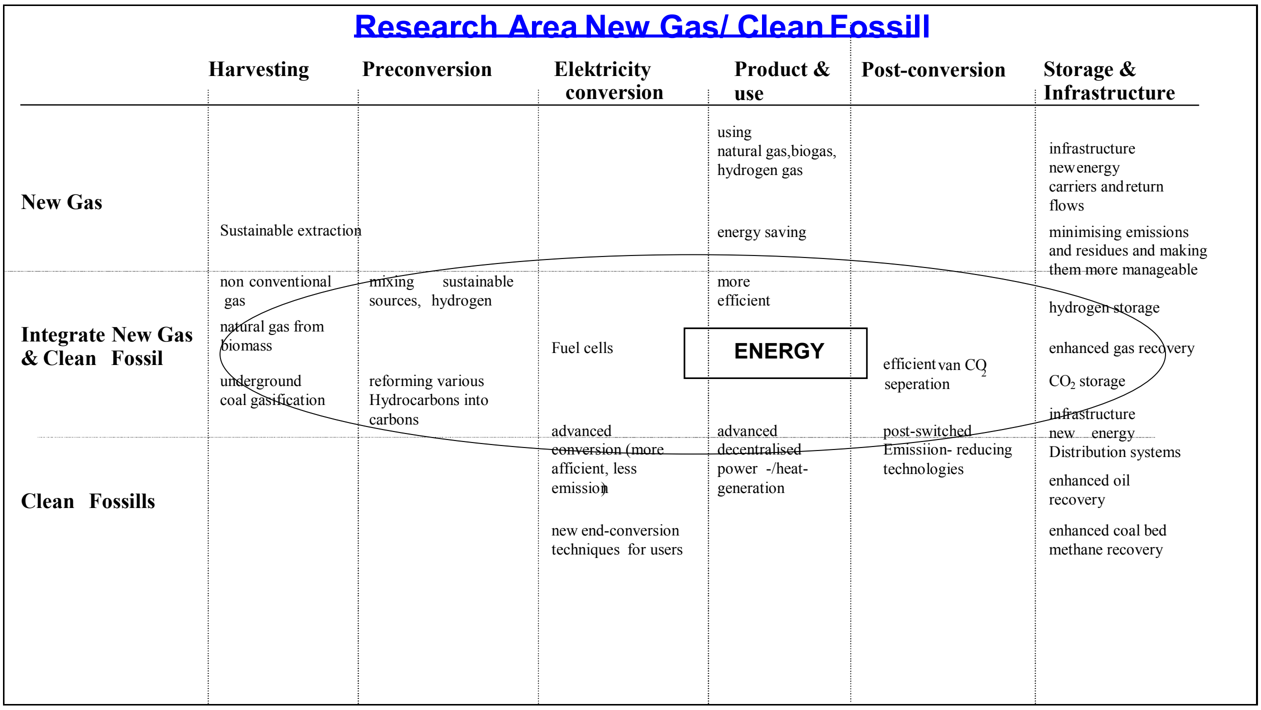
New Gas focuses on the use of gaseous energy carriers (other than the current forms) in the transition towards a sustainable energy economy [4]. Gas is becoming increasingly important. Consumers are used to the traditional use of natural gas, which has the advantage for climate policy that it is a relatively low-carbon fuel when compared to coal and oil. However, there will be considerably less European natural gas available over the coming decades. The entire gas sector is trying to define its strategy for operating in a liberalised gas market, and includes working towards a sustainable gas usage in order to accelerate the transition to a sustainable energy supply. In the long term this transition means moving towards a hydrogen economy. The logical steps include:

- **Efficiency measures**: the increasing total gas demand, and thereby the emissions, can be substantially reduced in the short term through energy conservation measures;
- **Mobile application of natural gas**: the short-term advantage of having vehicles run on natural gas involves the beneficial CO_2 reduction; in the medium term there may be opportunities to use biogas and hydrogen, which take us a step closer to the mobile application of biogas and hydrogen;
- **Decentralised electricity generation**: further sustainability is possible by making the best possible use of opportunities concerning increased efficiency and environmental effects of decentralised energy generation (electricity and heat) in the consumer market;
- **Gas production**: the production of unconventional gas, e.g. from biomass and/or coal layers, can result in emissions reductions in the gas chain;
- **Auxiliary mixing**: introducing mixing gas can form an important link to a hydrogen economy. Hydrogen gas can be transported in two ways: mixed with natural gas or in its purest form. Mixing gas can probably be transported via the current infrastructure and, to a certain degree, can be used in current equipment;
- **Using hydrogen**: a very long-term scenario concerns the complete transition to a hydrogen-fed gas supply, where the hydrogen is generated in a sustainable manner and supplied to the net in CO_2-free form, using CO_2 capture and sequestration.

Integrating New Gas and Clean Fossils

Clean Fossils has a clear chain approach. From the extraction of the raw material through to its use, CO_2 emissions to the atmosphere are prevented wherever possible. New Gas concerns a number of developments that work towards (the transition to) a hydrogen economy. Each step has a certain value, from the viewpoint of making gas use more sustainable, and these developments also help to support and strengthen each other.

Integrating Clean Fossils and New Gas produces a clear consistency and synergy. This is shown in Figure 3.1, which is based on the aforementioned demarcation. The vertical axis splits New Gas, Clean Fossils and a complementary area. The horizontal axis shows the extraction chain for fuels through to using the energy. All technologies, phases and developments mentioned in Clean Fossils and New Gas are shown in the figure. The integration is shown in the centre of the figure.



Research Area New Gas/ Clean Fossill

	Harvesting	Preconversion	Elektricity conversion	Product & use	Post-conversion	Storage & Infrastructure
New Gas	Sustainable extraction			using natural gas,biogas, hydrogen gas energy saving		infrastructure new energy carriers and return flows minimising emissions and residues and making them more manageable
Integrate New Gas & Clean Fossil	non conventional gas natural gas from biomass underground coal gasification	mixing sustainable sources, hydrogen reforming various Hydrocarbons into carbons	Fuel cells	more efficient ENERGY	efficient van CO_2 seperation	hydrogen storage enhanced gas recovery CO_2 storage infrastructure new energy Distribution systems
Clean Fossills			advanced conversion (more afficient, less emission) new end-conversion techniques for users	advanced decentralised power -/heat-generation	post-switched Emissiion- reducing technologies	enhanced oil recovery enhanced coal bed methane recovery

Figure 3.1: Integrating New Gas/Clean Fossils into the supply chain

3.1.2 Ongoing programmes and activities

Appendix 3.1 provides an extensive overview of the national New Gas/Clean Fossils initiatives and programmes.

3.1.3 International prospects

Appendix 3.2 contains an overview of a number of leading international initiatives.

3.1.4 Knowledge clients

The clients using this knowledge can be split into a number of categories.

Government
Decarbonising fossil fuels will cost extra money and energy, compared to the current use of fossil fuels. The industrial sector is not expected to be enthusiastic about investing in R&D. The government could play the role of knowledge client during this phase.

Knowledge institutes and universities
The knowledge obtained can be made available on both the national/international markets.

Industry
The development of new technologies will lead to new market opportunities. These technologies will make companies more environmentally friendly and allow them to operate more economically.

NGOs and the Dutch general public
Social acceptance is an important aspect within the New Gas/Clean Fossils theme. NGOs form a credible partner in the eyes of Dutch citizens.

3.1.5 Energy transition

Transition management includes several areas that overlap New Gas/Clean Fossils:

- Biomass Transition: advanced coal conversion (co-/auxiliary biomass incineration) and hydrocarbons (from biomass) can be reformed into hydrogen;
- New Gas: decentralised energy generation, use of hydrogen, auxiliary mixing of hydrogen in natural gas, sustainable gas production, mobile gas applications;
- Modernising energy chains (MEK II): improving efficiency;
- R3, sustainable corporate management in the Rotterdam Harbours and Industrial Complex: infrastructure for hydrogen and CO_2 efficiency improvements, using hydrogen and CO_2 usage and storage.

3.2 Research areas and objectives

3.2.1 Vision

This philosophy is based on the existing visions of the New Gas Team [4] and the Clean Fossil Policy Document [3]. Fossil energy sources will continue to play a major role in our energy management system. The cleaner and more efficient use of these fossil fuels is seen as a bridging option towards a complete sustainable energy supply (renewable sources) in the longer term. Sustainable energy from renewable sources is currently too expensive to be used on a large scale. The price of fossil fuels will probably remain low over the next few years. The stocks of fossil fuels that are (technically) still available are more than enough to guarantee a long-term energy supply. In addition to the security of supply, reliability and affordability, the government's objectives include the reduction of environmental pollution and climate change as a result of the large-scale use of fossil fuels. In particular, the prevention of greenhouse gas (CO_2) emissions into the atmosphere should be prevented wherever possible.

Section 3.1.1 describes the six New Gas transition paths. The New Gas Team has defined a vision for each of these transition paths (see Appendix 3.3). The vision regarding hydrogen as an energy carrier is the most relevant for this research area, because introducing hydrogen into the energy system can accelerate the sustainability of our energy management.

This vision has been formulated by the New Gas Team as follows: 'The stepped introduction of hydrogen into the Dutch energy supply, using specific Dutch characteristics and taking into account international developments and the economic and social feasibility of such plans. The stepped introduction of hydrogen and hydrogen-related technology can be achieved by mixing hydrogen with natural gas and by encouraging the use of pure hydrogen in niche markets'.

The efficient and clean use of fossil fuels means converting them into hydrogen while separating and storing the CO_2. The final conversion of hydrogen would ideally be achieved electrochemically. The route towards the final goal can be achieved in two ways (see Figure 3.2).

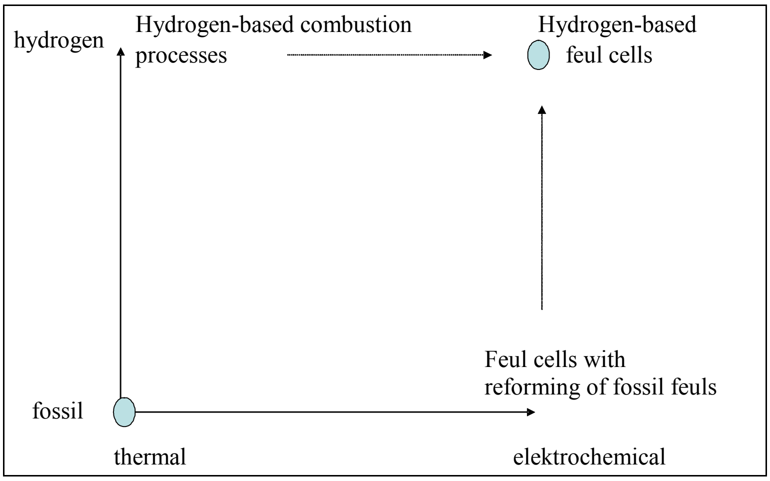


Figure 3.2: The efficient and clean use of fossil fuels.

Simultaneously replacing fuel and conversion technology is unlikely due to economic reasons and security of supply aspects. The EOS theme New Gas/Clean Fossils includes both transition routes.

Appendix 3.3 defines the philosophies behind the other New Gas transition paths, as specified by the New Gas Team.

3.2.2 Demarcation

Achieving the previously defined research philosophies is an enormous technological and economic challenge, and will require huge research efforts in order to make this dream come true. Within the New Gas/Clean Fossils research area, the research objectives have been formulated that should bring the Netherlands several steps closer to achieving this vision.

The focal points and knowledge import themes within this research area are split into three sections: CO_2, hydrogen and advanced conversion. Table 3.1 shows these research areas along with the associated focal points and knowledge import themes.

Research area	Focal point or knowledge import theme	
CO_2	Focal point	CO_2 storage (underground)
		CO_2 separation technology
Hydrogen	Focal point	Fuel cells (PEMFC, SOFC)
		Reforming hydrocarbons into hydrogen (excl. LPG)
Advanced conversion	Focal point	Advanced coal conversion with CO_2 separation
	Knowledge import theme	Natural gas conversion, gas turbine technology

Table 3.1: Research area New Gas/Clean Fossils.

The CATO project (supported through the BSIK programme) focuses on CO_2 capture, transport and storage. The CATO research activities have some common ground with the research activities within the CO_2 research area and gamma aspects (see Section 3.3). Harmonising these plans with the CATO project can prevent double research activities. This also applies to the ACTS Sustainable Hydrogen Programme. Appendices 3.4 and 3.5 describe both the ACTS and CATO programmes.

The subject of ‘gas quality’ is an important condition along the route to a sustainable energy supply.

The gas composition, and the related chemical and physical characteristics, is an important aspect for the production, transport, distribution and use of all gases within the New Gas/Clean Fossils programme. Matching gas quality throughout the entire gas chain is one of the conditions for the successful use of gas (excluding biogas) within the New Gas/Clean Fossils programme.

The range of characteristics from the spectrum of combustible gases within New Gas/Clean Fossils is far greater than those specified for the current applications. This places new demands and restrictions on the processes of ‘gas extraction’, ‘pre-conversion’, ‘conversion’, ‘product and use’, and ‘storage and infrastructure’. For example, the gas applications determine that raw biogases need to be upgraded to a certain minimum quality level before being used. In order to use New Gas/Clean Fossils effectively, new developments are required to increase the flexibility of the aforementioned processes with regard to the gas quality.

Research regarding ‘gas quality’ with respect to New Gas/Clean Fossil gases is a separate theme that is included in the specific focal points and knowledge import themes. This also applies to system studies (excluding exergetic studies), which should have a direct link to the chosen focal points.

NB: The summaries of the research objectives in the following sections are not exclusive, and their emphasis will shift over the course of time. The short-term research objectives are not part of the EOS and are only included here in order to provide a complete picture. A number of research objectives are implemented in several places. This has been done in order to present a cohesive research package for each research area.

3.2.3 Research area: CO_2

This research area consists of the focal points ‘CO_2 storage (underground)’ and ‘CO_2 separation technology’.

