Energy Technology Research Programmes 1993-1998

Intermediate report

TEKES

TECHNOLOGY DEVELOPMENT CENTRE
FINLAND

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Tekes – Your contact for Finnish technology

Tekes primary objective is to promote the technological competitiveness in Finnish industry. Activities should lead to an increase and diversification of industrial production and exports and an improvement of well-being in society.

Annually, Tekes grants about one and a half billions Finnish marks for financing applied and industrial R&D in Finland. Tekes offers excellent channels for technological co-operation with Finnish companies, universities and research institutes.

Technology programmes
– part of the innovation chain

The technology programmes for developing innovative products and processes, are an essential part of the Finnish innovation system. These programmes are characterised by close co-operation of the industry, universities and research institutes. The programmes also form a solid basis for international co-operation. Currently there are about 50 active technology programmes

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Chapter 1
Energy technology research programmes 1993-1998

The Tekes energy technology research programmes were launched in 1993. The aim is to produce innovative solutions that are efficient, environmentally sound and widely - even globally - applicable.

Since the liberation of world trade is affecting the energy market too, Finnish research must be able to anticipate the needs of the market and outline the areas in which Finnish companies have the best success potential. Finnish energy technology cannot be protected or given priority in any way. The need for international action to reduce environmental damage further emphasizes the global aspect.

Internationalization has proceeded perhaps even more rapidly and intensively than was anticipated a few years ago. This has been allowed for in energy technology research programmes by focusing more on the industrial applicability of research and on supporting industrial competitiveness. In balancing the new challenges, internationalization - particularly Finnish membership of the EU - has offered scientists opportunities for improving their competence through cooperation.

The scientists involved in these research programmes are taking part in several international ventures through projects managed by the EU and the IEA, the energy body of the OECD. The funding criteria for these activities are in the main the same as for domestic projects. The aim of IEA cooperation is to bring added value to Finnish energy research through technology transfer and cooperation between scientists. Finland is participating in 15 IEA programmes through Tekes programmes.

Certain projects in the EU Joule II programme have links with national programmes. In the Joule-Thermie programme, a number of research and demonstration projects whose results will also be passed on to Finnish parties have also been launched since 1995.

The energy market has been deregulated through a number of international and national decisions, Finland being one of the pioneers in this field.

Parties that have enjoyed direct legislative protection from competition and the companies whose clientele has been mainly in the public sector have been forced to adapt to the new market situation. This change has opened up new opportunities for equipment suppliers that can offer means of enhancing their clients' operations. On the other hand, the same clients' capacity for bearing technology risks has been reduced, a fact which is evident in that there is now less willingness to invest in technology which is only just being commercialized.

As regulations disappear, economic incentives and sanctions have been envisaged as tools for guiding the energy market towards the desired objectives. Financial instruments of this kind include taxes and charges, on the one hand, and various subsidies, on the other. These have not been implemented on the scale that was anticipated when the research programmes were launched. Europe has not reached consensus on a carbon/energy tax, and Finland has had to revise its own energy taxation system because of this. Use of investment subsidies in the new energy technology market has been limited by the government's financial problems. Research and development funding has become perhaps the most significant form of public support for energy technology.

In the period covered by this report, i.e. 1993 to 1995, Tekes managed a total of 11 energy technology research programmes. Their total funding for 1993-1998 is FIM 1.5 billion. About half of this is coming from Tekes, with the companies participating in the programmes providing a significant por-

tion of the remainder. Tekes is running about 50 technology programmes in all.

This interim report on the energy technology research programme describes how far the programmes have succeeded in attaining their objectives during the first half of their operating life, viz. 1993-1995, and how they have adapted their content to changes in the operating environment. The final reports on the programmes will be produced during 1998.

Technology exports balance energy imports

After the energy crisis in 1973-1974, it seemed that the insufficiency of the world's energy resources could well be the greatest obstacle to economic growth. Economic expansion would inevitably lead to rising consumption of energy and other natural resources, and oil-exporting countries would be in a position to gain a share in the economic growth of industrialized countries by raising the price of oil.

However, when energy became more expensive, a number of economic and technological adaptation mechanisms came into play. The industrialized countries began looking for ways to conserve energy, and work on the development of new forms of energy expanded. These efforts are still going on, since they still promise a good return on investment.

In the crisis years of the 1970s, few would have expected Finland to be able to balance a major portion of its energy imports with energy technology exports. This, however, is precisely what is happening. Energy prices have come down steadily due to an abundance of supply, and at the same time Finland has developed energy technologies that are in great demand abroad.

This development encapsulates an essential economic and technical process. The relative economic importance of raw materials and natural resources will decrease, and the importance of technological competence and other intangible assets will increase. Renewable intangible assets are a more important resource than natural resources.

The same technical and economic adaptation mechanism will also help in solving environmental problems. The Tekes technology programmes are developing and renewing the intangible assets that will allow us to meet the challenges posed by environmental impact for the energy market of the future.

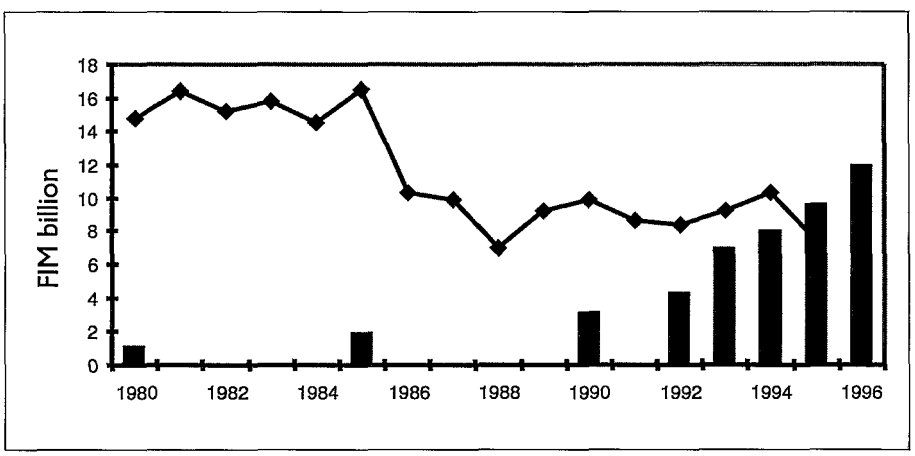

Figure 1. Energy technology exports (columns) and energy imports (line) 1980-1996. Data not available for every year.

Table 1. Summaries of energy technology research programme objectives.

Programme	Research area	Main objective
Tekes Energy Programmes	Energy technology	To develop efficient and environmentally sound energy technologies that are competitive in the international marketplace.
BIOENERGIA	Bioenergy	New cost-efficient methods of producing biomass-based fuels from wood and peat; development of utilization and conversion methods and equipment for biomass; increasing use of wood by 1 Mtoe per annum.
EDISON	Electricity distribution automation	Improvement of electric power distribution; creating a technical basis for competition within electric power distribution and use; developing competitive products in the electric power industry.
FFUSION	Fusion energy	To provide a high-level Finnish contribution to international fusion research and to promote the participation of Finnish industry and research units in the development and planning of the ITER test reactor.
SUSTAINABLE PAPER	Energy in paper and board production	To make the specific energy consumption of present manufacturing processes the lowest in the world; to develop new process solutions; to develop paper products requiring a minimal energy input.
LIEKKI 2	Combustion and gasification	To develop energy conversion technology based on combustion and gasification employing technology and placing a minimal load on the environment; applications including fluidized bed combustion, pressurized fluidized bed techniques, diesel power plants, black liquor recovery boilers, black liquor gasification and waste incineration.
MOBILE	Energy and the environment in transportation	The development of low-emission fuels and engines; the introduction of low-pollution urban vehicles; improving the efficiency of existing traffic systems.
NEMO 2	Advanced energy systems and technologies	To promote the export of advanced energy systems; to increase the use of wind and solar energy on the domestic market.
RAKET	Energy use in buildings	To turn energy-saving technology and environmentally sound building construction solutions into products; to develop new structural and equipment systems.
SIHTI 2	Energy and environmental technology	To reduce emissions of harmful substances, to recycle raw materials and to limit the amount of waste and utilize them in the energy sector.
SULA 2	Energy in steel and base metal production	The world's lowest specific consumption of energy in existing processes; world leadership in reducing the energy consumption of certain unit operations; new energy-saving processes.
TERMO	District heating	Top-notch district heating know-how by developing new technology.

Table 2. Examples of energy technology research programme results.

Programme	Research area	Examples of commercial applications of research results
BIOENERGIA	Bioenergy	Terrain chipper, multi-purpose chipping lorry, agricultural tractor-based chopped firewood and chip harvesting technique and logistic calculation model for woodfuel. In peat production: linear ridger and light equipment chain: plastic miller - light weight loader - collecting wagon; peat conveyance method to reduce the amount of residual peat on peatland.
EDISON	Electricity distribution automation	Energy management system prototype, energy meter monitoring electricity quality, demand management planning system prototype, data transfer solutions to meet the needs of network automation and the deregulated electricity market.
FFUSION	Fusion energy	Several computer programmes for fusion plasma radio frequency applications, used for analyzing test results. Finnish fusion research has been integrated with the EU fusion research programme.
SUSTAINABLE PAPER	Energy in paper and board production	Recycled pulp production line based on new screening technology and Condebelt-drier developed to demonstration stage. Audits made at industrial plants have established an energy conservation potential worth about FIM 50 million per annum.
LIEKKI 2	Combustion and gasification	Development of pressurized processes and fluidized bed techniques. Combustion process modelling. Diesel engine development.
MOBILE	Energy and the environment in transportation	Reformulated gasoline and diesel fuel, low-emission medium-speed diesel engines for ships, heavy-duty automotive gas engine, low-emission high-speed diesels for off-road applications, oxidation catalyst for diesel engines, LPG-fueled heavy-duty truck.
NEMO 2	Advanced energy systems and technologies	Hydrogen technology energy storage, deicing systems and icing sensor for wind power stations, solar cell facade of amorphous silicon for buildings.
RAKET	Energy use in buildings	Single-family house with a total energy consumption half that of a normal building; two prototypes for a ground source heat pump for small houses; fault diagnosis methods for district heating heat exchangers, oil burners and air conditioning systems; air conditioning systems with simplified couplings.
SIHTI 2	Energy and environmental technology	Equipment for separating ultrafine particles from flue gases; low-pressure impactor for real-time measurement of ultrafine particles; photoacoustic analysis equipment; and development of evaporators for closed water cycles in the process industry.
SULA 2	Energy in steel and base metal production	The programme has produced energy savings worth over FIM 30 million per annum. Also, the steel melting capacity of Tornio stainless steel plant has increased by over 20% and the production capacity of the Finnish blast furnaces has increased by 7.5%. Blast furnace and cooking plant control, automation and expert systems. FeCr converter. Development of strip casting method.
TERMO	District heating	System for predicting district heating load, to optimize power station operation; network thermography method; basic information on district cooling techniques.