3.2.3.1 CO_2 storage (underground)

With far-reaching limitations of CO_2 emissions, it will become necessary to use fossil energy sources and ensure the large-scale application of CO_2 capture, transport and storage technology. This infrastructure will primarily be coupled to large-scale central energy conversion facilities, e.g. power plants, the steel and cement industry, and chemical plants, such as refineries, hydrogen and fertiliser production facilities. All these large-sized conversion facilities will be able to capture, store and possibly reuse CO_2 (and heat, see Chapter 1), whereby the CO_2 emissions can be reduced by a considerable percentage. In favourable circumstances, this transition scenario could be implemented on a wide scale in some areas from 2014 onwards, and become standard everywhere in 2030. This scenario includes decentralised, hydrogen-based systems for transport and residential purposes.

The main question under this theme concerns whether CO_2 storage is *safe and environmentally friendly*, both in the operational phase of the storage facility, and in the longer term. CO_2 migration risk evaluation and management techniques are essential in answering this question.

In addition, queries are also raised regarding the correct technology and the most *cost effective* method of CO_2 storage: is this EGR (Enhanced Gas Recovery), EOR (Enhanced Oil Recovery), ECBM (Enhanced Coal Bed Methane) or storage in aquifers?

Extensive research is being conducted worldwide into CO_2 storage, supported by international consortia and government bodies. International cooperation is essential in creating support at national, European and global levels. Examples include the IEA GHG (GreenHouse Gas) network, CO_2 Sequestration Leadership Forum (CSLF), the Carbon Capture and Storage Project (CCP) and the recently initiated European Integrated Projects known as CASTOR and CO2SINK, plus the CO2GeoNet Network of Excellence. National projects, such as CRUST (CO_2 Reuse through Underground Storage) and CATO (CO_2 capture, transport and storage) also play an important role.

Demarcation

CO_2 storage techniques overlap with CO_2 capture (focal point), energy extraction (ECBM, EGR, EOR, coal gasification) and storage of energy carriers (gas, hydrogen, heat). The following table contains the technology portfolio and the demarcation. For CO_2 storage, the mineral recording/storage of CO_2 is not explicitly excluded.

Storage method	Injection/production technology system	Environment and safety analysis technology	Monitoring and remediation technology
EGR	Low reservoir pressures and CO_2 phase Mixing, smart wells	Migration processes in geological system, wells, faults, ground movements	Geophysical sensing Geochemical sensing Extraction and remediation (pumping up)
EOR	Optimising oil production versus CO_2 storage, + thermal, smart wells	Migration processes in geological system, wells, ground movements	Geophysical sensing Geochemical sensing Extraction and remediation (pumping up)
ECBM	Adsorption/desorption processes, swelling, +aquifers, smart wells	Migration processes in geological system, wells, ground movements	Geophysical sensing Geochemical sensing Extraction and remediation
Aquifer	Characterisation sealed layers, fluid migration, smart wells	Migration processes in geological system, wells, ground movements	Geophysical sensing Geochemical sensing Extraction and remediation

Table 3.2: Technology portfolio for CO_2 storage.

The first column contains research aimed at specific storage methods. The last two columns concern research that is largely the same for the various types of storage systems, since this focuses on the geological layers above the CO_2 storage where leaks could potentially occur.

Breakthroughs

- CO_2 storage provides a safe and accepted solution;
- Inexpensive and intelligent wells, 50% cost reduction (compared to 2004) for production, capture, conversion, and injection (downhole factory);
- Large-scale storage in EGR or EOR.

Research objectives

Long-term objectives (commercial applications > 10 years)

- Long-term monitoring infrastructure for the Netherlands (permanent geophysical and geochemical monitoring, both underground and on the surface), per area and not per site;
- Monitoring and managing auxiliary mixing in the CO_2 flow;
- Integrated large-scale infrastructure for capture and storage of CO_2;
- Development and acceptance of large-scale storage in EGR, or EOR on a large scale;
- CO_2 storage in aquifers and empty gas fields;
- Coupled CO_2 migration process prediction models;
- Over 50% cost reduction (compared to 2004) for aspects such as: risk evaluation techniques and flexible wells for both CO_2 production and injection;
- Integrity of current boreholes and new borehole/casing monitoring techniques for operational and post-abandonment phases;
- Underground capture and energy conversion prototypes.

In order to provide a complete picture, the short-term objectives are also listed here (commercial applications 0-10 years)

- Feasibility of the clean fossil strategy/underground CO_2 storage in a liberalised market;
- CO_2 storage in empty gas and oil fields: resolve injection problems, well processing prediction software (CRUST and CATO);
- Verification and validation of stand-alone CO_2 migration process prediction models;
- Determining the feasibility of monitoring strategies and techniques (onshore and offshore);
- Cost/benefit analysis of land/sea coverage versus storage-specific monitoring strategies.

3.2.3.2 CO_2 separation technology

The use of fossil energy sources makes it necessary to apply CO_2 separation techniques in order to achieve far-reaching limitations of CO_2 emissions. CO_2 is released in concentrated, almost pure, or diluted form during all fossil conversion routes. This also occurs when using biomass and biofuels. The concentrated CO_2 flows can immediately be transported elsewhere. However, the diluted CO_2 will first need to be concentrated or removed before it can be stored. There are three decarbonisation routes:

- Capture of CO_2 from flue gases (post-combustion);
- Capture of CO_2 from flue gases (pre-combustion);
- Nitrogen-free conversion (denitrogenation, or oxyfuel).

The capture from flue gases can be widely used for retrofit situations, but also for new applications and as post-combustion technology.

The last two routes require new conversion systems (gasifiers, oxygen-based incinerators) to be built. All these routes require huge investment, as well as a large, parasitic, energy consumption for the CO_2 separation. In addition to the currently most used commercial technology of absorption liquids (MEA), there are also other options available, such as membranes. Research should focus on developing (and making commercially available) aspects such as new absorption technologies and/or new absorption liquids, new membrane technologies and process integration. The break in the trend can be found in cost reductions. The following table shows the technology portfolio for CO_2 capture with respect to the three decarbonisation routes.

Capture method	Post-combustion processes	Pre-combustion processes	Denitrogenation/oxyfuel
Solvents	New solvents Contactors Process design	New solvents Contactors Process design	O_2/N_2 absorbent
Membranes	Membrane absorption, polymeric, ceramic, FT, carbon membranes	CO_2/H_2 separation: Ceramic, polymeric, palladium, membrane absorption	O_2-conducting membranes
Sorbents	Lime carbonation	Dolomite Zirconates	Chemical looping O_2/N_2 adsorbents

Table 3.3: Technology portfolio for CO_2 capture.

In the medium term, which includes storing CO_2 from less CO_2-concentrated large-scale flue and heating gas products in nearby gas fields or aquifers, research should focus on separating the CO_2 from these gases. Costs and energy losses are extremely high, and must be considerably reduced. Substantial technical knowledge is required in order to achieve this.

On a global level, international consortia and government-support programmes are conducting extensive research into CO_2 capture. International cooperation is essential to reduce costs and prevent duplication of research efforts. Examples include the IEA GHG capture test centre network and the recently started European Integrated Projects of CASTER and ENCAP. CASTOR focuses on capture from flue gases, while ENCAP works towards capture from heating gases and nitrogen-free conversion. Japan, Canada and the USA are frontrunners in this respect.

Demarcation

CO_2 separation technology has elements that are common to two other focal points, i.e. advanced coal technology and reforming hydrocarbons and biofuels energy production. There are also links with knowledge import themes that focus on natural gas conversion. Integrating CO_2 separation technology into energy conversion processes requires very careful harmonisation. The criteria concerning storage and reuse of CO_2 that are applied to the CO_2 production process are also important. Research into energy conversion processes does not fall under the scope of this focal point, though integrating capture technology into energy conversion is included. This also requires careful harmonisation.

Breakthrough

- The trend break stems from cost reductions and restricting energy losses by at least 50% (compared to 2004).

Research objectives

Long-term objectives (commercial applications >10 years)

- ‘Zero-emission’ electricity power plants;
- Energy-efficient and inexpensive capture processes on a realistic scale;
- Integrating the capture and storage of CO_2;
- CO_2 separation technology from flue and heating gases: developing new absorption technologies, absorption liquids, membrane technologies and process integration;
- CO_2 separation technology: cost reductions of over 50% compared to 2004;
- CO_2 separation technology: reducing energy losses by over 50% compared to 2004 (innovation as target);
- Cheaper techniques for O_2 production (via separation, using high-temperature membranes, adsorbents etc.);
- CO_2 capture in biofuel energy production;
- Cheaper techniques for H_2 separation (ceramic membranes etc.);
- Integrating separation into energy conversion processes;

In order to provide a complete picture, the short-term objectives are also listed here (commercial applications 0-10 years)

Reducing the costs of energy losses by at least 30%; CO_2 reuse: optimising commercial reuse; multi-pollutant removal; feasibility of clean fossil strategy/capture in a liberalised market.

3.2.4 Research area: Hydrogen

The research area for hydrogen consists of the focal points ‘fuel cells’ and ‘reforming hydrocarbons into hydrogen (excluding LPG)’.

For mobile applications the objective behind this is to replace the current combustion engine with a cleaner and more efficient conversion technology, i.e. the fuel cell. Hydrogen will become the main fuel in the long term but, in the transition to this situation, on-board reforming of available fuels will become an important intermediate link. For stationary applications, considerable benefits can be obtained by combining heat and power generation. Of the various small-scale options for electricity generation, the fuel cell has the highest electrical efficiency.

3.2.4.1 Fuel cell

PEMFC (proton exchange membrane fuel cell)

The objective is to develop PEMFC technology to achieve a more efficient conversion of fuels (such as natural gas, transport fuels and hydrogen) into electricity, eventually in combination with regenerated heat.

At stack level the PEMFC should have an electrical efficiency of at least 50%, which is defined as the ratio between DC energy provided by the PEMFC stack and the lower combustion value of the hydrogen feeding the PEMFC stack.

For mobile applications the expected lifespan would be around 5,000 hours, while for stationary applications this would be around 40,000 hours.

Demarcation

The most important objective for large-scale PEMFC application is to increase the operating temperature of the PEMFC (currently around 70°C) to 100-150°C. Firstly, because this considerably improves the resistance to polluting components, and secondly, it significantly improves the cooling of the PEMFC, which is a critical aspect for mobile applications. For stationary applications, a higher quality of the residual heat is particularly important due to the fact that tap water and space heating are used. Buffering the heat is also one of the options. An electrolytic membrane that allows operation at 100-150°C is not yet available, so development of such a membrane therefore has the highest priority, although results are not expected in the short term.

Breakthroughs

- At stack level, an electrical efficiency of the PEMFC of at least 50%;
- Increasing the operating temperature of the PEMFC to 100-150°C;
- For mobile applications, an expected lifespan of around 5,000 hours;
- For stationary applications, an expected lifespan of around 40,000 hours.

MERGEFORMAT**Research objectives**

Long-term objectives (>10 years)

An important objective is to finalise the state-of-the-art PEMFC technology so that it can be used in combination with reformer technology: thus demonstrating its improved robustness. Stationary and transport applications of PEMFC technologies largely run parallel.

At cell level:

- Developing and demonstrating high-temperature membranes;
- Development of PEMFC electrodes optimised for operation at 100-150°C, particularly by reducing the precious metal loads;
- Lowering the over-potential for oxygen reduction (improved efficiency);
- Research into electrodes without precious metals;
- Research into extending the lifespan of fuel cells;
- Improving the resistance to polluting components, particularly CO and CO_2.

At stack level:

- Research into the suitability of existing stack components and concepts for operation at 100-150°C;
- Developing advanced sealing concepts;
- Developing cheaper separator plates, suitable for mass production.

At system level:

- System integration of PEMFC stacks with reformers;
- Development of control systems for stationary applications, particularly for intelligent network coupling.

In order to provide a complete picture, the short-term objectives are also listed here (commercial applications 0-10 years)

Commercial introduction within the next 10 years is limited to a number of niche markets.

SOFC (solid oxide fuel cell)
The main objective is to develop SOFC technology for efficiently converting natural gas into electricity. A sub-objective of this is to demonstrate an SOFC stack with an electrical efficiency of around 48% (fuelled by natural gas), and a total efficiency (including the supplied heat) in excess of 95%. The lifespan of the SOFC conversion system should be around 40,000 hours, with system costs of 900-1500 euro/kWe. This results in a stack price of 300-500 euro/kWe.

For the conversion module, research should primarily focus on demonstrating a reliable (robust) SOFC stack, based on materials and manufacturing processes that show potential for achieving cost-price targets at mass production scales. Therefore developments need to focus on:

- Stack design;
- SOFC cell;
- Interconnection (cell separation plates).

The identification and/or development of materials for the required oxygen-conductive membranes, which need a sufficiently high oxygen flux, chemical stability and mechanical integrity, is a basic condition for this research. However, reactor design should run parallel to this and guide the material development. As with the conversion module, here too the development of cost-efficient manufacturing processes form an essential element in the success of this research.

Demarcation
Initially, the material research and reactor design will run parallel for the first few years, with limited interaction. The results of both development lines have considerable value in helping to reach emission targets, because they can also be combined with, or even integrated into, other energy systems. However, an umbrella activity for system design and evaluation should be initiated from the very beginning, to continually question the feasibility and, eventually, to guide development activities. The amount of interaction will increase throughout the development phase and, during the last segment, this will result in a single integration of development activities.

BreakthroughsMERGEFORMAT

- SOFC stack with an electrical efficiency of around 48% (fuelled by natural gas) and a total efficiency (including heat output) of over 95%;
- The lifespan of the SOFC conversion system should be around 40,000 hours;
- The system costs should be 900-1500 euro per kWe. This results in a stack price of 300-500 euro/kWe.