Table 3. Energy research programme funding.

Programme	Research institution projects		Company projects		Total
	Tekes	Total funding	Tekes	Total funding	Total
BIOENERGY	24,0	42,0	42,6	106,0	148,8
EDISON	8,5	17,4	[1]	[1]	17,4
FFUSION	6,9	16,1	2,6	6,1	22,2
SUSTAINABLE PAPER	17,9	26,8	21,6	84,3	111,1
LIEKKI 2	54,8	82,7	28,5	87,1	169,8
MOBILE	7,6	13,7	20,9	45,3	59,0
NEMO 2	20,6	36,5	17,9	45,5	82,0
RAKET	25,1	38,0	22,8	57,4	95,4
SIHTI 2	16,0	25,4	25,8	70,7	96,1
SULA 2	8,1	10,3	20,6	49,7	60,1
TERMO	[2]	[2]	3,8	7,6	7,6
Total	**189,5**	**311,7**	**206,9**	**559,7**	**871,4**

[1] Funding not publicized due to the limited number of projects involved.
[2] Research institution projects in the programme have been financed through corporate financing.

Table 4. Energy technology programmes.

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Chapter 2
BIOENERGY – Bioenergia Research Programme

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1 Background and objectives

1.1 Background

The programme is based on the general justification for increasing the use of biofuels, the abundance of raw materials and the need for more energy, particularly electricity. However, the competitiveness of new bioenergy sources that would allow increased use is a problem.

The general justifications for increasing the use of biofuels are that by increasing the use of bioenergy

- CO_2 emissions from energy production can be reduced
- economically viable uses for wood from first thinnings can be created through integrated production methods that increase the production potential for both merchantable wood and wood for energy production
- the degree of self-sufficiency in energy production can be improved, and potential for new companies and new employment can be created
- technology and equipment exports in the field can be enhanced.

Finland has set targets for reductions in nitrogen oxide, sulphur dioxide and carbon dioxide emissions in the 1990s. The best results have been achieved in sulphur emissions: the objective of an 80% reduction from the 1980 level has almost been achieved. The objective to reduce nitrogen oxide emissions by 30% by 1998 will probably not be attained. The stabilization of carbon dioxide and other greenhouse gas emissions at the 1990 level in accordance with the Rio Convention is the most difficult goal. Increasing the use of biofuels will decrease carbon dioxide and sulphur emissions above all.

Finland has an abundance of bioenergy resources. The annual volume of peat used is only a fraction of the resources available, and the growth rate of Finland's forests is greater than the volume of wood cut down annually. It is estimated that nurseries and the management of young forests would yield the equivalent of nearly 0.5 million tonnes of oil (toe) in wood fuel in a year. The production potential from first thinnings is also about 0.5 million toe annually. However, the main production potential is in the logging residue of final cuttings, which could easily produce about 1.0 million toe of wood chips for burning annually. In all, the production potential for wood fuel is about 2.0 million toe; this means an annual volume of over 10 million cu.m of wood biomass, taking technical, economical and environmental aspects into account.

The Council of State approved the bioenergy promotion programme on April 7, 1994. The objective is to increase the use of bioenergy by at least one quarter from the present level over the next 10 years. This would mean an increase of the equivalent of 1.5 million toe by the year 2005.

The present Council of State took a decision in principle on energy policy on December 21, 1995. This decision states that the Government will continue to implement the bioenergy promotion programme. The main focus of the programme is on increasing the use of wood for energy production. The significant status of bioenergy and other renewable energy sources in publicly funded energy technology research and commercialization is emphasized. In order to promote the competitiveness of domestic energy sources, demonstration plants and R&D that creates new industry and increases exports are subsidized. Investment and tax subsidies biased in favour of the energy market are being

phased out, but separate goals established for bioenergy use are being taken into account.

In 1994, the Commission published an estimate of the present and future use of bioenergy in the EU Member States. This estimate shows that the objective is to increase the relative significance of bioenergy. The Commission has set a target of raising the share of renewable energy sources in total energy production from 4% in 1991 to 8% by the year 2005 (8% is equivalent to 109 million toe). The objective in electricity production is to triple production to 135 TWh (excluding large water power stations). The objective in transport is that biofuels have a 5% market share by 2005. According to the Green Paper on renewable energy sources, distributed by the EU in November 1996, the Commission proposes that the objective should be for the share of renewable energy sources to be 12% in 2010. Bioenergy would account for the largest part of this. The estimates for future use of biomass are large compared with Finland, so the export potential for the technology being developed is considerable.

1.2 Objectives

The main objectives of the BIOENERGIA Research Programme are:

- to develop new methods of producing biofuels with the aim of making them competitively priced compared with imported fuels. The most promising production methods will be demonstrated through pilot schemes.
- To develop 3-4 new pieces of equipment or methods connected with the handling and use of bioenergy and bring them at least to the demonstration stage.
- To produce basic information on conversion techniques and evaluate the quality, usability and environmental impacts of the products as well as the overall economy of the entire production chain and to create 2-3 conversion methods for follow-up development by industry.

Clear-cut objectives have also been defined for the programme's research areas (the production of wood and peat, the use of bioenergy and biomass conversion): For large consumers, the costs of producing wood-based fuel on site will fall to FIM 45/MWh, which means that annual use of wood-based fuels can be increased by nearly 1 million toe/a. Peat production costs will decline by 20% on the 1992 level (FIM 5-6/MWh).

Prioritizing the production of wood-derived fuels

BIOENERGIA is concentrating on fields that are important for Finland's energy supply structure, self-sufficiency and overall economy, since international research information is not available on all these aspects of the energy picture.

The principal research areas are:

- development of production technology for wood-derived fuels
- Peat production
- The use of bioenergy
- Biomass conversion

In addition, the programme includes separate projects in which scientists are studying the production of biofuels in open fields and the utilization of solid wastes and sludges in energy production.

Production technology for wood fuels

Development work is being carried out in both the separate production of wood-derived fuels and in their integrated production. The viability of the methods will be tested in pilot-scale demonstrations.

Integrated methods in which wood fuel is brought to the power plant from the forest in connection with roundwood procurement for the wood-processing industry offer a number of advantages. A shift from the individual timber grade method to undelimbed harvesting can nearly double the amount of wood obtained from the same area. The benefits of mass-production methods can be applied to wood handling, with consequent cost savings.

The R&D projects are directed at finding better methods of harvesting undelimbed or partially delimbed trees, the separation of whole-tree chips to produce fuel and industrial raw material, and the bundled delimbing and debarking of roundwood.

In separate wood fuel production, the wood is harvested only for energy use. In this case, use is made of stands that are not suitable as industrial raw material, and of the harvesting residue of stands felled for industrial use. The wood usually has to be harvested in forests consisting mainly of small-diameter trees, resulting in high harvesting costs per unit.

The programme is studying the production of wood fuels from the harvesting residues of final fellings, harvesting techniques for small-diameter trees that are unsuitable for industrial use, and wood fuel production on farms.

Peat production

The main focus of the research is on finding better ways of obtaining peat from shallow bogs and developing production methods and machinery. The goal is to lower production costs and to reduce emissions from the production process. Production costs can be lowered by shortening the preparation time of bogs, by employing covered drains in the production fields and by using modern production design and control methods and up-to-date work and traction machines incorporating a maximum amount of automatic functions. Other ways of lowering total production costs are to utilize shallow bogs and post-farming peat areas efficiently and ensure the integrated use of peat production machinery in the production of wood and other biomass.

Use of bioenergy

Research into the use of bioenergy is concentrating on applications in the small size class (under 20 MWth) and on the handling of biofuels in all size classes. The objective is to eliminate the technical obstacles standing in the way of more exclusive use of wood and peat fuels, and to develop economical and environmentally sound energy production technology for small-scale applications.

The forest industry offers a natural area for pilot demonstrations of the use of biofuels. Not only is the industry the largest consumer of energy in Finland, it is also the largest producer of energy from forest sources. Other potential demonstration sites are different-sized heat and power plants that burn indigenous fuels.

Biomass conversion

Research into biomass conversion is concentrating on solid biofuels and spent liquors from the forest industry. The objective is to convert these and other by-products into gasified, liquefied and solid fuels. Their main users are likely to be small-scale power plants based on steam turbine, diesel and gas turbine technology.

The programme also addresses the production of fuels and lubricants for road vehicles from raw materials produced on farms and in the pulp industry. The main research projects deal with liquid fuel production from the by-products of the pulp industry (black liquor, lignin, sulphate soap and tall oil) and with the production of liquid fuel from wood and peat by means of the flash pyrolysis method.

It is possible to use set-a-side agricultural land for non-food production. In 1995 the management group of the research programme, together with the Ministry of Agriculture and Forestry, assessed the need to extend the research programme to the study of agrobiomass by setting tangible goals for this area. It was decided to continue the work on a project basis, and to produce a separate report at the end of 1996 when the present project ends.

1.3 Programme financing

The original projected financing framework for the bioenergy research programme comprises FIM 210 million, or FIM 35 million per annum. Contributors include the Ministry of Trade and Industry and the Ministry of Agriculture and Forestry.

Total funding granted in 1993-1995 totalled nearly FIM 150 million, which exceeded the plan by nearly 50%. The share of companies and other financiers in the overall funding continued to increase to nearly 60% in 1995.

Table 1. Financing for the BIOENERGIA research programme.

Financier	Projected financing	Actual support, FIM million				
	yearly	1993–98	1993	1994	1995	1996
Tekes/MTI total	16	96	27	20	19,4	
- research institution projects			8	8	8	5
- corporate projects			8	7	5,2	2*
- demonstration projects			11	5	6,4	*
– EU structural fund						2,4
MAF	7	42	1,5	2,8	2,7	2,5
Companies and other financiers						
	12	72	22	23	29,4	14,6
Total	35	**210**	**50,5**	**45,8**	**51,7**	**27**

*) status on September 13, 1996. Companies and other financiers partly unclear.

1.4 Projects in 1995

The programme contained a total of 66 ongoing projects at the end of 1995: 32 in universities and research institutions, 19 in companies and 15 demonstration projects. The number of research projects increased considerably.

About 60% of the funding allocated in 1995 has been used on research into wood fuel. This share has increased significantly. About 15% of funding, or 5 percentage points less than in 1994, was allocated to peat production.

Over 30 companies participated in the programme in 1995. In wood fuels, 11 projects were implemented in SMEs in 1995. Several SMEs also contributed to research institution projects. SMEs were also involved primarily in projects managed by the Work Efficiency Association. Two SMEs were involved in bioenergy use with their own projects. Also, several companies participated in research projects in this area.

Overall Tekes financing for research institution projects has dropped from FIM 8 million to FIM 5 million due to funding cuts. However, co-ordination financing for 1996 could be obtained from other sources, so the actual research financing only went down by FIM 2.04 million. The overall financing has remained more or less the same, due to an increase in other funding, mainly EU funding obtained for the use and conversion areas. Another significant change is the reduction in Tekes funding for peat research by nearly FIM 1.5 million, reducing overall financing by FIM 2.5 million.

The share of corporate funding in research institution project funding is already the greatest as a percentage in peat production research. In wood fuel production and biomass conversion, the corporate input is about 15%, while bioenergy use projects, which also have EU funding, have only an 11% share of corporate funding.

1.5 Export potential

Development work has produced new machinery and equipment for the domestic market, and these products also have considerable export potential. The following is a study of the wood fuel production equipment market in Europe, based on fibre wood cutting volumes measured as debarked stemwood. The assumption is that the potential share

of integrated methods in fibre wood cuttings is 15% to 25% in Finland and Sweden and 25% to 50% elsewhere in Europe, depending on the country. The yield of wood fuel in the calculation is 40%. According to the study, the greatest potential for integrated methods, apart from Finland, is in Sweden. Other potential countries for applying the methods are Spain, Portugal, Germany and France.

The following examination of equipment export potential for various machines and equipment and as machinery chains has been discussed here on the basis of the potential for fibre wood cuttings and integrated methods. The calculation is based on the estimated output of the various chains and the price information for individual pieces of equipment. Equipment volumes have been converted into FIM, and various equipment chains have been considered.

Chains

1. Harvester-forwarder + whole-tree and tree-section lorry transport + chain delimbing and debarking equipment
2. Terrain chipper + MASSAHAKE processing
3. Harvester-forwarder + whole-tree and tree-section lorry transport + MASSAHAKE processing
4. Feller-forwarder + compressing load space + whole-tree and tree-section lorry transport + chain delimbing and debarking equipment
5. Feller-forwarder + compressing load space + whole-tree and tree-section lorry transport + MASSAHAKE processing

According to the calculation, the annual market potential for the production chain consisting of a combination of harvester-forwarder, whole-tree and tree-section lorry transport and chain delimbing and debarking equipment in Europe would come to a total of FIM 88 to 151 million. The potential for the production chain consisting of plot chippers and MASSAHAKE equipment would be FIM 171 to 292 million. The potential market for the production chain consisting of feller-forwarders, compressing loaders, whole-tree and tree-section lorry transport and chain delimbing and debarking equipment would be FIM 46 to 79 million per annum, and for the production chain consisting of feller-forwarders, compressing loaders, whole-tree and tree-section lorry transport and MASSAHAKE equipment FIM 78 to 133 million per annum.

The annual domestic market potential will be FIM 17 to 108 million, depending on the method adopted and its degree of use. The market for exporting equipment technology to Europe will be FIM 29 to 184 million. The greatest potential is in the production chain based on the plot chipper and the MASSAHAKE method.

Table 2. Annual market potential for equipment in various method chains.

	1. (FIM million)	2. (FIM million)	3. (FIM million)	4. (FIM million)	5. (FIM million)
Finland	34-57	65-108	47-78	17-28	30-50
Sweden	43-72	83-138	60-100	21-35	38-63
Spain	3-6	5-10	3-6	2-4	2-4
Portugal	2-4	3-6	3-6	2-4	2-4
Germany	3-6	8-16	5-10	2-4	3-6
France	3-6	7-14	5-10	2-4	3-6
Total	**88-151**	**171-292**	**123-210**	**46-79**	**78-133**

2 Results in main research areas

The speciality of the BIOENERGY research programme is tangible goals and a strong corporate input in management group work and research institution project assessment. In 1995, the BIOENERGY research programme was the third largest of the then current Tekes technology programmes.

Some of the goals in wood fuel and peat production technology have already been attained, well ahead of schedule. Demonstration of new technologies has begun. Many projects have already progressed from research to demos, and new export products have been created.

2.1 Wood fuel production technology

The wood fuel production research area has produced new information for development work in working methods for final cuttings, the biomass balance and properties of pine and spruce from early thinnings, the basics of chain delimbing and debarking, the basics of compressing, the separation properties of wood chips and pneumatic conveyors. A cost calculation model has been prepared for small scale production, and the bases for measurements and quality of chopped firewood have been established.

Firewood production

Six commercial prototypes have been tested for forest work in the 'farmer' class. This represents a significant technological advance from chainsaws to new felling and forest transport technologies. Also, 'heat entrepreneurship' has been developed in wood chip production; this means that the wood chip supplier also carries responsibility for heat production, thus avoiding the difficult problem of assessing the energy content of the wood chips delivered.

New equipment is being commercially tested for the machine production of traditional chopped firewood, applying recyclable processing and distribution technology "from the forest to the customer".

Wood fuel production in nursery thinnings

Nursery management instructions have recently been upgraded to state that thinning should be done later than previously, i.e., when the trees are 4 to 7 m high. The trees felled are then large enough to produce a cumulative total of 40 to 50 cu.m of biomass per hectare (at least 100 cu.m of wood chips).

The annual nursery management area needed is about 200,000 ha. It has been cautiously estimated that nursery management and young forest maintenance could easily yield 2.5 million cu.m (nearly 0.5 million toe) per annum.

Wood fuel production in commercial thinnings

The main development focus in wood fuel production from first thinnings has been the integrated production of merchantable wood for industry and wood fuel.

The cost comparison of the use of pine from first thinnings as wood fuel shows that integrated methods provide a competitive alternative for the acquisition of wood from first thinnings, on condition that the raw material is of acceptable quality for the forest industry. The goal of FIM 45 per MWh in wood fuel production costs seems to be attainable with the proposed methods.

The calculation is based on a comparison between the single-tree method and the bulk handling method, where the bulk handling method has reduced the cost per cu.m from FIM 276 to FIM 264 between 1992 and 1996. The price of the energy component is FIM 45 per MWh. In comparing the new methods, the price of wood chips for pulp has been kept the same.

The production potential for the whole of Finland has been estimated at about 0.5 million toe per annum. The stage of development of the production methods shown in the table varies: some could be implemented immediately with existing equipment, while others still require product develop-

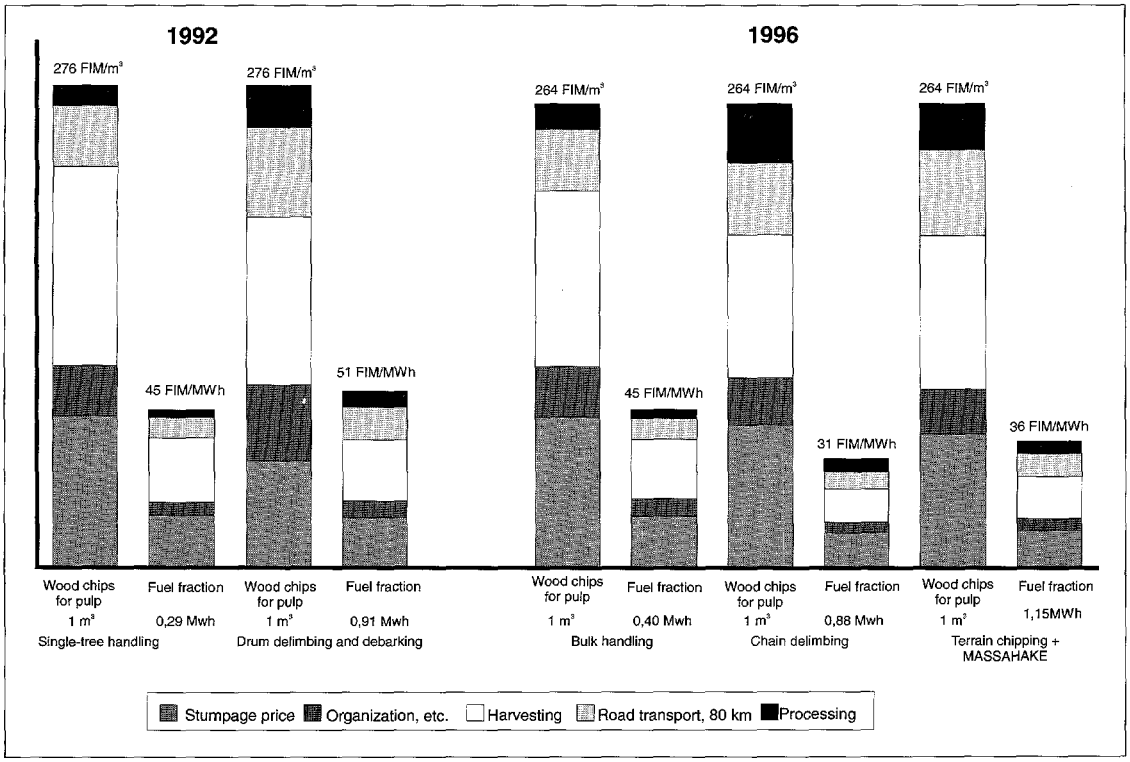

Figure 1. Wood fuel production costs. Pine from first thinnings.