Research objectives
Long-term objectives (> 10 years)
The entire development is focused on the introduction of the projected clean and efficient conversion systems, over a period of 10-20 years, and is split into the following sub-sections:

- Cost-efficient, reliable SOFC (conversion) stack with an (expected) lifespan of around 40,000 hours (10-12 years);

- Integrated conversion/separation module based on SOFC technology and membranes (15-20 years);
- Development of cell components, interconnections and associated stack-related sub-aspects, such as gas sealers, electrical contact coatings etc.

In order to provide a complete picture, the short-tem objectives are also listed here (commercial application 0-10 years)
Short-term objectives related to the (actual, large-scale) commercial introduction are not feasible within a 10-year period. For the SOFC conversion module, a limited introduction in so-called niche markets may be possible, where the product has so much added value (compared to conventional solutions) that a substantially higher price is considered acceptable.

3.2.4.2 Reforming hydrocarbons into hydrogen (excluding LPG)

The large-scale production of hydrogen gas is a mature industrial process. The Netherlands has considerable knowledge and experience of this process within its chemical industry. This focal point focuses on small-scale reforming. In the short term (over the next 10 years) there will be almost no ‘sustainable hydrogen’ available in the Netherlands. Hydrogen is available locally as an industrial residue and, via reforming (from natural gas or via electrolysis), can be produced locally. Reforming from hydrocarbons will certainly play an important role for small-scale applications, both for stationary and mobile applications.

Demarcation
For the transport sector, the fuels currently available for vehicles are extremely important. The vision defined by the New Gas Team includes the fact that natural gas can be used on a large scale for the transport sector. This large-scale use of natural gas provides extra encouragement for introducing fuel cell vehicles, due to the fact that natural gas is easier to reform than petrol and diesel. To enable the large-scale introduction of fuel cell vehicles, reformers (fuel processors) need to be developed that can generate hydrogen from natural gas, petrol or diesel. This is seen as an intermediate step towards sustainable energy management.

Natural gas is also the main choice for stationary applications. It is expected that the reduced amount of European natural gas that will remain available can be replaced by an increasing supply from other parts of the world. Therefore, over the coming decades, natural gas will continue to play a leading role for both household and industrial use. When introducing fuel cells into stationary and decentralised markets, reformers will need to be developed to convert natural gas into hydrogen, which allow small-scale but highly efficient conversion (1-200 kW).

Breakthroughs
Small-scale, reliable and inexpensive technology to produce hydrogen (efficiency over 80%) from fossil sources, for mobile and stationary applications.

Research objectives
Long-term objectives (>10 years)

For transport applications, compact and efficient fuel processors need to be developed, which can convert petrol, diesel and liquid biofuels into hydrogen, both for mobile applications and niche markets. Although the system simplicity makes hydrogen more preferable, the lack of both a hydrogen infrastructure and suitable hydrogen storage technology mean that the option for on-board reforming cannot be dismissed.

The most important research items include:

- Development of desulphurisation technology to produce low-sulphur petrol and diesel (< 50 ppm S) in small-scale applications. Technology based on direct selective absorption or low-pressure HDS absorption. Sulphur content, after desulphurisation, of < 0.01 ppm;
- Development of efficient (primary) reforming technology (ATR/SR) for petrol, diesel and biofuels;
    - -Optimising reactor design: robust evaporation of fuel, optimising the efficiency through improved heat integration;
    - -Optimising catalytic converters/developing alternative catalysts: sulphur resistance, increased activity for components that are difficult to convert (e.g. aromatics), increased selectivity (higher efficiency), minimum NMHC slip (non-methane hydrocarbons), longer stability.
- Development of catalytic converters for gas cleaning;
    - -Development of very active and stable catalytic converters for water-gas shift and preferential oxidation of CO. Increased tolerance for (temporary) low concentrations of higher hydrocarbons and sulphur;
    - -Development of alternative cost-effective precious-metal-free or low-precious-metal catalytic converters and afterburners.

Small-scale stationary applications require compact and efficient fuel processors to convert natural gas into hydrogen. This technology should eventually also be available for mobile applications. The most important research items are:

- Development of an efficient, inexpensive desulphurisation technology;
- Development of efficient fuel processors to produce hydrogen (at least 80% efficiency). Increased efficiency can be achieved through optimum reactors/system integration, and improved catalytic converters;
- Robust and cost-effective water-gas shift catalytic converters;
- Development of alternative reforming technology.

In order to provide a complete picture, the short-term objectives are also listed here (commercial applications 0-10 years)
Small-scale reformers will not be commercially available within the next 5-10 years.

3.2.5 Research area: Advanced conversion

This research area consists of the focal point ‘advanced coal conversion with CO_2 separation’ and the knowledge import themes ‘natural gas conversion’ and ‘gas turbine technology’.

The focal point and the knowledge import themes have strong international components. Due to the high development costs and the lack of important expertise in the Netherlands, close international collaborative efforts will be necessary.

Directly coupling this research to other focal points (such as CO_2 separation/storage and fuel cells) should result in better coordination between these focal points.

3.2.5.1 Advanced coal conversion with CO_2 separation

This focal point concerns a slightly different aspect of CO_2 separation technology that focuses on electricity production via advanced coal conversion.

In the medium term, routes such as 'coal gasification-shift-CO_2-separation' and 'O_2-coal combustion-CO_2-separation' will be the most cost effective. The research objectives listed below aim to secure a reliable and affordable market introduction in the Netherlands.

For coal combustion using air, the post-combustion-capture route currently seems a fairly expensive option. The obvious research challenge is to halve these costs.

In the medium and long term (post Kyoto) in 2020 and 2040, most fuel for electricity generation will still come from gas, coal and increasing amounts of biomass. The objective for the transition path 'biomass and coal/gas' is to ensure that, in 2040, the Netherlands has a new generation of large-scale coal- and gas-fired power plants alongside an extensive network of small-scale (sustainable) energy generation systems. Around 2000 PJ of biomass will be used, resulting in 40% co-/auxiliary fuel in coal-fired plants (and 30% auxiliary fuel in gas-fired plants).

In 2040 there will be a mixture of 'zero-emission' and 'near-zero-emission' coal-fired plants. Near-zero-emission biomass/coal plants with a high efficiency rate (> 50%) and a CO_2 emission that is comparable to modern gas-fired STEG plants, will be a proven technology in 2020.

Demarcation

Clean fossil applications are a medium-term necessity for the Netherlands, if CO_2 reduction targets are to be achieved. Depending on the market price for CO_2 and the achievement of objectives set by this EOS focal point (CO_2 separation with minimum efficiency losses at minimum costs), advanced coal conversion with CO_2 separation should be demonstrable from 2015. This will mean that, after construction and demonstration of this plant, the first generation should be a proven technology around the year 2020. In the longer term (2040), the current breakthrough technologies form the following generations of zero-emission plants.

Breakthroughs

- Making reliable and inexpensive coal gasifiers and combustion technologies available, with CO2 separation for full-scale demonstration;
- Halving the costs in euro/t CO_2.

Research objectives

Pre-combustion coal gasification

Long-term objectives (>10 years)
Reliable and inexpensive coal gasifiers with CO_2 separation, available for demonstration in 2015. Critical breakthrough aspects are:

- Gas turbine development focusing on H_2-rich gas combustion (knowledge import theme);
- New air-separation methodology;
- Improved solvents for physical (CO_2) absorption;
- New CO_2/H_2 separation methodology;
- Optimised catalytic converters for water-gas shift reaction.

In order to provide a complete picture, the short-term objectives are also listed here (commercial applications 0-10 years)
Research focuses on gasification development aimed at optimum syngas production and maximum efficiency.

Pre-combustion oxygen-coal (Oxyfuel) combustion

Long-term objectives (>10 years)
Reliable and inexpensive oxygen-coal combustion (with CO_2 separation), available for demonstration in 2015. Critical breakthrough aspects are:

- Development of efficient air separation (95% pure O_2) for large-scale application;
- Optimalisation (particularly of heat transfer) of the USC (ultra supercritical) unit for O_2 combustion of coal/biomass;
- Pollution, slagging;
- Defining the NO_x formation and eventual reduction;
- Conditioning the captured CO_2;
- Chemical looping combustion;
- Pressurised fluidised bed combustion.

The high-efficiency unit with USC steam conditions can be seen as a parallel intermediate phase towards a reliable and inexpensive coal combustion with CO_2 separation that should be available for demonstration in 2015.

Long-term research themes include:
- Material development and long-endurance behaviour;
- Maximising biomass input, such that the CO_2 emission is lower than that of the best current STEGs.

Post-combustion CO_2 capture

Long-term objectives (>10 years)
Halving the costs per avoided ton of CO_2 compared to the current chemical absorption technologies, and making the technique available for demonstration in 2015. Critical breakthrough aspects are:

- Reducing heat consumption during regeneration;
- Developing post-combustion capture techniques (membranes);

- Reducing (pump) energy consumption and installation costs for absorbents with higher CO_2 load capacity;
- Reducing degradation of absorbents through SO_x, NO_x, O_2, T;
- Reducing flue gas ventilator energy consumption through reduced pressure using more efficient sorbent packing.

3.2.5.2 Natural gas conversion, gas turbine technology (Knowledge import theme)

The development of STEGs with an efficiency of >60% will be achieved entirely through OEM (Original Equipment Manufacturers) efforts. Critical components include the so-called ‘hot gas pad’ components, such as the rotor blades and the combustion chamber. Before introduction in the Netherlands, the future operator will need to have adequate condition monitoring of these components, in order to guarantee a reliable and flexible operation. Development will therefore focus on these aspects. Several consortia will undertake research to introduce a gas turbine suitable for H_2-rich combustion in a KV-STEG installation with CO_2 separation, and a gas turbine with integral CO_2 separation.

Demarcation

The larger OEMs (e.g. Alstrom, GE, Siemens-Westinghouse) are fully equipped to develop STEGs with an efficiency of >60%. The USA is a leading player in developing suitable condition monitoring systems. The aforementioned OEMs also play an important part in developing H_2-rich combustion, and various EU stakeholders are working on integral CO_2 separation. This means placing a conductive membrane in the combustion chamber.

Breakthroughs

- Increasing the STEG efficiency to over 60%;
- Introducing a gas turbine suitable for hydrogen-rich combustion;
- Introducing a gas turbine with integrated CO_2 separation.

Research objectives

Long-term objectives (>10 years)

- Monitoring the components in high-temperature sections of advanced gas turbines;
  -Knowledge concerning the degradation of new materials;
  -Advanced, and fast, inspection methods;
- Using hydrogen-gas-rich combustion;
- Managing material degradation in high-temperature sections of advanced gas turbines;
- Integral CO_2 separation.

3.3 Non-technological aspects

Both Clean Fossils and New Gas are confronted with the problems of public acceptance, i.e. aspects such as safety, the NIMBY (not in my back yard) syndrome, awareness of the necessity etc. Proposals for non-technical research may be submitted, provided that these form (a limited) part of the research proposal concerning focal points and import themes.

The main emphasis of the R&D work has, up to now, focused on technical and economic aspects. However, since the social aspects can sometimes form the breaking point for these new technologies, increasingly more attention is being paid to the social aspects involved. It is obviously difficult to draw a clear line between technical and sociological research, e.g. risk analyses are an important part of the opinion-forming process.

There are relatively few national and international efforts focusing on elements such as the long-term safety aspects, and social acceptance concerning CO_2 capture, transport and storage. This is partially due to the fact that these questions are often specific to certain locations and projects. However, several general questions require further study. For example, the safety aspects require an internationally accepted analysis method. Risk analysis methods are currently being developed.

A previous survey concluded that industry requires long-term regulations and a protocol concerning underground storage. The government should therefore provide clear and unambiguous definitions so that all stakeholders can see precisely what is understood by CO_2 storage, and the criteria with which such facilities must comply. The relevant bodies are currently considering how this can be fitted into the current legislation.

Important gamma aspects for the typical Dutch situation have been studied and developed as part of the aforementioned CATO project:

- Standardisation and regulations;
- Safety and risk analysis;
- Risk perception;
- Public acceptance and providing information;
- Chain collaboration and organisation.

During the recent past (December 2003) a student at Eindhoven Technical University studied the various aspects relating to the public acceptance of underground CO_2 storage. This study also included other research, such as that carried out by Leiden University. The most relevant problems for Clean Fossils and New Gas are:

- Possible risks have been qualified, but not yet quantified;
- The implementation of new technologies can interfere with the interests of residents (e.g. studies concerning NIMBY);
- NGOs, in particular, want to retain the *trias energetica* (energy saving, transition to renewable energies and only then use clean fossils). It is clear that the national and regional NGOs have differing interests that should be taken into account;
- The ‘trust’ aspect is very important. Which messenger is most trusted by the general public? Presumably this is neither the government nor industry: both will be seen as biased. This is more a task for the NGOs and research institutes;
- The general public will have to be convinced of the importance of these technologies. The results are global, but the negative effects are local.

3.4 References

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[3] Beleidsnotitie Schoon Fossiel (Clean Fossil Policy Document), September 2003.

[4] Wegen naar Nieuw Gas: ‘De eerste stap is een daalder waard’. Visie naar een duurzame gasinzet. (Roads toward New Gas: the first step is the hardest. A vision of sustainable gas usage) New Gas Team, November 2003.