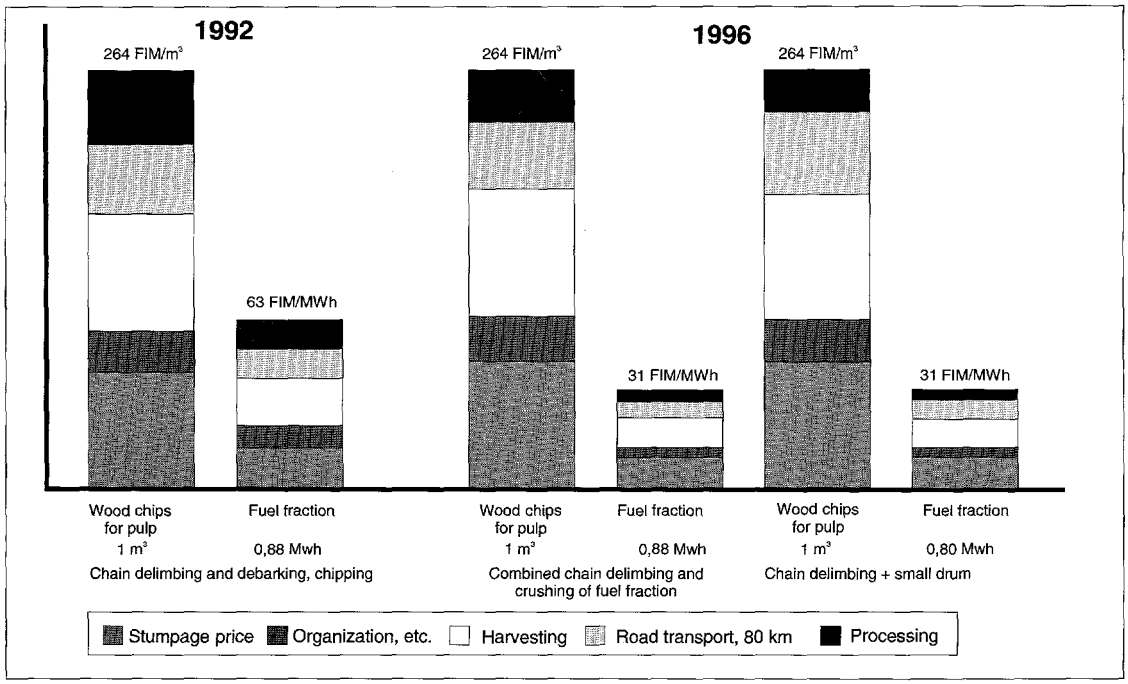

Figure 2. Development of methods in the research programme and techno-economical comparison.

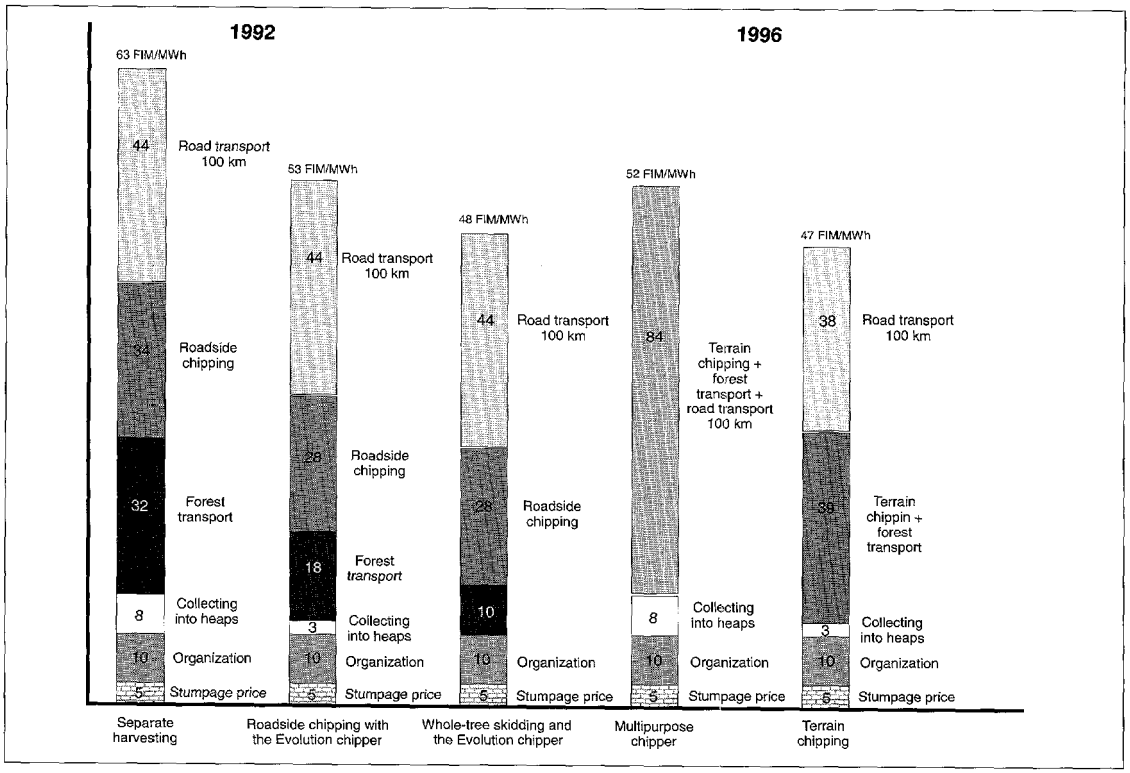

Figure 3. Cost comparison of production chains of logging residue chips researched and developed in the research programme.

ment for essential equipment or a demonstration of the entire chain.

The harvesting of wood from first thinnings and wood fuel production has been examined mainly with pine. This is justified in that stands with pine as the major tree comprise about 80% of all early thinnings. The requirement for early thinnings in private forests amounts to at least 6 million cu.m of stemwood per annum.

The chip harvester developed by Oy Logset Ab has already reached the commercial stage. Four machines are in operation and four more on order. Exports to Germany are also getting under way.

The multi-tree harvester for the handling of small trees attained a 20% more efficient result per working hour in the sites examined than single-tree felling. This translates to about FIM 5 to 15 per cu.m in the purchase price. The development work was undertaken by Outokummun Metalli Oy and Metsäteho in co-operation with Enso Oy. The machine is a commercially finished product.

The general technical feasibility of the MASSA-HAKE method was established in a demonstration plant that was started up in Kankaanpää in June 1995. The research programme has continued to develop sub-categories within this method.

The problem in chain delimbing and debarking is the high proportion of bark in wood chips in winter. To reduce this, a study of chain delimbing and debarking with a research device has been started. A pilot installation applying chain delimbing and debarking technology combined with small drum debarking was completed at a wood processing terminal in 1995. The demonstration project managed by Hooli Oy has produced a machine combination based on chain delimbing and debarking together with hammer crushing; this product was tested in 1995.

Wood fuel production from final cuttings

According to the cost comparison performed in the research programme, the goal of FIM 45 per MWh set for the costs of production methods suitable for the harvesting of logging residue from spruce-dominated final cuttings is attainable.

The production potential in final cuttings in Finland is 1.0 million toe per annum. The development stage of the production methods outlined in Fig. 3 varies: some methods could be introduced immediately with existing equipment, while in most projects essential equipment needs to be further developed or the entire chain demonstrated. Fig. 3 shows the current status according to the goal of 100 km transport distance defined in the programme. In practice, many of the new methods are already competitive with transport distances under 60 to 80 km.

The basic method in harvesting logging residue in final cuttings has at its best, in a demonstration project in the Mikkeli area, gone below FIM 43 per MWh using commercially available technology. The method costs were assessed at FIM 60 per MWh in 1992. The method has been further developed by Kotimaiset Energiat Pekka Lahti Ky, producing a new efficient chipper called Evolution. The new final cutting method based on the Chipset terrain chipper has already reached the commercial stage.

A competitive price can be attained using a production chain featuring a MOHA-SISU truck fitted with a chipper, and transfer containers. MOHA-SISU enables a new kind of production logistics for firewood chips, with advantages over the traditional method and other production chains. The method was introduced for commercial testing in 1995.

Developing the method on the basis of the Jaakko Pöyry concept offers further potential. The logging residue would be harvested with the same equipment and at the same time as the fibre wood is transported to the roadside. The chipping is managed with a transfer container fitted with a chipper, and a three-container module for long distance transport.

An integrated harvesting method for fibre stemwood and energy wood based on whole-tree felling has also been tested in spruce-dominated final cuttings; in this method, the harvesting costs for logging waste would be as low as FIM 10 per cu.m. This would resolve into less than FIM 45 per MWh in production costs over an 80 km range, provided that the development of temporary storage arrangements can be solved. The method is ready for demonstration.

2.2 Peat production

The main objects of research in peat production are ditching and maintenance technology, drying technology, machine technology, method technology, integration of wood harvesting and peat production, and implementing the results of the Optimiturve research programme in practice. The theoretical side in peat production research has also gained importance. Knowledge of the basics of drying in particular forms a foundation for other development work and is an important link in the chain. Research has also produced new information on new materials, underground drainage and the use of wood chippings as covering for peat stockpiles.

The main research results from 1993-1995 are:

- A mathematical model has proved that open ditch spacing can be increased from 20 m to 60 m by using underground drainage. These results are being verified in practice;
- A physical model of peat drying has been created to enable the construction of a peat layer structure optimal for drying speed and production;
- A compressed peat production principle has been formulated to enhance drying; the main parts of this process have been tested and are now ready for technical development;
- A peat transfer method, the 'Tarkkaturve method', has been developed; it will halve the amount of peat remaining at the bottom of the bog. The method also includes the prototype of a new, fireproof machine chain consisting of a plastic miller, lightweight loader and collecting wagon. The new peat transfer method was in

use on nearly 500 ha of bog in 1995, and it is projected that in 1996 the method will be used on over 1000 ha;
- The sod peat spreading wagon method has been developed to reduce the amount of residual peat on the peatland. This method is in production testing;
- A method has been developed and introduced where wood chips are used to replace plastic as covering material for peat stockpiles. Vapo Oy used about 0.5 million loose cu.m of wood fuel for covering peat stockpiles in 1995;
- Development work on a new machine chain for large-scale production of sod peat by the ridge drying method was begun and a prototype miller built;
- The new scraper-ridger developed in the early stages of the programme was in use in most of the milled peat production in the 1995 production season.

The research results show that the objective of the peat production research area is attainable if the partial goals are reached. Increasing the distance between open ditches from 20 m to 60 m will lower production costs by 5%. Increasing the use of solar energy from 30% to 40% will lower production costs by 8%. The reduction of the amount of peat remaining at the bottom of the peatland from the equivalent of 3000 MWh to 1500 MWh will lower production costs by 6%, the development of light and fireproof machines by 3% and combined wood harvesting by 3%. Achieving these subgoals will reduce peat production costs by over 20% altogether.

2.3 Bioenergy use

New information in the area of bioenergy use has been produced on the basics of drying, drying models, basics of fireplace combustion and catalytic cleaning of flue gases.

The bioenergy use projects have focused on fuel treatment and drying technologies and on developing building-sized heating equipment. In fuel processing, projects have focused on fuel input in pressurized power plant processes.

Development work on two different types of dryer has been started as corporate projects. One of the dryers is being tested on an installation scale at a small power station in Kuusamo. This bed-mixing dryer gets its drying energy from the hot sand of the fluidized bed. The dryer increases the district heating output of the plant by about 20 percentage points. The method is ready for demonstration at a larger power plant. In the second dryer type being developed, the fuel is dried with flue gases in the bed. The final moisture target is 15% to 20%. The method is ready for demonstration.

New demands are being placed on fuel handling technologies in pressurised power stations. Two different types of sequence-guided piston feeders are being developed as corporate projects for fuel input. The design of both is intended to cut investment and operating costs in comparison with the bin system. The feeders have been tested under near-actual conditions with good results. The devices are ready for demonstration.

Högfors Lämpö Oy has demonstrated an automatic heating system the development work on which was begun in the research programme. On the basis of experience gained from the prototype boiler (200 kW), a 600 kW boiler was built and, after laboratory testing, installed as the heating system at a market garden in 1995. The experience in using this boiler has been very good. The only problems have been caused by unhomogeneous quality of the fuel.

Catalytic cleaning of flue gases from furnaces has succeeded, but for naturally ventilated fireplaces it seems that it is necessary to build a bypass duct for the ignition stage. Results show that introduction of a catalyst would be possible with present technology in all fireplaces except storage furnace, which need further development. The application is ready for product development.

2.4 Biomass conversion

In 1995, the research on biomass conversion has concentrated on upgrading by-products of the pulp industry and conversion of solid biomass into liquid fuel through flash pyrolysis. Characteristics,

combustion properties and basics for use of pyrolysis oil in diesel engines are examples of data produced by research in this area.

Research into tall soap conversion has shown that it is possible to produce low-cost fuel oil.

Research on flash pyrolysis has been continued by determining the characteristics of the fuel, particularly for use in the diesel fuel and light fuel oil classes. Flash pyrolysis means fuel decomposition in an oxygen-free environment very rapidly, in less than a second. This method is very well suited to biofuels. According to a study by Neste Oy, the use of flash pyrolysis oil as a substitute for light fuel oil is most feasible when pyrolysis oil is mixed with light fuel oil, but even then the burners need to be modified. Research on the production and use of flash pyrolysis oil has been continued by acquiring three laboratory-scale testing apparatuses. The goal is to develop the 'ITP concept' of the Technical Research Centre of Finland (VTT) to the demonstration stage in the next few years. Tests on a 1.5 MW power station engine were begun in early 1996 with 60 tonnes of imported wood pyrolysis oil. The test results were promising, and development work on a stationary power station engine for pyrolysis oil will be continued.

2.5 Production of agrobiomass

The bioenergy research programme has not included a separate area for agrobioenergy, although one was planned. However, several projects in this area were started, mainly financed by the Ministry of Agriculture and Forestry. As part of the bioenergy research programme, they were also funded through Tekes. The level of financing has been increasing slightly. About FIM 3 million of public money altogether was used for the major research institution projects. At the moment, agrobiomass projects are research-oriented. New data have been gained on the properties of reed canary grass, and on the diesel oil properties and fractionation of rapeseed.

Major projects in 1995 were:

- Demonstration of rapeseed and reed canary grass cultivation for processing into fuel oil, paper fibre and flash pyrolysis oil at existing pressing mills as an extensive non-food production line;
- Cultivation experiment for energy plants on peatlands and application of the bioenergy produced to various ends;
- Production of biomass in agricultural land and peatlands and its use for energy production;
- Developing separation and sorting technologies for various parts of crop plants;
- Upgraded fuel from reed canary grass (international project in the EU-FAIR programme).

These projects were widely supported by the agrofibre project financed by the Ministry of Agriculture and Forestry examining the suitability of agrofibres, particularly reed canary grass, for pulp and paper production. The Ministry financed the project with about FIM 3.6 million in 1995. The final reports of the project were published in May 1996.

All projects mentioned are still unfinished.

The research carried out has largely covered the total chain of agroenergy production from raw material production to end-use in the boilers of district heating plants or private homes or as diesel fuel.

2.6 Dissemination of information, PR and international contacts

The research programme has organised an annual seminar, with over 200 participants at each. In 1995, a seminar was organised for the wood processing industry together with the SUSTAINABLE PAPER, LIEKKI 2 and SIHTI 2 programmes. About 130 energy and forestry professionals from the wood processing industry participated in the seminar.

The three-volume yearbook of the research programme, and state-of-the-art and preliminary reports on integrated wood fuel methods were published in the research programme publication series in 1995. Furthermore, results from the research projects have been published in the publication series of the Finnish Forest Research Institute (METLA), Work Efficiency Association, VTT and Metsäteho.

Two to three issues of the research programme newsletter have been published each year. This newsletter contains practical information on project results and reports published. The newsletter has had a circulation of 1000 copies. The results of the research programme have been presented at several exhibitions and conferences: at the Forest Week of the Finnish Forestry Association in March; at the international forest conference of the IUFRO in Tampere and the 2nd American Biomass Conference in August; and at the wood and forest fair in Jyväskylä in September. Nearly 10,000 copies of bulletins with information on project results were distributed during 1995. The machines developed in five projects were also demonstrated at the forest machinery exhibition at the wood and forest fair.

Publicity has followed the publicity plan drafted in 1994, providing for a variety of means: seminars, bulletins, exhibitions and continuous contact with trade journals. The director of the research programme has also kept the managers of interest groups informed. To present tangible results achieved in the programme, a seminar was organized in Otaniemi on November 30, 1996 demonstrating these results for the media and for experts in the field. The results of several wood projects were also presented at seminars in the ALTENER programme, particularly those of the Central Finland Forest Energy project. VTT Energy has published information on the BIOENERGY research programme and its results through the European Energy Network (EnR) and AFB-NETT projects in the ALTENER programme.

Finland has participated in IEA work through the Bioenergy Agreement, originally a forest energy research programme. The IEA focuses on information dissemination and does not finance research. The programme has been linked in joint research projects concerning integrated production methods and separate firewood harvesting, with an official representative of the Finnish Forest Research Institute (METLA) participating in the work. The BIOENERGY research programme has contributed towards the costs of maintaining this contact.

The programme management group presented the programme and its results to the EU in March 1995. During 1996, the first EU projects in the programme were launched.

The research programme has a WWW site with comprehensive coverage of the programme in both Finnish and English. A special feature is the Intranet feature through which project personnel can report their progress to co-ordinating personnel and programme management.

The programme home page presents the main points of the programme in summary, with information on contacts, main research areas and organization. The presentation page contains more detailed information on the main research areas, budgeting and programme content. The site also contains project lists, publication lists with available publications and reports, a bulletin board and links to partners. The programme newsletters are also available in electronic form. The research programme also has Intranet pages that are used for progress and finance reporting within the programme.

3 Result effectiveness

3.1 Industrial effectiveness

When the programme was launched, the amount of interest displayed and financing provided by industry for programme projects was a pleasant surprise for the management group. Apparently there was a need for this sort of programme. There were existing ideas and even demonstration projects just waiting for money. Interest has remained high even though the market situation, particularly for companies manufacturing forest machines, has improved considerably.

However, the forest industry and to some extent energy companies did show a certain scepticism towards the objectives of the programme. This was evident in that they were slow to warm to the programme. The situation has improved, though, and faith in the potential of wood as a major-scale affordable fuel has increased.

The benefit of the programme to companies is particularly clear in the company projects managed by SMEs. These companies have brought their most important development projects into the programmes. Since their own product development

cannot reach critical mass, so to speak, the programme framework provides considerable added value to the companies through research institution expertise and networking. These companies emphasise the benefits of the programme and consider projects in the programme extremely important for their business.