HYPERLINK

4 Built environment

Introduction

The R&D portfolio for the built environment consists of the following:

Focal points	- System approach to the built environment and local energy generation - Solar conversion PV, multicrystalline-silicon PV technology - Solar conversion PV, thin-film PV technology (anorganic and organic solar cells)
Knowledge import themes	- Using ground-air heat in the built environment through heat pumps
Knowledge export themes	- Solar conversion PV solar-thermal systems
No R&D themes	- End-use/reuse of residual heat in industry and the built environment, heat pumps - Hot and cold storage in the built environment - Natural gas conversion via Stirling micro cogeneration coupling

The PVC for the built environment consisted of the following persons:

Ir. J. de Leeuw	SBR, Chair
Ir. J.J. Buitenhuis	DWA
Prof ir. C. Duijvestein	TU Delft, BOOM
Prof.dr. W. Sinke	ECN
Drs. C. Stap	Ecofys
Drs. S.M. Koomen	Ministry of Economic Affairs, observer
Ir. J. Verlinden	VROM, observer
Ir. P. Heijnen	SenterNovem, coordinator
Ir. L. Bosselaar, Ir. P.G. Ramsak	SenterNovem, support

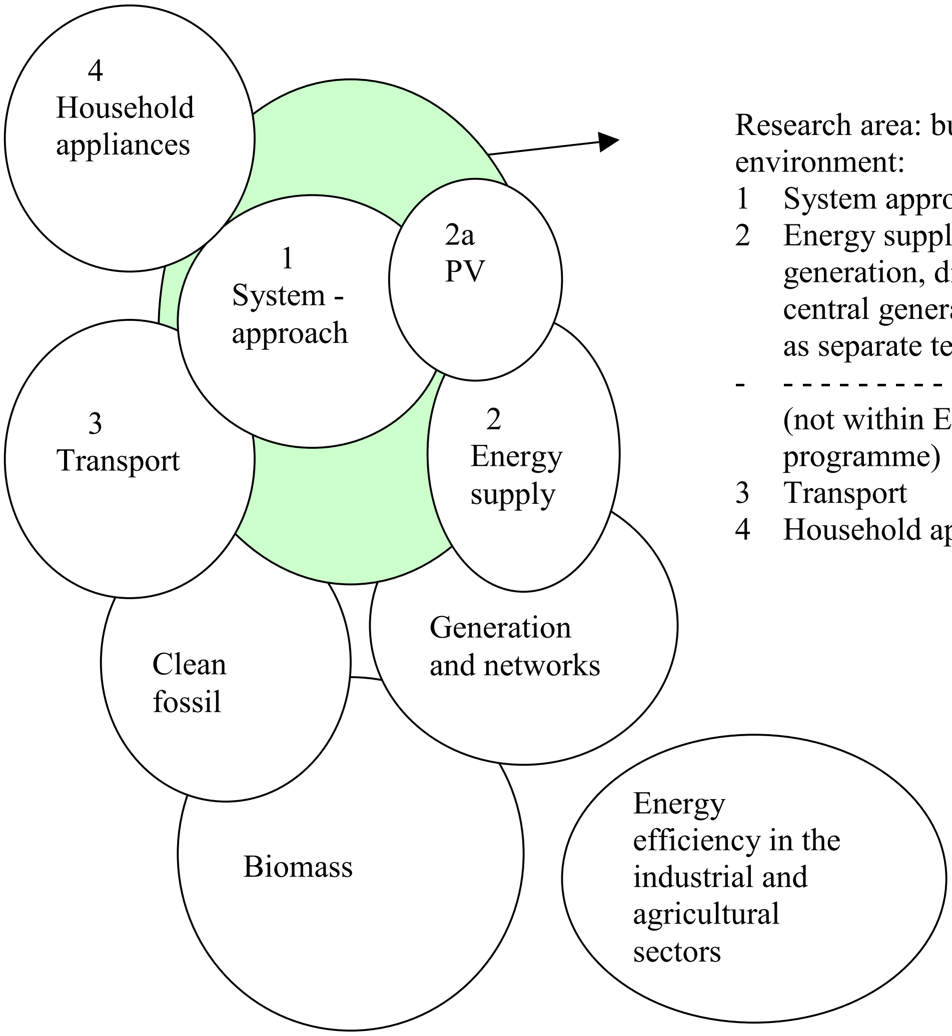
Within this research area, the term ‘built environment’ includes:

- Physical buildings and their associated energy infrastructure;
- Local energy generation;
- Equipment for non-building related processes (office equipment, household appliances);
- Transport (vehicles, infrastructure, refuelling stations).

The research areas ‘generation and networks’ and ‘biomass’ have some common ground with the ‘built environment’ with regard to (de)centralised energy supplies.

The following figure shows the cohesion between the various research areas, as they are traced within EOS, and the position taken by the built environment. The sub-elements ‘equipment’ and ‘transport’ are not included in the scope of this research programme.

The following aspects are all included in the built environment:
System approach, local energy generation, Household appliances and transport. Electricity production using solar cells (PV) forms a separate area, and is an important technique for local energy generation and an important component of the system approach.



Research area: built environment:
1 System approach
2 Energy supply: local generation, distribution, central generation, with PV as separate technique
- -
(not within EOS GO programme)
3 Transport
4 Household appliance

4.1 Description

4.1.1 The research area

The built environment research area covers both new construction and the existing stock of residential and other buildings. The focus is not only aimed at the approach to individual buildings, but primarily towards an integral approach to clusters of buildings at several scale levels (suburb/town section), including the associated energy infrastructure.

Several statistics:

According to the CBS (Statistics Netherlands) the total primary energy consumption for the Netherlands in 2000 amounted to 3050 PJ. The end-use by the various client sectors (industry, transport, households and others) amounted to around 2400 PJ in that year [1]. Of this total energy consumption, around 35% comes from the built environment.

Energy consumption figures for the built environment in 2000*

Segment	Primary energy consumption (total)	CO_2 production		
		Direct (gas and heat	Indirect (electrical)	Total
	PJ	Mton	Mton	Mton
Residential buildings	560	21.3	10.2	31.5
Non-residential sector	306	8.0	9.2	17.2

Expected energy consumption figures in 2010 *

Segment	Primary energy consumption (total)	CO_2 production		
		Direct (gas and heat	Indirect (electrical)	Total
	PJ	Mton	Mton	Mton
Residential buildings	591	20.3	12.9	33.2
Non-residential sector	341	7.6	11.5	19.1

* Based on Strategic Framework CO_2 Reduction for the Built Environment 2004 [2] and Update Reference Estimate [3]

Several trends for the future

A number of trends can be predicted for energy management in the built environment. Several of these trends are considered probable and are included in the vision (see Section 4.2.1), which has then led to the formulation of the following research areas.

The years up to 2030 are expected to result in a very small heating demand for new construction, thanks to the successful perfection of good insulation, air-tightness, extremely insulating glazing and high-efficiency heat recovery systems. A gradual increase in (integrated) solar boiler systems will also reduce the demand for domestic hot water.

Existing buildings will also require considerably less heat, as a result of high-efficiency glazing, after-insulation with vacuum panels etc., though this will be less drastic than for new construction.

Electricity will become more important as an energy carrier (compared to gas) because electricity can be generated locally and is universally available. There is also a good connection with central generation (wind, biomass) and transport is very simple.

However, it will become necessary over the next few years to watch the energetic cohesion between living, working, relaxing and travelling, and to aim for synergy in order to reduce the consumption of fossil fuels.

Residential consumers (individually or in groups), corporations, property owners and tenants all have the freedom to make their own choices after the liberalisation of the energy market. As a result of increasingly stringent environmental regulations (at national, European and global levels), these groups have an increasing interest in the purchase and generation of sustainable energy. The value of sustainably generated energy is increasing, and therefore the room for investment is also increasing.

Within the built environment the importance of electricity and heat that is locally generated and stored will continue to increase. The sun is the primary renewable energy source in the built environment, and compact, high-efficiency storage of electricity (or derivative thereof) and heat is a necessary link in achieving the aforementioned cohesion and synergy between functions within the suburb. Storage is necessary in order to bridge the gap between generation (at one point in time) and demand for electricity (at another point in time).

Existing residential buildings require compact modules that can generate and buffer electricity and heat. Flexibility and careful implementation are keywords for an affordable and successful market penetration.

The current trend (that the electricity-consuming inventory of a house or non-residential building plays an increasingly greater role in the total energy consumption) will probably continue. Product development (more efficient equipment) and more intelligent switching, controlling and feedback using information technology, should result in considerable energy savings.

The ever-increasing internal heat sources and the demand for comfort result in an increasing demand for cooling in residential buildings. This form of energy consumption could increase further, but architectural techniques (e.g. passive cooling) can produce a considerable drop in demand.

Building constructors will play a more important role in new construction, thus ensuring that stakeholders who focus on their clients and continue to innovate will benefit from this development and be able to exert more influence on the working methods and organisation of the construction process.

4.1.2 Knowledge infrastructure in the Netherlands

Introduction

The current research infrastructure is one of the most important points for the long-term EOS programme. The results obtained from the research conducted under this programme will not be directly applied in commercial products. However, it is important that long-term research should take into account the (future) context within which its innovations will be used. For the built environment this means both the physical construction methods and the structure within the sector.

Knowledge infrastructure energy research in the built environment

Various research institutes and consultancies are currently working on the system approach. Researchers often collaborate with companies in the sector and large-scale practical experiments are being carried out. Many research efforts and studies focus on the short and medium term. Internationally, there are close contacts and collaborative agreements with organisations such as the IEA and the CIB (International Council for Research and Innovation in Building and Construction). There are also a number of European networks currently working on decentralised energy generation and network modifications.

The construction process and sector structure

The frontrunners are busy adapting to the changes in the construction market. The demand for buildings is changing considerably. Future building users are becoming increasingly more demanding, the progressive technical requirements mean increasingly more complex design and implementation contracts, and the post-war quantitative scarcity is now becoming a qualitative scarcity. This applies to both new and existing residences and non-residential buildings. Adapting to possible changes today is a positive element, but this concerns a changing process that will continue for many years. In addition, part of the market will remain traditional because it is price-oriented and is suitable for an innovative approach (a large part of the renovation and maintenance market is very fragmented but, in terms of volume, forms a substantial part of the total construction volume. See EIB (Economic Institute for the Building Industry) publications).

It is extremely important that the decisions concerning new construction and renovations should primarily be taken by investors, property developers, corporations and private clients. The design and implementation phases of the construction can influence the specifications, and this should not be overestimated. In the future (just as they do now) these decision-makers will primarily be led firstly by the demand for housing and secondly by general social interests (e.g. sustainability in the built environment and climate-change problems). The use of technical innovations is also strongly determined by such aspects.

Creating the demand for innovation by decision-makers is the best guarantee for success. The construction industry's attitude is very clear: innovations are generally seen as high-risk and the cause of increasing costs, although there is a culture of 'we can supply anything you like, and the customer is always right'.

The role of the government is also important here, since the government acts as policymaker (e.g. by encouraging energy conservation, subsidies), as controller (e.g. the Building Decree etc.) and as principal (contracting road-building, waterways, buildings etc.). The local authorities act as secondary-level policymakers that indicate specific individual accents, but can also implement regulations and, in some cases, may also act as principals and allocate contracts. The local authorities primarily play a significant role in spatial planning aspects.

Finally, the knowledge infrastructure within the construction sector is anchored in a number of recognised institutes. International contacts are maintained via the CIB.

Relationships with ongoing programmes

Various studies are taking place with regard to the system approach, also under the framework of the SMT (subsidy scheme for environment-oriented technology) from the Ministry of Spatial Planning, Housing and the Environment (VROM). These studies are generally limited to the construction level, and sometimes concern a collective approach. This scheme resulted in a number of projects during 2002 and 2003, whereby innovation regarding energy-saving concepts was encouraged.

Studies are also being implemented in collaborative efforts between industry and research institutes. Eindhoven Technical University's prospectus includes a separate specialisation in integral design. Delft Technical University has specific advice for all faculties and specialised studies (TiDO: technology in sustainable development).

Within the framework of the DEN (sustainable energy in the Netherlands), companies and institutes are looking for new products or concept optimisation (solar boiler, PV, WP (heat pumps), storage) for building-oriented sustainable energy. Local and provincial authorities are studying the viability of larger projects such as local wind energy, making policy plans etc.

The EDI (energy conservation through innovation) subsidy scheme has honoured projects where a number of new techniques (in product form) have been (or are being) developed. For the built environment this means evaporation cooling (very low energy consumption) and facade ventilation with heat recovery.

The NEO programme includes a number of projects from both universities and individual 'innovators', aimed at innovative/unconventional concepts concerning the system approach in the built environment, at concept, system and component levels.

Novem finances a lot of (long-term) research into sustainable energy in buildings, through programmes such as Solar-thermal, NOZ-PV (Dutch solar research programme into PV), LTGO (long-term built environment), and the Heat Pump Programme. These programmes were merged with the DEN programme in 2001: this means that the room for long-term research into renewable energy is now considerably reduced.

Within the framework of the BSIK scheme there are currently two projects with a direct link to system research in the built environment, i.e. ‘next generation infrastructure’ and ‘system innovation spatial use and suburb development in town and country (Habiforum)’.

4.1.3 International prospects

There are currently a large number of organisations all around the world (governments, universities, knowledge institutes, corporations, NGOs, etc.) conducting R&D into making the built environment more sustainable. Participation in international research projects, international knowledge platforms and collaborative agreements is a prerequisite for top research. Research carried out ‘on an island’ will miss the necessary references, quality and scope.

With regard to the system approach in the built environment, we see that past research has primarily focused on building concepts and/or demonstrations of concepts for individual buildings. Alongside this system approach in buildings, many other developments are taking place with regard to installations and their mutual integration, computer-driven computer management processes, model development, domotics-related subjects and integrating decentralised electricity generation.

Many of these projects concern theoretical studies that result in guidelines, proposals for standards, models, or feasibility studies of techniques that are still in a pre-competitive phase. System approach studies are also extremely suitable for an international approach. It will therefore be a challenge to make use of the benefits of international collaboration within the EOS framework.

However, international collaboration for component development is an entirely different story. As soon as specific product development starts to take shape, companies will be less likely to share information in order to retain their competitive advantage. Product development will therefore be less suitable for an international approach. However, this is compensated by the fact that there are many manufacturers operate in an international setting.

A number of research institutes and a select number of consultancies work within the European research circuit (IEA, EU programmes, ISO, CEN etc.). The Dutch government plays an important role in providing (additional) funds for Dutch participation in European research programmes. Certainly for aspects that, due to their subject matter or the fact that they are in a phase where they have not yet found any real ‘stakeholders’, government funding is often the only possibility to achieve participation.