Over 30 companies participated in the programme in 1995. In 1995, eleven company and demo projects were implemented in SMEs in the wood fuel area. Several SMEs also participated as co-financiers in research institution projects. Co-operation involving SMEs was also practised mainly in Work Efficiency Association projects. Two SMEs were involved in the bioenergy use area with their own projects, and several companies were involved in research projects in this area.

Since large companies have their own development organisation and other ways of linking with research institutions, they have not considered the projects and structure of the programme as important as SMEs do. However, they do consider them to be quite important.

A special feature in the BIOENERGY research programme is the participation of a completely new group, contractors. The innovative input of contractors particularly in wood fuel production is significant.

The BIOENERGY research programme contained a total of nineteen company projects and fifteen demo projects in 1995; this means that the commercialization of research results is proceeding as planned.

The objective of the peat production research area is to achieve a 20% reduction in production costs. In the light of present results, this objective can be achieved if the sub-objectives are achieved. With the present rate of production, a reduction of 20% in production costs would mean a saving of FIM 57 million per annum. Several production models of machinery and equipment developed in the programme have been built, and they have been in production use. The employment effect of peat production for energy in 1994 was about 3000 man-years.

If the research programme objectives are achieved, the first three years having proved that this is possible, the objective for biofuel competitiveness will also be achieved. Competitive biofuels can then achieve the objective set by the Council of State for their increased use. Domestic biofuels will be able to partially replace imports.

The volume of 1 million toe in wood fuel corresponds to FIM 165 million in terms of the situation in Finland in 1992. In the fuel production business, 1 million toe would amount to FIM 500 million per annum. If all of this capacity were produced by the terrain chipping method, for example, this would create a FIM 440 million market for chippers.

The first commercial installation developed using the MASSAHAKE method and the company running it, Pohjois-Satakunnan Massahake Oy, are examples of a completely new kind of business. Biowatti Oy has expanded considerably and is now applying several devices and methods developed in the programme. Vapo Oy has started wood fuel production, with a production volume of 0.5 million loose m^3 in 1995.

3.2 Technological improvements

Table 3 shows the technological improvements achieved in each area. The results have also been grouped as 'knowledge', 'technology', 'small equipment' and 'methods'. The progress of each project (development, demo, commercial) has also been shown. Otherwise, the technological results have been presented above in section 2.3.

3.3 Implementation of networking

The programme has promoted networking between research clusters and between these and industry. The management group considers it particularly significant that it has proved possible to harmonise the rather different research practices of the re-

Table 3. Technological improvements.

Wood fuel production		
Knowledge	Technology	Small equipment
– final cutting work methods – early thinning pine and spruce: biomass balance, properties – basics of chain delimbing and debarking – basics of compression – chip separation properties – pneumatic transfer – small-scale production cost calculation model, basics/development – chopped firewood measurement and quality, basics – heat generation entrepreneurship, work methods, basics/demo	– plot chipper (Chipset), commercial – multi-function chipper lorry (Moha), demo – integrated energy wood production (Hooli), demo – mobile chipper (Lahti), demo – chipper, development – bundling technology, development – multi-tree handling, demo – combine harvester-forwarder, demonstration – harvester branch guide, development – wood fuel guidance system, commercial	– cage conveyor systemcommercial – wood chip and firewood system based on farmer tractor, commercial – production systems based on chopped firewood processing and harvester, development – firewood distribution and marketing systems, commercial
Peat production		
Knowledge	Technology	Methods
– drying – new materials – underground drainage – using wood chips to cover peat stockpiles	– light machine chain: plastic miller – loader – collecting wagon – scraper-ridger	– Tarkkaturve, demo – Teho method, commercial – sod peat method, demonstration – Compeat method, development – wood chip stockpile covering
Bioenergy use		
Knowledge	Technology	Methods
– basics of drying – drying model – basics of fireplace combustion – catalytic purification	– feeder (IVO), ready for demo – feeder (FW), ready for demo – dryer (IVO), demo – dryer (FW), ready for demo – burner, demo	– wood chip entrepreneurship, commercial – superpulp, ready for demo
Biomass conversion		
Knowledge	Technology	Methods
– properties of pyrolysis oil – combustion properties of pyrolysis oil – basics of using pyrolysis oil as a diesel substitute		– ITP method development
Agroenergy		
Knowledge	Technology	Methods
– properties of reed canary grass – diesel properties of rapeseed – fractionation		– growing and harvesting reed canary grass, demonstration

search institutes of Tekes, the MTI and the MAF. Teething troubles in this area have shown that co-operation is by no means self-evident. In particular, networking has been increased between research institutions and SMEs practising wood harvesting. Centres of excellence have also been strengthened in the course of the programme.

Small and large companies have also become networked through the programme. One example of this phenomenon is the company network that has evolved around the chain delimbing technology: a large company using the fuel has networked a number of research institutions and smaller companies that produce the fuel and manufacture and develop equipment.

Examples of programme networks:

- Financing network; Tekes + the Ministry of Trade and Industry and the Ministry of Agriculture and Forestry
- Wood fuel research co-operation; Finnish Forestry Research Institute (METLA) + Metsäteho Oy + Technical Research Centre of Finland (VTT) + Work Efficiency Association
- Chain delimbing cluster around Enso Oy
- Oulu region agroenergy network; Vapo Oy + Chempolis Oy + University of Oulu + MTT
- Central Finland Forest Energy project as a local network involving the user
- Sector-specific co-operation in the peat industry: industry now participating in research institution projects instead of carrying out separate projects
- Work Efficiency Association network: research institution + several small equipment manufacturers

3.4 Implementing scientist training

Various groups within the programme have trained themselves for object-oriented practical development work meeting the technological challenges involved. The tangible quantitative objectives of the programme and the projects in particular have guided research.

The programme has generated one doctoral dissertation and several diploma theses, pro gradu theses and special projects.

4 Essential results of the intermediate assessment

The objectives of the programme were designed to be tangible and measurable from the start. The programme has done well in achieving the content objectives originally set. The strict, measurable and in part financial objectives set have helped the programme management group to concentrate development work on those points of the production chain or those areas of technology that contain the best potential for achieving the set objectives. It can safely be assumed that a device or innovation addressing a critical point in the chain has immediate market potential as a finished product.

The Ministry of Trade and Industry lists the price of wood chips at FIM 58 per KWh (MTI Energy Review 3/1996), which is clearly less than earlier. Also, the management group has become convinced that the on-site price of biomass fuel from logging residue in final cuttings could even fall below the programme objective of FIM 45 per KWh under favourable conditions.

The general vision of the potential of wood fuel has become more precise in the course of the programme. Several both commercial and experimental integrated wood production chains have been launched within and with the support of the programme. Equipment has also been developed for harvesting other types of wood biomass. The three-year duration of the programme is too short for the development and extensive commercialisation of new technology. We may expect that some, but certainly not all, of the production chains now at the demonstration stage will come into general use in wood harvesting in the next few years. Also, some technologies now in the early stages of development will proceed to the demonstration stage.

In peat production, the programme makes use of the results of earlier research programmes. This has helped greatly in the identification of essential potential for improvement on which to concentrate

effort. Clear and tangible results that improve the competitiveness of peat energy have been achieved through the centralisation of large-scale peat production and the research that goes into it, and the small number of companies practising it.

In use technology, progress has been made in management of emissions from small boilers, and power station fuel handling and drying technology. Several technologies have been brought to the demonstration stage. New technologies for small power stations have been developed. The pyrolysis diesel technology for instance is moving into the demonstration stage. Development in this area is not as important to wood or peat use volume increase as harvesting research is. On the other hand, it is more significant in reducing the environmental impact of use and to exports.

In conversion technology, the focus has been on long-term technology, while also on conveying to decision-makers a realistic image of the feasibility of conversion designs planned for Finland for reasons of energy policy, agricultural policy or regional policy.

The most important positive environmental impact in wood energy production is the reduction of CO_2 emissions when wood is used to replace fossil fuels. With peat, several development ventures have contributed towards reducing the load on the environment. In use technology, the use of a small boiler catalyst for instance can reduce CO and NO_x emissions from heating, while a bed-mixing dryer can conserve fuel use and thus emissions in district heating by over 15%.

The various areas of this research programme have unequal status with regard to technology export. Wood production technology and the equipment being developed for it can be exported as it is, mainly to the northern coniferous zone. Broader exports are possible, although systems will need to be tailored to local conditions. Relatively small companies are involved in the programme in this area; from their point of view, the main aim is to cover the near market in the short term.

Peat technology development does not have much export potential even though equipment is being exported. The benefit of peat technology development in foreign trade manifests itself in the maintenance and promotion of competitiveness in replacing imports. This also applies to wood energy. With peat, the import savings amount to FIM 0.5 billion per annum; with wood, the figure is about FIM 1 billion.

The bioenergy use and refinement areas are more obviously relevant to the export market. These areas have also developed technologies that support the export of existing technologies, such as the method for reducing emissions from small boilers; this technology is a requirement for exports in this field. The export of bioenergy use technology is supported by electricity prices higher than those in Finland in certain markets such as Western Europe.

The programme has been well managed by the co-ordinating staff. The co-ordination is particularly demanding because the programme is being financed by two sectors of Government administration, the MTI and the MAF.

The programme has been well publicised. Information distribution will be increasingly aimed at bioenergy users.

5 Further planning on the basis of intermediate assessment

5.1 Feasibility of the research areas

The objective, content and foci of the programme correspond well to the needs of Finnish trade and industry and society. They also serve the aims of Finnish energy policy such as environmentally sound energy production, safety and diversity. The basics on which the programme was founded still exist.

Peat and wood use for energy has increased throughout the duration of the programme. With peat, this is at least in part due to the high level of competitiveness achieved through research, while with wood the cause is the high rate of production

in the forest industry and, more generally, of the positive image that wood has as a domestic, environment-friendly fuel.