The following section provides a brief description of the most important common denominators for international cooperation with regard to system approach and/or technique development.

International cooperation is currently taking place within the built environment research area and is primarily conducted within the IEA and EU programmes. There are also various other European and global networks, and collaborative agreements actively undertaking such studies.

The following IEA Implementing Agreements are relevant for research within the focal point 'system approach in the built environment': *Energy Conservation in Buildings and Community Systems* and its related *Future Buildings Forum* (see Appendix 4.1). Relevant research is also taking place within the IAs *Solar Heating & Cooling*, *Heat Pumps*, *Energy Storage*, *Demand Side Management*, *District Heating and Cooling including CHP,* and *PV Power Systems.*

The Netherlands participates in all these IAs, with the exception of Energy Storage. The work of the various IAs is coordinated by the IEA's Building Coordination Group (BCG). The chairpersons of the individual agreements are members of the BCG. The Working Parties (of the IEA) for Renewable Energy and Energy Conservation also play a role in the mutual coordination.

The work plans of the IAs are organised into various long-term Annexes or Tasks. The subjects and the Strategic Plans of the IAs provide a good indication of the current (international) research priorities.

At the European level, most collaborative research is undertaken within the EU support frameworks, such as the 6th Framework Programme (FP6). Some of the priority subjects are the same as those of the EOS built environment research. The programme provides research support at component level (including building-related sustainable options) and projects concerning an integral system approach at suburb/district levels. In particular, the recent EU CONCERTO call for sustainable energy proposals (which also included several successful Dutch proposals) fits in well with the system approach to the built environment.

Finally, the EU programme ERA-NET supports the preparation of initiatives that lead to collaborative agreements or multinational research programmes.

There are also various international networks concerned with making the built environment more sustainable, e.g. within the CIB, Enerbuild and LowExNet. Participation in these groups often provides a low-cost opportunity to coordinate national philosophies, knowledge exchange, and to generate ideas concerning subjects that are relevant to EOS-GO (energy research strategy for the built environment), particularly with respect to a system approach.

With regard to solar conversion (PV), over the past few years various consortia have been active in research programmes and implementation policy. Within the framework of the EU project PV-EC-NET researchers are working on benchmarking the national programmes for research, development and demonstration (RD&D) of PV. The long-term objective is to define a collective European approach and to anchor this into a roadmap. The PV-NET project has already defined a PV-R&D roadmap (including long-term research). Finally, the EPIA (European PV Industry Association) has published a PV Technology Roadmap, which focuses on short-term and medium-term research and policy measures that are essential for the European PV industry and for market introduction.

4.1.4 Knowledge clients

Just as with the 'knowledge infrastructure' it is important to know from the outset which knowledge clients will play a role in the subsequent phases.

It is important to involve these knowledge clients as early as possible in the research process, in order to create support for the implementation of new developments, and to ensure continuity of the research based on the initial results achieved.

Depending on the type of product or system, research can be undertaken by research institutes, universities, industrial companies, consultancies, town planners, or suppliers in the construction industry. The necessity for research projects to take demonstrable account of the knowledge clients will encourage cooperation. EOS is concerned with achieving the objective, not the actual research results.

4.1.5 Energy transition

When energy transition was originally defined, the built environment was not included in this theme, despite pleas from stakeholders to do so. However, the Ministry of VROM has recently started to think in terms of transitions for the period after 2030.

4.2 Research areas and objectives

4.2.1 Vision, objectives and strategy

The following vision has been formulated:

Vision
Since it is responsible for around 35% of the energy consumption in the Netherlands, the built environment plays an important role in the transition to a sustainable (affordable, reliable and cleaner) energy supply in the future. The contribution to this transition is achieved by introducing integrated systems aimed at various forms of synergy, e.g. between supply and demand, various technical components, and the built environment with other user sectors. This approach leads to several benefits, including heat-neutral buildings (averaged out over the year), where the necessary electricity is largely generated in a sustainable manner.

Objectives

The EOS built environment programme aims to encourage long-term research into solutions that lead to a sustainable energy supply that is clean, affordable and reliable.

Long-term research objectives for the built environment (>10 years)

An integral approach (design, innovative concepts, intelligent systems etc.) should lead to buildings being built or renovated in a sustainable manner. The use of fossil fuels for building-related functions (heating, cooling, ventilation) should be minimal. For new construction, gas or electricity should generally not be converted to heating or cooling alone; for renovation this should be reduced by at least 50% (compared to 2004). At least 60% of the electricity consumption in new buildings should be generated locally from renewable sources. The built environment as a whole aims to have at least 10% of the electricity consumption generated from renewable sources.

Long-term objectives can only be realised if short-term steps are taken towards a system approach. However, research that can be implemented in the short term is not included in this EOS programme.

Strategy

A strategy is required in order to achieve these objectives, whereby the targets for saving energy are placed within the wider framework of social and economic aspects of buildings and living conditions. This framework can be characterised as:

- *People*: The research results must meet people's requirements concerning reliability, safety and comfort. The quality of the living and working environment should benefit from this research;
- *Planet*: Applying the *trias energetica*. This is the general strategy for implementing a cleaner energy supply. The three steps are:
  1 Reducing the demand for energy;
  2 Using renewable sources;
  3 Efficiently converting fossil fuels to meet the remaining demand.
  In addition, the general starting point assumes that high-grade energy (gas, electricity) will only be used for high-grade applications (driving equipment, heat pumps etc.);
- *Profit*: Research should always strive to provide affordable and reliable solutions, although the term 'affordable' greatly depends on the context. If these two conditions are not met, solutions will never be accepted in the market (on a large scale), and will never form a substantial part of the (sustainable) energy supply.

The phase leading up to heat-neutral buildings will be a gradual process. Research over the next few years is expected to focus on the component level. This should create the necessary room for integrating new components into systems. Eventually, large-scale experiments will be conducted in integral concepts. The experience gained should mean another step towards energy-neutral buildings and energy systems that can supply all energy functions in the built environment at considerably lower fossil fuel consumption and CO_2 emissions.

Implementation of new techniques is only possible if there is an adequate knowledge infrastructure and if principals and implementers in the built environment are encouraged to apply these new developments.

4.2.2 Demarcation

The EOS programme for the built environment consists of the following research areas:

1. **System approach in the built environment**

- Theme 1.1: integral concepts at higher system level (including exergetic optimisation of the chain);
- Theme 1.2: integral concepts for buildings or suburbs.

2. Local energy generation

- Theme 2.1: decentralised energy generation;
- Theme 2.2: using ground-air heat in the built environment through heat pumps;
- Theme 2.3: solar conversion, or PV, split into:
    - 2.3.1: multicrystalline-silicon PV technology;
    - 2.3.2: thin-film PV technology.

Research area 1: System approach in the built environment
Research area 1 encourages research, whereby the focus lies on the conceptual treatment of the total energy infrastructure within the (inter)national energy supply.
This includes:

- A combination of measures for efficient use, generation of renewable energy and the use of clean fossil fuels;
- Energy-related aspects, combined with a focus on comfort, health, indoor air quality, integral environmental performance, the construction process, aesthetics, behaviour and costs.

Apart from the physical built environment, traffic and transport also play an important role in the integral system of energy supply. Integrating living and working conditions (mobility) will be included in alternative attitudes to living and working concepts, which will eventually contribute to a more efficient energy consumption. In short, this means synergetic relationships between buildings, (local) infrastructure and users.

This research area includes the following focal point:

- System approach in the built environment (and locally generated energy).

Research area 2: Local energy generation
This research area encourages efforts towards components and their integration into the system for (local) generation and transport of renewable energy, efficient and clean conversion of fossil fuels, as well as using renewable sources plus extra fossil-based energy.

This research area contains the following EOS priorities:

- Local energy generation (focal point);
- Using ground-air heat for the built environment via heat pumps (knowledge import theme).

This research area also concerns photovoltaic conversion of solar energy (PV), via the focal points:

- Solar conversion PV, multicrystalline silicon PV technology;
- Solar conversion PV, thin-film PV technology.

Subjects regarding the ‘balance of system’ and ‘network integration’ are covered under research area 1 and/or theme 2.1.

4.2.3 Research area 1: System approach in the built environment

Objective: To develop integral systems or concepts to achieve a CO_2 reduction of over 60% compared to current (2004) systems, including supply and storage of renewable energy (both large and small scale) and those that meet the People, Planet and Profit criteria.

4.2.3.1 Theme 1.1: Integral concepts at higher system level

The phased decentralisation of the energy supply (particularly electricity) also produces a number of technical-economic challenges and opportunities. Electricity generation is location-related and, with a decentralised supply, is primarily located in the built environment (e.g. micro- and mini-cogeneration coupling and PV. Electricity can be transported instantaneously over considerable distances, which means optimisation opportunities over a wide area, e.g. outside the street, suburb or town (which is naturally dependant on the grid infrastructure) ‘at a higher system level’.

Consider the following:
- Decentralised generation in combination with electricity buffering and/or demand guidance and information on current or future electricity prices as the building blocks of a new electricity infrastructure. The hierarchical grid structure will gradually be replaced by a network structure in which all components communicate with, and influence, each other. The people’s choice of electricity, storage or supply will be an informed choice in which various factors can play a role: minimum costs or maximum efficiency, maximum reliability, minimum environmental load etc.;
- Arranging the space (spatial planning aspects) and the consequences for possible energy infrastructures.

This theme concentrates only on research that has a clear connection with the built environment. There is some common ground with ‘Generation and networks’ (see Chapter 5). The (further) development of individual components, which are not included in this envisaged system, form no part of this EOS programme.

4.2.3.2 Theme 1.2: Integral concepts for buildings and/or suburbs

This theme primarily includes projects whereby the research area, in contrast to theme 1.1, largely focuses on the suburb and/or the building as a system. This includes the following subjects:
- Civil engineering and urban planning designs with ‘intelligent’ systems and installations (smart buildings) for energy generation, storage, communication and ICT for coordinating the supply and demand of energy;
- Combining living, working and transport so that energy functions are coupled. Integrating energy management for mobility into the energy management for the built environment. Constructing residences then becomes part of a larger, integrated energy network, with local sources and the necessary local management and control systems;
- Optimum harmonisation between the quality of the energy supplied and the quality of the energy demand and local storage (low-exergy concept);
- Local heating supply through solar energy, biomass or ambient heat, eventually coupled to local networks;

- Compact high-efficiency storage systems for various forms of energy, allowing the supply and demand to be uncoupled;
- Energy conservation (demand limitation) via the approach to building segments, provided these segments are included in the system, e.g. integrated lighting systems etc.

Based on the aforementioned consultation, the following subjects are defined as having no R&D theme, and therefore are not included in this EOS programme:

- End-use/reuse of residual heat in industry and the built environment, heat pumps;
- Hot and cold storage in the built environment.

Relationship with other research areas
It is primarily on the generation side of the energy chain that research area 'System approach, theme 1.1' has common ground with the research areas 'Generation and networks' and 'New Gas/Clean Fossils'. However, theme 1.2 also has some common elements with the research area 'Generation and networks', where the networks physically connect to the built environment.

4.2.4 Research area 2: Local energy generation

Objective: To develop subsystems or integrate components that are necessary to ensure long-term sustainable and/or high-efficiency energy generation, on a large scale, at local level.

4.2.4.1 Theme 2.1: Decentralised energy generation

Various technologies and components are currently being researched, developed or are even commercially available for generating energy locally, with minimum use of fossil fuels, e.g. PV panels, solar collectors, heat pumps, micro-cogeneration plants etc.

This theme considers how long-term research can remove important problems and restrictions from these types of components and technologies, so that (in time) they can be incorporated into a concept or system, yet still be reliable and affordable, on a large scale. This may also include completely new options, if these are developed.

The (further) development of the components themselves, which is not part of the envisaged system, is not included in this EOS programme.

The following subjects are considered:

- The more efficient use of fuels to achieve a better accessibility etc. through combined generation of several energy forms (electricity/heating, electricity/cooling, hot/cold), either independently or in combination with energy storage;
- Concepts and components for network integration of electricity generators (micro-cogeneration, PV, etc.) with considerably lower overall costs, higher reliability or possibilities for combinations with other functions, e.g. energy- and comfort-management aspects;

- Local facilities to make local generation easier to integrate into a larger energy infrastructure, with advantages such as: higher reliability, lower overall costs, and more opportunities for energy management;
- Using ICT, low-cost sensor techniques and technology for data transport in order to make better use of energy-related information flows and thus reduce the demand for energy (switching off equipment, etc.), to better coordinate the supply and demand, identify unnecessarily high energy consumption etc.;
- Products or solutions that allow a better ‘integration’ of local energy generators within a building or the built environment, with respect to safety, aesthetics, implementation, organisational streamlining, social acceptance etc.

Relationship with other research areas
Theme 2.1 is primarily related to the research areas ‘New Gas/Clean Fossils’, ‘Biomass’, and ‘Generation and networks’, where distribution sections form part of the built environment, both at suburb level and (on a small scale) for buildings or building complexes.

4.2.4.2 Theme 2.2: Using ground-air heat for the built environment via heat pumps (Knowledge import theme)

Major research themes for heat pumps focus on integrating and standardising systems. In a Novem-implemented strengths-weakness analysis of Dutch market parties, some 14 subjects [4][1] were selected. The market is already active in a number of these themes, and it is expected that government support for applications, support of field experiments and demonstrations will be sufficient to ensure continued development in the immediate future.

Many developments concerning components are currently taking place in other countries, however heat pumps for residential heating have also been developed in the Netherlands over the past few years. For larger systems, the Netherlands has mainly built up experience with open-source systems, in combination with cold storage. With regard to quality in relation to regulations, the BEB (ground as energy source and buffer) programme has gained a lot of knowledge that is important for the development of future European regulations. Large systems have also been standardised, allowing Dutch suppliers to be competitive at European level.