The market situation for the forest industry has changed during the programme period. This and the forest conservation debate have upstaged the discussion on logging savings. The foci selected at the start of the programme, integrated production methods for pulpwood and wood fuel, have proved correct choices even for this new situation. Integrated methods enable utilisation for energy of the portion of harvested wood that is not suitable for pulping; besides, these methods also increase the volume of pulpwood produced.

The emphasis on wood and peat production development has caused some discussion in the management group. This is due to the fact that promoting bioenergy use is being justified by a variety of criteria, and these criteria have not been sufficiently discussed within the management group. Also, wood and peat are competitive as fuels in local markets. A clear and apparently continuing trend in the programme is that peat projects have gradually become company projects.

The programme focuses on applications and product development. This approach should be maintained, although research must not be forgotten. New ideas should be taken up in the future too, although these must support the main objectives of the programme.

New research projects in agrobiomass have been launched. However, this is seen more as an issue of agricultural policy and regional policy than energy policy. The justifications for this work are in fact based on the first two policies mentioned, with funding provided by the MAF.

It is not advisable to introduce new main research areas into the programme at this point. However, the management group did propose that the following points could do with some attention:

- Development project supporting small-scale peat production, aimed at helping small producers of peat (BIOENERGIA, project started in 1996);
- Project examining emissions from small boilers and ovens, to improve export potential for small boilers and ovens (BIOENERGIA, RAKET or separate project; Tekes Panos-poltto programme launched in 1996);
- Multifuel and fuel mixture handling project (BIOENERGIA or separate project; separate multifuel and fuel mixture project launched in 1996)

5.2 National and international division of duties

If a separate research programme is set up for the raw material use of wood from thinnings, the BIOENERGIA programme and the new programme must be co-ordinated. (HARJU programme launched in 1996.) The programmes can be mutually beneficial. In other respects, the division of duties between BIOENERGY and other research programmes is clear.

Bioenergy is an important component in EU research programmes. However, the role of peat in EU programmes is practically non-existent. The role of wood in harvesting technology is minor, but field cultivation is a major application. Considering the effect of local conditions on the technology needed, we can observe that the EU programmes provide a major opportunity for obtaining outside funding in addition to national funding in field cultivation; in other areas, EU funding can be little more than supplementary.

6 Research organization and management groups

The research programme management group is company-driven. The management group has included representatives from the funding bodies (Tekes, MTI and MAF), industry and research institutes. The industry representation is significant.

The management group makes proposals on research institute projects annually within the framework defined by the funding bodies. Thus, industry also guides research. The funding decisions for company-driven development and demonstration projects have been made at Tekes and at the energy department of the MTI, and the management group

has assessed the suitability of project subjects to the foci of the programme.

At the end of 1994, the funding for research and development in the energy programmes was transferred to the Tekes energy technology line, while investment subsidies for new technology demos are still provided by the MTI energy department. The programme includes small-scale demo investments and particularly follow-up of demonstration projects.

Since the beginning of 1996, the research programme has been co-ordinated by Jyväskylä Science Park Ltd. The responsible director is Prof. Dan Asplund, with Pirjo Nikku in charge of co-ordination and publicity. Previously, co-ordination was the responsibility of VTT Energy.

The chairman of the management group for 1993-1996 is Martti Äijälä, Head of Technology at Imatran Voima Oy; the members are

- Matti Heikurainen, Senior Inspector, Ministry of Agriculture and Forestry
- Heikki Karppimaa, Head of Development, Turveruukki Oy
- Kari Kuvaja, Forest Manager, Enso Oy
- Pekka Laurila, Managing Director, Biowatti Oy
- Ilpo Mattila, Head of Division, Central Union of Agricultural Producers and Forest Owners (MTK)
- Keijo Mutanen, Deputy Managing Director, Sermet Oy
- Pekka Nevalainen, Managing Director, Outokummun Metalli Oy
- Jukka-Pekka Nieminen, M.Sc. (Tech), Neste Oy
- Timo Nyrönen, Head of Research, Vapo Oy
- Seppo Paananen, Head of Design, UPM-Kymmene Metsä
- Tarja-Liisa Perttala, Senior Technical Advisor, Tekes
- Tuomo Ruohola, Head of Technology, Kvaerner Pulping Oy

The Tekes contact is Tarja-Liisa Perttala, the Ministry of Agriculture and Forestry contact is Matti Heikurainen, and the Ministry of Trade and Industry contact is Senior Inspector Aimo Aalto.

The research programme has four supervision groups by research area:

- Wood fuel production, chairman: Antti Korpilahti, Metsäteho Oy
- Peat production, chairman: Arvo Leinonen, VTT Energy
- Bioenergy use, chairman: Satu Helynen, VTT Energy
- Biomass conversion, chairman: Kai Sipilä, VTT Energy

Chapter 3
EDISON
– Electricity distribution automation research programme

Matti Lehtonen
Technical Research Centre of Finland VTT

1 Background and objectives

The objective of the EDISON research programme is to develop a comprehensive next-generation electricity distribution automation system including a control room with support functions, links with other information systems in the power company and functions related to grid management and demand management.

The system is being developed using the latest information processing and data transfer technologies. The automation system is being developed for use in Finnish power companies, though with a view to export potential. The aim is to have the system ready for demonstration when the programme ends in 1997.

It is to be expected that a technical and economic breakthrough in the area will be made by the end of the decade, with a powerful increase in the market for electricity industry products related to electricity distribution automation.

Sales of Finnish electricity distribution automation products in 1994 totalled over FIM 400 million. This includes the turnover of ABB and Enermet Oy. Sales of all Finnish power distribution station products exceeded FIM 1000 million. Exports account for between 60% and 90% of the total electricity distribution automation technology produced.

It is important for users to obtain electricity that is as affordable as possible and of sufficiently high quality. At the moment, power failures interrupt electricity distribution for one to three hours annually. The economic impact of these power failures is significant on the level of the national economy, being estimated at about FIM 100 to 300 million. Extra costs are also caused by other quality factors, such as power fluctuations and surges.

The research programme has been financed by Tekes, the Development Pool for Electric Power Technology, the Finnish Electricity Association SENER and ABB Transmit Oy. Several small and medium-size production companies and power companies have also been involved, mainly through work input and field measurements. The research programme has been coordinated and managed by VTT Energy.

2 Results in major research areas

In the first four years, the main research areas of the EDISON programme have been

- creating the basic concept of electricity distribution automation
- new communication technologies
- use and management of the power grid
- demand side management (DSM)
- managing the quality of electricity
- deregulation of the electricity market

2.1 The basic concept of electricity distribution automation

The new basic concept for electricity distribution automation includes a comprehensive system, its control room design and the necessary information systems. The basic concept was defined during the

first two years of the programme and discussed extensively in a report in 1995.

In connection with this work, profitability calculations on electricity distribution automation were performed for five power companies, using a tailor-made software package. This software has been subsequently distributed to interested parties. A version for commercialization has been developed by Tietosavo Oy.

2.2 New communication technologies

New communication technologies are one component of the development work on the system. This area focuses on establishing the available communication alternatives and selecting the protocols used. New solutions are being developed in co-operation with the Finnish telecommunications industry and telecommunications companies.

Data transfer solutions have been surveyed and developed for the needs of network automation and the electricity market, which is being deregulated. Four telecommunications technologies are being tested at the moment: Autonet/Actionet, packet radio in network automation, and NMT and GSM in remote meter reading.

2.3 Use and management of the network

The programme is developing new methods for solving problem situations in the power grid and for monitoring loads and network status. Automatic fault location and isolation is also being promoted through equipment development. IT tools for managing various problem situations are also being developed for the control room. The monitoring of network loads is being implemented particularly at distribution transformers, whose utilization rate is being raised closer to the economic break-even point.

ABB and VTT have co-developed a fault location function for grid use and maintenance; this function is being used in the ABB remote control system. The Versoft Oy distribution management system (DSM) has been developed in a joint research programme between Lappeenranta University of Technology, Tampere University of Technology and a utility called Koillis-Satakunnan Sähkö Oy. The new systems have significantly reduced the length of power failures experienced by consumers.

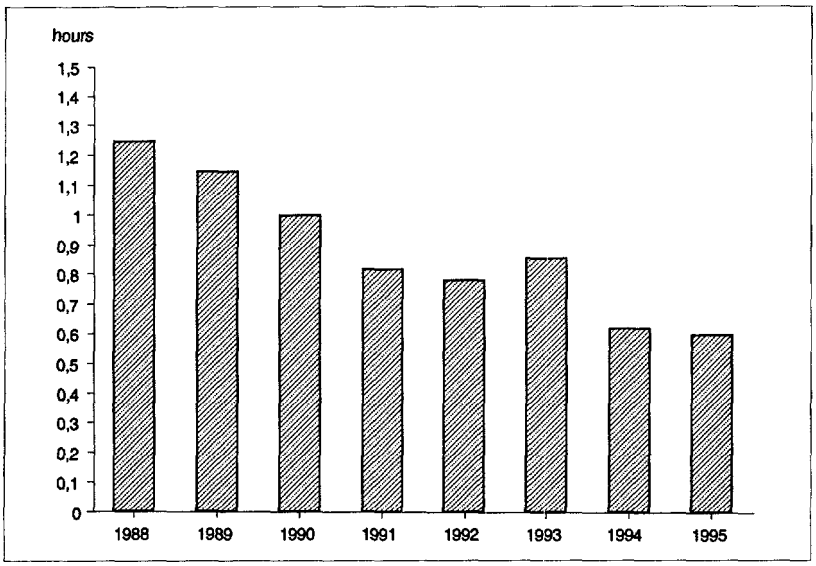

Figure 1. Network automation and the distribution management system have reduced the length of power outages (Koillis-Satakunnan Sähkö Oy and Versoft Oy).

2.4 Demand side management

Power company planning methods and technologies for data transfer between the power company's and the consumer's information systems are being developed for demand management purposes. Information on how power companies can control and manipulate demand is being obtained through practical test arrangements and demonstrations.