Cold resources (CO_2) and air-air systems are important new technological developments with huge potential in almost all markets with a high temperature requirement. The Netherlands has expertise in smaller sorption systems for housing renovations, but this knowledge needs to be extended. Since commercial companies are already active, facilitation by the government is sufficient to ensure that this technology is developed further under the right conditions.

Knowledge import
A compact source and easily integrated systems (heat pump and source) are important for the renovation market. Other countries have considerable knowledge of these aspects, although the development thereof is still in its infancy.

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[1] Small electrical heat pumps for residences, larger electrical heat pumps for non-residential buildings and the glass horticulture sector, small sorption systems for residences; larger sorption systems for non-residential buildings; quality assurance; industrial heat pumps; high-temperature industrial heat pumps; combinations with cogeneration, open ground sources/aquifers;closed source heat exchangers; compact chemical storage; CO_2 as coolant for building applications; compact heat exchangers, long-term experience through project monitoring.

Objective: To create compact heating/cooling systems using heat pumps that (exergetically) optimally meet (low-grade) energy requirements for heating and cooling in the built environment, which form the basis for heat-neutral concepts.

This primarily concerns research subjects such as:
- CO_2 as cooling agent for use in buildings;
- Compact physical and chemical storage;
- Closed-source heat exchangers;
- Innovative source systems to obtain heat from ground or air.

4.2.4.3 Theme 2.3: Solar conversion PV (photovoltaic conversion from solar energy)

The vision for solar conversion (photovoltaic conversion of solar energy, or PV) matches the PV roadmap for the Netherlands that was drawn up by market and research parties in 2002, and which was further defined and updated in 2004. In turn, this roadmap is also in line with European roadmaps (PV-NET, EPIA) and policy documents (including the PV Vision Paper), which were all published in 2004.

This research is primarily aimed at facilitating the continual learning process for PV modules, as summarised in the learning curve, in which the market price or manufacturing costs of modules (€/Watt-peak, or Wp) are defined as a function of the cumulative volume produced. The research also focuses on aspects that are usually not expressed in the learning curve, but which are considered important for successful and responsible large-scale applications: conversion efficiency, stability and lifespan, environmental quality and applicability. Some of these aspects have no direct relationship to the initial costs (purchase price), but are certainly related to the electricity generation costs over the lifespan of the module and with market acceptance.

The Solar Conversion PV research area covers everything from the basic materials through to complete modules. All aspects concerning the application of PV modules in complete systems (the balance-of-system, or BOS) are outside the scope of this research area. However, where they fit within the long-term framework of EOS, they can be included in research area 1: System approach in the built environment, or theme 2.1: Decentralised energy generation.

Modules form the basis of PV systems and currently account for around 60% of the turnkey (reference) system price. The targets and projections concerning turnkey system prices are used in this part of the programme as an indicator of the required module price reductions.

The expectation (EPIA, 2004) is that the turnkey system price will drop from the current 6 euro/Wp to around 3-4 euro/Wp in 2010, falling further to around 2 euro/Wp in 2020 and eventually dropping to below 1 euro/Wp (in 2030-2050). The associated prices of modules are therefore roughly expected to fall from the current 3.5 euro/Wp to 1.5-2.5 euro/Wp in 2020, and 1 euro/Wp in 2020, falling even further in the very long term to less than 0.5 euro/Wp. The manufacturing costs of modules therefore need to drop to well below these prices.

The research programme for PV modules is aimed at three problem areas, and is thus in line with the aforementioned information. Each project should contribute to solving the problem in at least one of these areas, i.e.

1. Manufacturing costs of cells and modules;
2. Cell and module performance (conversion efficiency, stability and lifespan);
3. Environmental quality (use of materials, energy content, recycling) and applicability (particularly in the built environment).

The associated research objectives have been further defined for various themes, whereby the development phase and the (type of) most important technological problems are determinate:
1. Multicrystalline-silicon PV technology;
2. Thin-film PV technology.

Figure 4.1 in Appendix 4 shows the pricing targets set out by EOS. These show the level of ambition and are purely indicative. Actual prices will vary according to system type and depend on production and volume, market circumstances etc.

It is currently uncertain how the various PV technologies (that match the research themes) will develop over the course of time. However, it is possible to give an indication.

<u>(Multi)crystalline-silicon PV technology</u>
This technology has been used for many years in industrial production and has around 90% of the market share. Multicrystalline silicon makes up most of this amount. Based on its potential for price reduction and improving performance, this technology is expected to continue to retain an important position in the market for many years (20 years or more).

<u>Thin-film PV technology</u>
Several thin-film PV technologies (amorphous silicon (a-Si) and copper-indium-diselenide (CIS)) have been in production for some time, although only on a modest scale. Upscaling is therefore expected to gradually take place over the coming decades. If successful, these technologies are expected to take an equal place beside multicrystalline silicon. Other thin-film concepts (sensitised oxides, super-high-efficiency structures etc.) are still in the development phase, or entirely in the laboratory phase.

The discussion concerning the price potential of the currently available thin-film technologies (including a-Si and CIS) are global, both in relation to crystalline silicon and in other comparisons. This is why EOS makes no presumptions, but various options are challenged to develop further and prove their abilities. A differentiated market will always have room for several options, where these differences are not based on price alone. Solar cells based only on organic materials (for the active layers) are still in the early stages of development. It is not clear if, and when, and in what form they will be able to meet the criteria for professional use. The promise of very low production costs and various new application opportunities in relation to other thin-film technologies make organisational solar cells a real ‘high risk, high potential’ option. It is too soon to give a price estimate for these new thin-film concepts, as the EOS programme is primarily concerned with improving performance and exploring new conversion routes.

Relationship with other research areas

When using PV it is not only the module costs that are important, but also the other system costs. Other system aspects (integration, electricity conversion etc.) are included in the research area 'System approach in the built environment'. Integrating PV electricity into the grid is included in the 'Decentralised energy generation' theme. Market acceptance, user experience etc. form part of the gamma research described in Section 4.3.

Theme 2.3.1: Solar conversion: (multi)crystalline-silicon PV technology

Long-term objective:

To achieve a PV module price of 1 euro/Wp (or less) in 2020, at an efficiency of 18% or higher (total area).

This concerns research to utilise the full potential of this technology, in terms of price and performance. Research is also required whereby the environmental performance of modules can be substantially improved.

This includes research subjects such as the following (non-exhaustive list):

- Innovations concerning basic materials (feedstock and wafers), which lead to substantially lower silicon costs (per Wp);
- Device concepts[1] and new process techniques for cells with a very high efficiency (> 18%) and lower costs;
- New module concepts (design and material use) and manufacturing techniques for modules with low costs and/or considerably improved environmental profile (the latter including the cells). The environmental profile is primarily concerned with alternatives for lead, silver and copper, as well as recycling opportunities and reducing the energy content.

Theme 2.3.2: Solar conversion: thin-film PV technology

Long-term objectives:

To achieve a PV module price of 1 euro/Wp in 2020, at an efficiency of 15% or higher (total area). The lifespan and stability must be sufficient for applications in the built environment, i.e. over 20 years, with an efficiency reduction of less than 20%. The environmental quality of modules needs to be explicitly addressed. For the period after 2020 the objective is to develop cell concepts for a very high efficiency (typically > 25% at module level, > 30% at cell level). It should be reasonable to expect that the proposed concepts can then be converted into modules that meet reasonable price and lifespan criteria. During this period, the objective is also to develop cell concepts that potentially offer considerably lower costs or new application opportunities (e.g. organic solar cells for professional all-weather use).

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[1] 'Device' refers here not to a complete solar cell but to, for example, a Si p-n structure with spectrum converter above or below, but may also be a strained multilayer as basis for a solar cell.

For example, the following research subjects (non-exhaustive list):

- Materials, devices and process techniques primarily aimed at a lower cost price (prospective module efficiency of 15%);
- Devices and process techniques primarily aimed at increasing efficiency up to a minimum 1% at module level (prospective module price = 1 euro/Wp);
- Sustainability aspects and stability: avoiding the use of scarce or damaging materials, efficiency losses less than 20% over 20 years;
- Other innovations that encourage the large-scale use of modules;
- Device concepts for a module efficiency of minimum 25%, as well as advanced control techniques.

With regard to organic solar cells, their development phase and the specific problems encountered mean that, for the time being, the following subjects are applicable:

- Materials for devices with a considerably improved stability and/or efficiency (> 10 years equipment lifespan, 10% cell efficiency);
- Device concepts for a considerably improved stability and/or efficiency (> 10 years equipment lifespan, 10% cell efficiency).

International collaboration and/or integration is particularly encouraged for organic solar cells.

Research into high-efficiency tandem cells based on gallium arsenide and related semiconductors are not included within EOS as a focal point or knowledge import theme.

4.3 Non-technological aspects

Section 4.2.1 sketches the main strategy for long-term research to achieve significant energy conservation in the built environment. It is crucial that the technological solutions developed for this energy saving fit into the socioeconomic framework within which building and living are being developed. Past and current experience show that these aspects are often neglected, which results in stagnation during development or when introducing valuable techniques (e.g. the NIMBY aspects with respect to wind energy).

This is why everyone submitting a research proposal is expressly asked to take non-technological aspects into account. Proposals for non-technical research may be submitted, provided this represents a (limited) segment of the research proposal for focal points or import themes. The inclusion of relevant, non-technical aspects increases the social value of the research proposal in the future.

When initiating long-term research projects, the research team should consider the following non-technical aspects (a non-exhaustive list of suggestions):

- What are the social consequences of the new system for the relevant market parties?
- How great is the chance that the new technical development will not be supported due to unfavourable ‘People’ or ‘Profit’ aspects?
- Can a NIMBY-effect be expected? Which social resistance and risks are expected?
- Which mechanisms are necessary in order to ensure that property developers/principals make the right choices? What role does the designer (and the final building), play in this respect?

- Which technically influential aspects can discourage, or particularly encourage, large-scale application of the developed technique?
- Are there misunderstandings or preconceptions concerning the technique to be developed, and how can these be removed?
- Is there insufficient knowledge concerning specific components: If so, how can this be remedied?
- A good process strategy of the construction process, including the energy conservation measures, can often result in initial energy savings, without adding extra costs to the budget. How can the developed technique be optimally integrated into the existing design and operational processes?

4.4 References

1. Statistisch jaarboek 2002; Centraal Bureau voor de statistiek (Annual 2002 Statistics; Statistics Netherlands).
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3. P. Boonenkamp et al. 2003: Sectorale CO_2- emissies tot 2010; Update referentieraming ten behoeve van besluitvorming over streefwaarden; (ECN/RIVM-studie). (2003: Sectoral CO_2 emissions up to 2010; Update reference framework for decision-making on target values).
4. Concurrentieanalyse van duurzame energietechnologieën (Novem studie). (Competitive analysis of renewable energy technologies.)

5 Generation and networks

Introduction

The R&D portfolio for ‘Generation and networks’ consists of:

Focal points	- Wind conversion offshore - Electricity transport, security of supply, network integration, power electronics - Electricity conversion, power quality, custom power, converters, EMC (electromagnetic compatibility)
Knowledge import themes	- Electricity storage, small-scale storage and system applications (including super-capacitors)
Knowledge export themes	- Wind conversion, land-based wind power systems - Wind conversion, turbines in the built environment
No R&D themes	- Wind conversion, decentralised network-coupled systems - Electricity storage, network-coupled battery systems

The PVC for this research consisted of the following persons:

Ir. G.J.M. Prieckaerts	Chair
Prof.ir. W.L. Kling	TenneT
Ir. G. Peppink	ECN
Prof.dr. J.J. Smit	Delft Technical University
Ir. P.T.M. Vaessen	Kema T&D
Drs. C.A. Westra	we@sea (wind energy consortium)
Ir. G.C. van Uitert	Ministry of Economic Affairs, observer
Ir. G.W. Boltje	SenterNovem, coordinator
Ing. J.L. ‘t Hooft	SenterNovem, support

5.1 Description

5.1.1 The research area

This research area concerns the large-scale supply of electricity. A limited number of aspects have been associated with this field of study, because EOS focuses on contributing to the transition to a sustainable energy supply with a safeguard for the security of supply.

Taking this limitation into account, wind energy is the most promising option for the Netherlands. Considering that wind energy for land-based sites has already largely been developed, R&D is only relevant for aspects that relate to offshore applications. Offshore wind conversion therefore forms a focal point, which is described below.

The consequences of the dynamic character are far-reaching, both for decentralised energy generation and the large-scale offshore generation of wind power. Maintaining the stability of transport and distribution networks, as well as the closely related safeguard to the security of supply, form an enormous challenge. On the one hand this requires a complete new approach to maintaining electricity network systems; thanks to new (yet to be designed) control algorithms, this can lead to 'intelligent' networks. However, on the other hand, a new generation of components will prove indispensable in ensuring these new necessary 'intelligent' characteristics. Power electronics will play a key role here, and cover not only component design, but also component behaviour in the network, and the effects that they cause.

Under the EOS framework there are four themes that focus on large-scale electricity supply; either based on a system approach, or on components (these are detailed below).

Offshore wind conversion

A considerable contribution from offshore wind energy will be indispensable in achieving Dutch objectives to use 10% renewable energy in 2020. In order to achieve this the Dutch government feels it is necessary to have 6000 MW available from offshore wind power installed by 2020. The government is therefore currently creating the conditions and criteria to achieve this, e.g. financial encouragement and spatial policies.

Wind turbine development is focused on increasingly larger units for specific locations. The largest commercially available wind turbines currently have around 3 MW of power. Depending on the specific sea conditions, these turbines are being installed in the first large offshore wind farms, and have a tower of 70-100 metres high and a blade diameter of 65-80 metres. In 2003, prototype 4.5 MW turbines were built in Germany and Denmark and, from 2004, ECN's test wind farm contains a 2.75 MW prototype.

There are currently two offshore wind farms being developed in the Dutch section of the North Sea: E-Connection's wind farm (known as Q7-WP) and Shell/Nuon's Near Shore Wind Farm. The former will consist of 60 turbines (2 MW each). The latter is a demonstration 100 MW wind farm that will be built in 2005 off the coast near Egmond aan Zee. An NSW-MEP (measurement and evaluation programme) is applicable to both wind farms, which will supply data and experience concerning the construction of larger offshore wind farms in the deeper waters of the North Sea.

New techniques need to be developed in order to achieve the required cost-price reductions and minimise risks. Developments that reduce construction costs and minimise maintenance are necessary for the successful implementation of offshore wind energy projects.

The power output from offshore wind farms will vary enormously, due to the varying winds in this part of the world. The way in which this fluctuating power is integrated into the national grid (at the magnitude stipulated by the government) is an important research point, and is described further in the following section.

Electricity transport: security of supply, network integration, power electronics
Until recently electricity networks were entirely passive. The electricity found its way through the national grid to the end-users. If demand increased temporarily then this caused a certain amount of overload, although other sections of the network had a certain amount of overcapacity. However, the 'Electricity Technology Roadmap' [2] shows that the amount of electrical energy in the total energy supply is increasing considerably: the electricity transport networks are becoming larger. This requires that all transport capacity be utilised as efficiently as possible. Power electronics allow these electricity flows to be controlled throughout the network. The networks can then be optimally managed, thus allowing more total power to be transported. Studies are required in order to define how future networks should be designed, and which techniques should be used. The question of optimising the capacity of the electricity transport is not only restricted to transport and distribution networks, but also applies to industrial networks, e.g. the railway network. In addition to the option of manageable networks, there are also new opportunities for cabled high-voltage networks, e.g. whereby direct current is transported (HVDC), with or without super-conducting cables.

Apart from the increasing demand for transport capacity, increased electricity generation using small-scale production units (solar, wind, heat/power) has important consequences for the electricity infrastructure. This requires a solid system approach in order to further modernise and expand the transport and distribution networks. The pre-survey into the implementation of EOS2 [1] has already made clear that the focal point 'Generation and networks' should not only focus on individual components: it is the 'system approach' that is absolutely crucial here.

The previous text has already described how this system approach can lead to 'intelligent' networks, thanks to new control algorithms that have yet to be designed. Simulators are therefore required to test these algorithms, since existing networks cannot be used to conduct such experiments. New calculation methods will also need to be developed, in order to keep calculations times within acceptable limits.

Large-scale power electronics form the main 'system carrier' of 'intelligent' networks, and are therefore the key technology for 'Generation and networks'. The Netherlands is in a good position to implement this high-grade research. Expertise is being developed quickly, thanks to unique facilities whereby the components are not only individually tested on a large scale, but their behaviour is studied within the network system, plus the effects that they cause. These subjects fall under two research areas, which are further described in Section 5.2.4.

Electricity conversion, power quality, custom power, converters, EMC
The theme 'Electricity conversion, power quality, custom power, converters, EMC (electromagnetic compatibility)' focuses more on the distribution and end-use of electricity than the aforementioned focal point 'Electricity transport: security of supply, network integration and power electronics'. Not only does security of supply play a role here, but also the quality of the supply and the future large-scale integration of decentralised generators 'low in the network structure'. Supervising, guarding and managing the energy flows require not only new components but also system modifications to the public grid (FACTS, or Flexible A/C Transmission System) and at the end-user (custom power). Power electronic converters play a crucial role in integrating sustainable sources.

This demands a new functionality and flexibility of the converters, e.g. with regard to topology, control behaviour, communication and EMC.

Electricity storage, small-scale storage and system applications
In the future, storage systems will be indispensable in harmonising the supply and demand of electricity. This applies particularly if an increasing share of the electricity supply is based on intermittent sources, such as solar and wind energy. There is already a broad spectrum of known storage technologies, both large and small scale, with varying energy content and power. The storage basics are also extremely diverse.

Large-scale systems are generally based on storage of potential energy from water reservoirs, with a height difference compared to the surroundings (Plan Lievense, or opposite principles) or from gas reservoirs under increased pressure. Medium-sized to small-scale systems often use electrochemical energy for storage (discharging and non-discharging batteries), while small-scale systems generally store electricity in the form of kinetic energy (flywheels), electrostatic or electromagnetic energy (capacitors, super-capacitors, and storage in superconducting magnets).

Storage systems can also have various additional functions that are important for the security of supply and the quality of the electricity. Finally, large-scale electricity storage systems are sometimes combined with totally different installations; these are outside the scope of this research area, but still have considerable influence on network efficiency, e.g. storage of natural gas or hydrogen.

This research area is a knowledge import theme, which means that research must complement research conducted in other countries and that specific knowledge import can be found within these projects. This research area primarily concerns the large-scale aspects of ‘Generation and networks’. Storage can therefore form an indispensable element (see Section 5.2.3.2). Small-scale storage principles may be interesting for managing distribution networks (see Section 5.2.4.1).

5.1.2 Knowledge infrastructure in the Netherlands

The knowledge infrastructure is extensively described and explained in Appendix 5.1.

5.1.3 International prospects

Until now the Netherlands has been among the world’s frontrunners when it comes to reliable and clean electricity supply. This forms an important element for a good business-establishment climate, for both companies and knowledge institutes.

The IOP-EMVT (industry research programme-electromagnetic power technologies) forms the start of a coherent research programme by universities and knowledge infrastructure with regard to intelligent electricity distribution networks and electronic energy converters. This programme is primarily subscribed to and actively supported by stakeholders from the electricity value chain and the machine building chain.

The most important (and relevant for the Netherlands) motivation for conducting research regarding EMVT is decentralisation of energy generation, increasing electrification and more efficient conversion of electrical power in a form that is suitable for the end-user.

ECN uses a market-oriented and internationally recognised model instrument to analyse developments in the European gas and electricity markets and, on the basis thereof, to analyse the bottlenecks and improvement options for policies with regard to regulations and market strategies.

In addition, KEMA is also working together with the Dutch knowledge infrastructure to further expand its unique position as the largest independent test and development laboratory for (high) power electronics. The objective is to create a totally unique laboratory facility that is integrated into the existing KEMA facilities, thus allowing EMVT applications to be properly tested.

The Dutch knowledge infrastructure for designing, operating and maintaining offshore wind turbines and wind farms is good, and is therefore in an excellent position. Dutch industry is involved in developing offshore technologies. Dutch consortia, such as Shell/Nuon, E-Connection and Evelop are developing wind farms in the North Sea and off the coast of the UK. The Dutch offshore industry is involved in creating and constructing large offshore wind parks such as Horns Rev, Nysted and Middelgrunden.

The collaboration between ECN and Delft Technical University has led to the realisation of a unique laboratory for testing wind turbine blades and materials. ECN has made available the necessary expertise, facilities and a test field for testing, measuring and developing offshore wind turbines.

5.1.4 Knowledge clients

Using the databases in SenterNovem, over 40 stakeholders have been identified that could be interested in research into the aforementioned focal points. Market knowledge then shows that 24 stakeholders are currently active in these areas. In addition to knowledge institutes (universities etc.) these include industrial companies and stakeholders in the services sector.

Most of the knowledge clients are already involved in the implementation of two ongoing research programmes: the IOP-EMVT programme (electromagnetic power technologies) and the BSIK programme into the large-scale offshore generation of wind power.

5.1.5 Energy transition

The LTVE (long-term vision on energy supply) [3], which preceded the transition approach, included two elements that appeared in each scenario for a sustainable energy supply. These were the so-called robust elements: ‘wind offshore’ and ‘quality of the electricity supply’. At the time it was decided not to start a transition path for these subjects because there were sufficient existing activities in the market, and because they were already well supported by existing policies.

In the meantime, ‘sustainable electricity’ has been defined as the fifth main route in the strategy of a transition to a sustainable energy supply, as seen in the ‘Innovation in energy policy’ [7] report, which the Minister of Economic Affairs submitted to Parliament on 29 April 2004. This fifth main route was already included in the current policy, which is aimed at encouraging the production of sustainable electricity.

5.2 Research areas and objectives

5.2.1 Vision

The vision of the ‘Generation and networks’ research area for the situation in 2030, is based on three Dutch studies that were finalised some time ago: the Electricity Technology Roadmap, written by KEMA [2], the LVTE (long-term vision of energy supply) 2050 [3] and the Inventory for integrating 6000 MW of offshore wind power into the electricity network in 2020 [4] written by KEMA and Delft Technical University. The further detailing of the research vision begins with a description of these three starting points, and goes on to cover 15 thesis. These are grouped into six categories: fuel usage, generation, import and export, infrastructure, storage and the environment.

Starting points
The development of this vision is based on a number of assumptions. These starting points are:

1. The growth in electricity consumption will continue (by 2.2-2.5% per year), and the percentage of electricity in the energy supply will increase sharply, from 14% of the final energy consumption in 2000 to around 20-25% in the year 2030.
2. The energy policy between the European Member States is largely converged. Umbrella EU objectives in energy policy focus on achieving a sustainable energy supply. The sub-objectives (affordable, reliable, clean) still apply, also to the electricity policy. This is translated into practical aspects, such as:
   - affordable – there is a totally free (liberalised) EU electricity market;
   - reliable – reduced gas stocks mean that there is less gas being used in the Dutch energy supply. Taking the security of supply and the environment into consideration, there is still a separate policy to encourage renewable energy;
   - clean – sustainability conditions, including CO_2 reduction, are harmoniously internalised into the EU market system (via the tax regime, or via duties/obligations’ trading systems). Exergy is generally accepted as a starting point for new energy systems.
3. The electricity network has grown in size and more countries are now coupled; North Africa and Eastern Europe (including Russia) are now connected to the European distribution network.

Vision: characteristics of electricity supply (between 2004 and 2030)

Fuel usage

1. Partly due to the introduction of emissions trading (plus CO_2 tax), the fuel usage at some of the electricity power plants has changed. The use of fossil fuels has come under pressure:

- Coal has been partly replaced by other fuels. However, there will still be coal-fired power stations in 2030, partially in the form of coal and/or biomass, but also partially using co-/auxiliary biomass incineration (see also Chapter 2).
- The use of gas in the Dutch electricity supply will possibly be reduced, partly as a result of reduced local gas stocks. However, gas use elsewhere will increase considerably.

2. The effects of the policy to support sustainable energy can primarily be seen in the electricity sector, but also in the use of wind and biomass. Approximately 25-35% of the electricity will be generated from renewable sources.
3. The offshore wind farms will mature. After achieving the government's target of 6000 MW in 2020, these wind farms will expand even further.

Generation

4. Due to high transport costs and the need to reduce distribution losses, electricity will be generated as close as possible to the end-user. The development of decentralised household systems continues, e.g. micro-cogeneration and renewable energy systems in the built environment (see also Chapter 4). Electricity generation is therefore far more decentralised.
5. For other sectors, electricity generation occurs on a large scale at suitable locations along the coast and offshore (wind farms).

Import/Export

6. Due to the long-term implementation time required for the energy policy to filter through, there are still considerable differences in fuel usage among the various EU Member States (e.g. nuclear energy in France). Climatic and geographic variations also contribute to these differences.
7. As a result of the varying energy generation costs within the (extended) EU, the direct competition between various fuel options leads to the bulk transport of electricity over long distances. The Netherlands will also exchange electricity with other countries (approximately 10% of its consumption).

Infrastructure/Networks

8. The main structure of the network, the selected current levels and the required redundancy in the network will possibly change.
9. The electricity networks are heavily automated and include intelligent systems that make them self-regulating, thus producing very high reliability levels.
10. The decentralised power is integrated into the national grid at a large number of input points. Power electronic converters will often be required to convert the various energy forms. Special equipment (including for energy storage) will also be required to guarantee stability.
11. The infrastructure is increasingly implemented underground.
12. Cable connections will be laid along the seabed. Due to the size of the offshore wind farms, a robust high-capacity transport network will be required, probably in the form of HVDC.
13. The exchange with other European countries (outside the EU) can restrict the type of transport network used. There are a number of options, with varying characteristics. It is therefore not possible to predict which option will be selected.

Storage

14. Large-scale storage systems may prove to be indispensable for the security of supply and the quality of electricity in systems with a large percentage of intermittent sources.

Environment

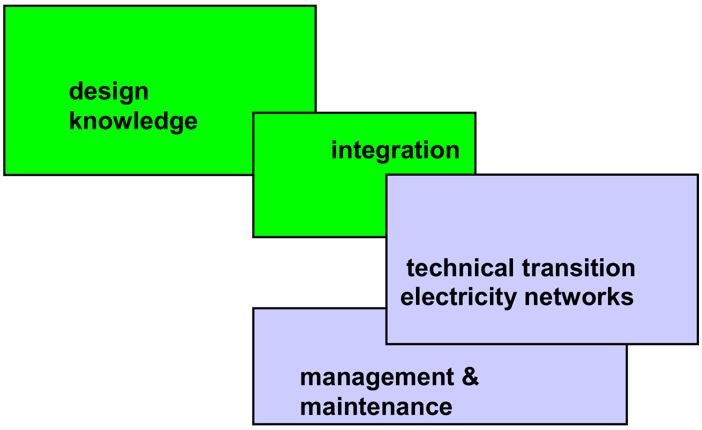
15. The changes that are considered necessary in the electricity supply are not only technically and economically viable, but also need to be socially accepted due to the attempts at sustainability. This means attempting to minimise the negative effects on the environment throughout the entire life cycle of technologies (LCA, or life cycle analysis). It is not only technical solutions that are important, but also the question of how these will be perceived by society.

5.2.2 Demarcation

If the vision described in the aforementioned section is to be achieved, then new technologies need to be developed. This leads to certain research objectives, as described in the following section. However, only the technological options described in Section 5.1.1 are taken into account.

The ‘Generation’ research area consists of only one focal point: offshore wind conversion. The ‘Networks’ research area includes the focal points ‘Electricity transport, security of supply, network integration, and power electronics’ and ‘Electricity conversion, power quality, custom power, converters, and EMC’, plus the knowledge import theme ‘Electricity storage, small-scale storage, and system applications (including super-capacitors)’.

These three themes are again framed so that they complement and supplement each other. Some overlap in unavoidable. This creates four research areas within ‘Generation and networks’, as shown in the following figure.



Figuur 5.1.: Relationship between the ‘Generation and networks’ research area.

Since ‘Generation’ only focuses on offshore wind conversion, very high reliability and cost effectiveness are the main characteristics demanded of future technologies. The research area ‘Design knowledge’ focuses on these aspects.
The generated wind energy will need to be integrated into the national grid, but the extremely fluctuating character forms a challenge for economic integration – thus the research area for ‘Integration’. These two research areas together form the original focal point for offshore wind conversion.

The existing national grid will also undergo a technical transition to allow for future sustainable energy supply. These ‘Technical transition electricity networks’ form the third research area. Naturally, this has consequences for ‘Management and maintenance’, which is the fourth research area. These last two research areas have therefore been created through their mutual relationship to the ‘Networks’ theme.

Due to the fact that ‘Networks’ has several elements that are also common to the IOP-EMVT, the PVC has specified the focal points and import themes in such a way that they are well harmonised. This also applies to ‘Generation’ in relation to the BSIK programme ‘Large-scale offshore generation of wind power’.

Summary
Generation consists of only one focal point, ‘Offshore wind conversion’, which is split into two research areas:

- Design knowledge;
- Integration.

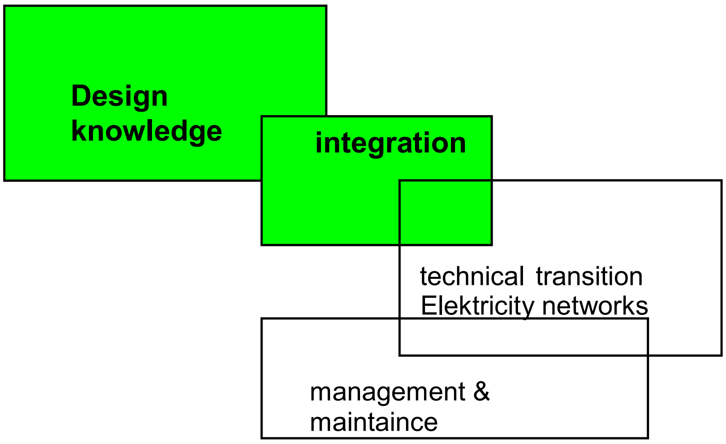
‘Networks’ consist of two focal points and are split into two research areas:

- Technical transition of electricity networks;
- Management and maintenance.

Research areas
The previous demarcation led to four research areas, within which projects to develop new technologies must be implemented, thus leading to realisation of the vision. In the first place this means design knowledge for offshore wind farms, so that wind energy can compete against fossil-based generation in the year 2020, and which is also integrated into the national grid in a stable manner and without introducing new bottlenecks. In addition, a path is formulated and solutions are proposed to achieve a land-based network that can cope with a sustainable energy supply in 2030. These research areas are further defined in the following sections, through descriptions that specifically include objectives and breakthroughs.

5.2.3 Focal point: Offshore wind conversion

The research area for ‘Generation’ focuses on offshore wind conversion, which is split into the research areas ‘Design knowledge’ and ‘Integration’.



5.2.3.1 Research area: Design knowledge

Objective: To have offshore wind conversion competing with land-based fossil energy generation (cost level per kWh supplied) in 2020.

Future offshore wind farms will be designed for specific, sometimes extreme, offshore conditions. Low costs and simple construction will mean that other turbine designs will be implemented. Extreme reliability criteria demand wind turbines with minimum numbers of sensitive components, which in turn will lead to, for example, the development of direct-driven generators with very high power. Developments in other technology fields (e.g. aerodynamics, strong materials, power electronics, EMVT, nanotechnology, ICT) will allow cost-effective concepts such as magnetic bearings, and large fast-moving rotors. The wind farms will be designed for high efficiency per turbine and the control systems will optimise the output of the entire wind energy plant, i.e. electricity production, ‘dispatchability’ and load factor. Controllability demands concerning wind energy plants and the quality of the generated electricity (blind-current management, voltage levels, higher harmonics, buffering short-term fluctuations) will lead to the further development of power-electronic converters and control concepts. When constructing very large turbines (> 3 MW) in water, the typical maritime physical characteristics should be taken into account, e.g. meteorological phenomena and wave impacts, which result in specific demands on support constructions, assembling techniques and maintenance/repairability.

The technological breakthrough comes from efficient construction techniques and corporate management methodologies.

Research guidelines are necessary in order to realise these breakthroughs, particularly with regard to:

- New wind turbine concepts, components and materials;
- Assembly, construction and transport techniques;
- Supporting constructions;
- Maintenance and repair methods;
- Control strategies for both individual converters and the wind farm as a whole.

5.2.3.2 Research area: Integration

Objective: Economic and reliable integration of wind farms into the Dutch national grid system, without causing instability or bottlenecks elsewhere in the network.

Offshore wind farms will produce 100-500 MW and the output of several wind farms will be transported to connection points in the high-voltage network (integration). In addition to the fact that this power will need to be transported from the generation location, large-scale integration of wind power also has a number of system consequences. The output fluctuates heavily and is barely manageable. The balance between supply and demand must be achieved through company resources on land, via the free-market mechanism. The unavoidable result is that, as more wind power is generated, a reliable prediction of the supply (in relation to the demand) is essential. Techniques are also required to modify the output.

Another approach to maintaining the balance is to use (large-scale) storage technology (known as buffering) whereby the supply pattern can be altered into a ‘flatter’ form. This allows the connections to be used more efficiently and reduces the need for control facilities of operation resources on the land. Converting wind energy into other forms of (non-electrical) energy that are easier to store and can be used at the required time, is also an option.

Integral system simulations provide an overview of the behaviour of wind conversion systems, with or without storage systems, and the network of existing electricity generators. This covers two timeframes: short-term power fluctuations and peaks/dips in the system (seconds, minutes) that lead to system instability, and the longer term fluctuations (> 15 minutes, up to several days) that can negatively influence the security of supply. The correct models, regulations and signalling functions are required in order to correct these problems. The greatest faults are due to short circuits in the network, sometimes with very fast loss of large quantities of wind power, e.g. through storms or faults in the offshore network. In addition to technical causes, long-term power fluctuations may also have organisational causes. Trading systems, procedures and routines play a role here.

The technological breakthrough comes from an integral system approach towards integrating wind power.

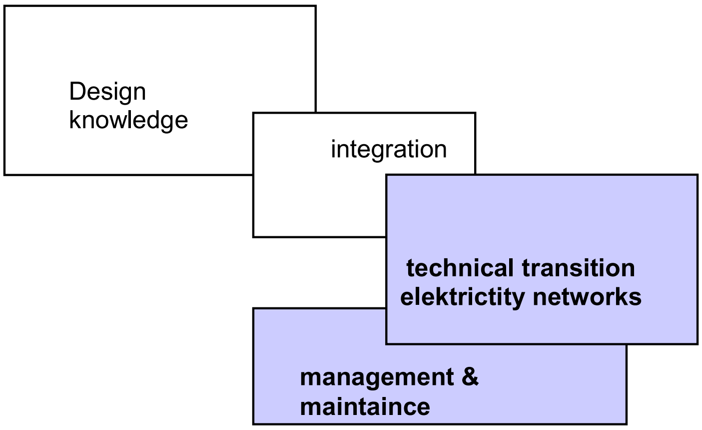
Research guidelines are necessary in order to achieve this breakthrough, e.g.:

- Integral control strategy;
- System research into large-scale storage systems;
- Consequences for existingland-based production capacity;

- Consequences for operating the land-based network (stability and capacity);
- Prediction methods (power supply in relation to the demand), including wind prediction.

5.2.4 Theme: Networks

The ‘Networks’ theme covers two research areas: ‘Technical transition of electricity networks’ and ‘Management and maintenance’.



5.2.4.1 Research area: Technical transition of electricity networks

Objective: To formulate an evolutionary path, with the availability of the necessary technologies for the transition from the current to the future network, thus allowing a sustainable energy supply in the year 2030.

This research objective includes elements from the themes ‘Electricity transport: security of supply, network integration and power electronics’ and ‘Electricity conversion, power quality, custom power, converters, and EMC’, as well as ‘Electricity storage, small-scale storage and system application’. In particular, it is the aspects/elements from the aforementioned themes that lead to an integral system approach and a transition path to a sustainable energy supply in 2030 that form the core of this research area. This type of approach has been lacking up to now. The theme ‘Electricity storage’ is an important import theme. Subsequent research within the framework of this programme should therefore also be coordinated with research in other countries that is relevant for the Netherlands.

The vision of a sustainable energy supply includes the security of supply plus a certain economic efficiency that is ecologically viable. The electricity network, on which this sustainable energy supply is based, must be able to handle large capacities of sustainable energy sources, both concentrated (offshore wind farms) and distributed (large amounts of small-scale decentralised sources such as PV and micro-cogeneration). The operation of the future network must be sufficiently flexible to cope with (large) fluctuations in both supply and demand and, with regard to power quality, and allow a differentiation in quality levels (depending on the clients). As an extension of the advice given by the General Energy Council [5,6] regarding the ‘evolution of revolution’, a transition will need to be realised from the existing current network structure (including operation) to a network that is suitable for future use and, through its robustness and flexibility, is (largely) independent of the precise economic and social developments that are being followed. The design of this new network is expected to look very similar to the current structure.

The differences will primarily lie in the administration, monitoring and security of the network, since future energy flows will be rather different. Specific new components, e.g. power electronic solutions will be included, for example to provide 'power steering', voltage maintenance, power quality and short-circuit limitations. Examples include storage systems for managing fluctuations between supply and demand, and possibly high-temperature superconducting applications for resolving bottlenecks, but also the uncoupling of network segments using DC connections to improve the robustness. More compact systems will also be created, and there will be an increased trend towards underground operations. In addition to these technological developments, the success of this transition depends on the fact that insight is gained into the behaviour of market parties, and the consequences for the networks as a result of changing market directions and regulations. The latter is actually the leading factor.

Within the research area 'Generation and networks', researchers should concentrate on 'Networks at sea'. The 'Electricity Technology Roadmap' [2] includes a North Sea Wind Festival. Networks at sea should harmonise with electricity generators at sea, such as wind farms, as well as land-based users. There is currently only a vague idea of how such a network could be created, which criteria it would have to meet, which (new) components would be required, how it should be operated, and what operational security would be necessary. Even the costs of creating such a network have never been properly estimated.

The technological breakthrough lies in developing tools for integral multi-stakeholder analysis.

Research guidelines are required in order to achieve this breakthrough, e.g.:
- What will future networks look like, including the industrial networks;
- Using power electronics and direct current;
- Making the existing network more flexible and intelligent;
- New components that are necessary;
- Setting up the future security, management and operational aspects;
- System design: which technology is applicable for networks at sea;
- New components, and making components and systems seaworthy;
- Behaviour and control strategy for DC network.

5.2.4.2 Research area: Management and maintenance

Objective: The socially responsible (sustainable) use of networks, both in terms of capacity and time.

Management and maintenance is an important research area, as it represents 35% of the costs. Anticipating the considerable changes in the energy scenario (with many decentralised generation units and networks), the priorities will lie in two main directions:
- Process-oriented technical, economic and social research that works towards efficiency, the environment and reliability;

- System-oriented research, to gather and process information for the generation of knowledge; decision-support aspects and exchange with intelligent systems.

In order to guarantee the reliability of the electricity supply during more concentrated use of the network, it is essential to gain insight into the relationship between the load on components and ageing. Working from the required 'sustainability' point of view, many new technological concepts will need to be developed for transport and distribution networks because both economic and ecological benefits can be gained here, by using advanced systems with integrated sensors, critical component selection, and through using systems with reduced environmental loads (materials, losses, noise).

In order to include technical, economic and ecological information in the decision-making framework, advanced tools (e.g. 'intelligent' components) are required, whereby automated remote management is possible in the future. Decision-support mechanisms at system level for individual components, based on knowledge norms and reference data in supporting information systems, have yet to be developed.

The technological breakthrough lies in successfully combining ecology and efficiency.

Research guidelines are required in order to achieve this breakthrough, e.g.

- New 'sustainable' techniques, materials and tools for management and maintenance;
- Allowing diagnostics to be used for transport and distribution networks, and components.

5.3 Non-technological aspects

Section 5.2.1, point 15 (environment), describes the meaning of gamma research in relation to the social perception of technical solutions. Research of non-technical aspects can play an important role in formulating future policies, as well as economic and social conditions concerning 'Generations and networks'. Proposals for non-technological research may be submitted, provided that this forms (a limited) part of a research proposal concerning focal points or import themes.

Encouragement or hindrance through regulations or ownership
Private networks with their own management structure (e.g. DC networks for trains, metro and trams) can apply new technologies that offer benefits. Such networks are usually not well developed, e.g. for large industrial and manufacturing complexes. The question is how far current regulations and ownership relationships are hindered, and which solutions can be found to improve this situation.

Micro-cogeneration would be too risky or too expensive for private stakeholders. Could lease constructions be the answer? If so, do subsidy schemes and legislation encourage this situation? New standards, norms and regulations, e.g. developed for the DTe (Dutch office of energy regulation) or the EU, can also hinder the proper functioning of a future electricity supply based on sustainable and decentralised energy generation. Technological developments can therefore be unnecessarily delayed if it is not clear which international standards will apply. Research should determine which organisations, procedures and regulations can ensure that policymakers, knowledge institutes and stakeholders co-ordinate their interests at the earliest possible phase of the development.

This could be achieved, for example, by introducing EU-wide technology standards for electricity exchange, similar to the EU-wide standards used for mobile telephony via the GSM network.

5.4 References

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