The EDISON programme has developed a prototype demand management planning system in cooperation with Tietosavo Oy.

2.5 Managing the quality of electricity

The quality of electricity is described in terms of voltage level, harmonic distortion, rapid voltage changes, flicker and voltage interruptions. The programme aims to improve power quality management by developing technical tools, investigating the technical and economic impact of quality, and establishing a quality level that is technically and economically optimal. The evolution of international quality standards is also being followed, and contributions made to their content as necessary.

The EDISON programme has developed a quality watchdog energy meter for power quality monitoring, in cooperation with Mittrix Oy and Enersoft Oy. This meter can continuously monitor the properties of the distribution power.

2.6 Deregulation of the electricity market

The programme is investigating the effects of electricity market deregulation on power companies. Work is also in progress on the data transfer and measurement technology required in the competitive situation, and on information systems support-

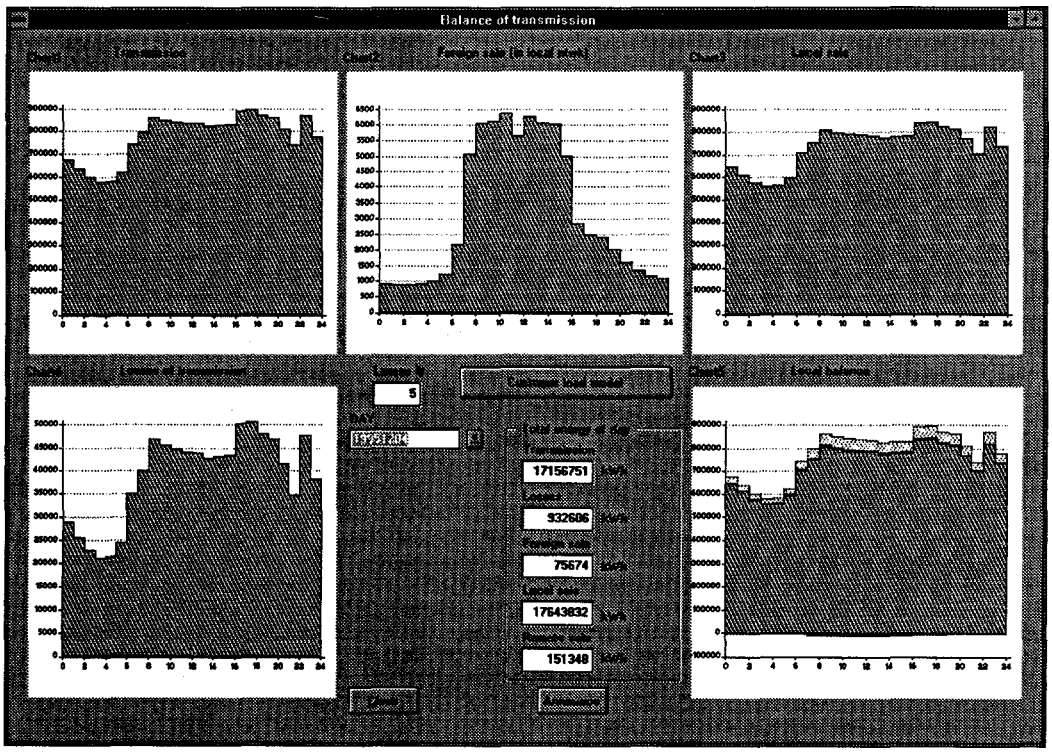

Figure 2. Example of the balance display of the distribution energy management (DEM) system (VTT Energy and ABB Transmit Oy).

ing energy acquisition and electricity sales planning.

Development of an energy management system for the distribution network has become a major project. This system meets the data processing needs of network companies and power companies on the free electricity market. The first prototype version has been tested at Espoon Sähkö Oy since late 1995. The decision has been taken to commercialize the system in cooperation with ABB during 1996 and 1997.

3 Effectiveness of results

The results of the EDISON programme will be used primarily as new products and design methods by power companies and the electricity industry. Their effectiveness will be ensured by taking prototypes and demonstrations into actual power system environments. Close cooperation between the parties involved ensures that the results will be used in further training and education.

The results of the programme will make power companies more effective. This will be seen in demand management and as an increase in network utilization. Thus, the costs of power distribution can be kept under control and the price of electricity will remain competitive. The quality of power distributed to consumers can be raised if it is economically feasible. The power system will become more effective, and there will be more potential for energy conservation. The technical competitiveness of the electricity industry will improve.

The practical results of the programme support the technical competitiveness of remote control and monitoring systems, for instance, and create potential for new markets. This is important in electricity distribution automation particularly, since it is expected that a technical and economic breakthrough will occur in this area by the end of the decade, causing strong growth in the market for related electricity industry products, e.g. power generation, IT and telecommunications applications.

SMEs and software companies can share in exports by cooperating with large companies. For instance, SMEs are major contributors in the manufacture and partial assembly of electronics components for ABB electricity distribution automation products, software development and the manufacture of geographical information systems.

The programme arranges annual seminars covering the entire programme and workshops covering individual areas within it. As a rule, the research results are public information, and they are published both in Finland and internationally.

The aim of international cooperation is to establish the level and content of the research and development being done elsewhere in order to make efficient use of it and to remain ahead of the competition. Furthermore, cooperation provides a better picture of the international market for which the programme is developing products. Intensive cooperation is impossible unless the Finnish parties have research and development work of their own.

This cooperation began at the start of the programme, via the Demand Side Management agreement projects of the International Energy Agency (IEA). The programme is participating in two IEA component projects on data transfer technologies and demand management planning method development.

Two EDISON projects have been approved for EU programmes, one in the JOULE programme (Method for integrated evaluation benefits, costs and effects of programmes for promoting energy conservation) and the other in the SAVE programme (Development and demonstration of strategies for promoting DSM, utility based IRP and energy efficiency services in the Finnish restructured energy market). EDISON scientists are responsible for coordination in the latter.

In international training in electricity distribution automation and demand management through the EU COMETT programme, lectures have been arranged and scientists in the programme sent to courses.

An efficient information exchange and cooperation network has been set up with major research and development organizations in the field. This network includes EPRI and the Lawrence-Berkeley

laboratory in North America, the CRIEPI and MITI laboratories in Japan and EA Technology in Europe.

International cooperation has also been actively sought at conferences. The EDISON programme is represented on the programme committee of the DA/DSM-Europe conference and the organizing committee of the Nordic electricity distribution automation conference (NORDAC). The most recent NORDAC conference was organized in Finland in June 1996, with the EDISON programme as host.

In researcher training, there has been active involvement in the power generation technology research school. The school, which currently has about 40 students, has been set up in cooperation between the Helsinki, Tampere and Lappeenranta Universities of Technology and VTT.

To date, the EDISON programme has produced six diploma theses, two licentiate theses and two doctoral dissertations.

4 Main results of the interim assessment

An interim assessment of the programme was carried out at the end of 1995 as a basis for orienting the programme during its last two years. The assessment was carried out by the research programme management group with the aid of four outside auditors:

- Ilmari Peltola, Managing Director, Hämeen Sähkö Oy
- Esa Pennanen, Managing Director, Enermet Oy
- Mikko Niinivaara, BA Manager, ABB BA Network Control & Protection
- Erkki Kemppainen, Division Manager, ABB Transmit Oy, MV Apparatus and Switchgear

The following is a brief summary of the interim assessment.

The original objective of EDISON was to develop and demonstrate a comprehensive electricity distribution automation concept in Finnish power companies, with a view to technology exports. The programme has proceeded well, being in fact ahead of schedule at the time of assessment.

The concept has been divided into areas of focus, which are broadly speaking network automation, information systems, energy management on the electricity market and demand management. The management group assessment and independent statements show that these are largely appropriate; however, more attention should be given to network automation and data transfer technologies. Cooperation with the telecommunications industry should be closer.

The EDISON programme is coordinated to combine the forces of all the major Finnish parties involved. Centres of competence have been created over a broad geographical area at several universities, research institutions and companies. The user parties, i.e. power companies, have provided active input.

International cooperation has been active and fruitful. Extensive international contacts and recognized status on the decision-making and executive bodies of conferences in the field testify to the high level of Finnish competence.

The EDISON programme is considered extremely important and well focused in power companies. Its results support technical competitiveness and promote exports from the point of view of the electrical manufacturing industry in Finland. This is particularly important now when the electricity distribution automation market is developing fast.

5 Further planning based on the interim assessment

The interim assessment shows that the EDISON programme is pursuing a policy that is largely appropriate. It has proceeded as planned and is even ahead of schedule.

During the programme, the need for technical development in the field has constantly increased, due to the restructuring of the electricity market, on the one hand, and the rapid development of telecom-

munications and data processing technology, on the other. However, it has not proved possible to expand the programme to meet the increased demand. Instead, resources have been concentrated on areas considered important in the interim assessment.

On the basis of the interim assessment, the EDISON programme has concentrated increasingly on telecommunications technology application development and the development of new technical solutions needed on the deregulated electricity market. It has been possible to shift the focus flexibly and quickly, primarily because the research programme plans ahead for one year at a time.

1997 is the last year of the EDISON programme, and will focus increasingly on the demonstration and commercialization of research results.

6 Research organization and Executive Committee

The EDISON programme has been implemented in cooperation between the electricity industry, research institutions, universities, and power and energy companies. This co-operation has been designed to utilize Finnish competence and experience as fully as possible in each problem area.

The main research parties are VTT Energy, Tampere University of Technology and Lappeenranta University of Technology. Research and development work is also being done at several companies, both large (ABB and Imatran Voima Oy) and small (Tietosavo Oy, Enermet Oy, Mittrix Oy, Tekla Oy and Versoft Oy).

The active involvement of power companies demonstrates user interest in electricity distribution automation. Ten distribution companies are involved in various projects, mainly in testing prototype systems and equipment. These companies are Espoon Sähkö Oy, Helsinki Energia, Hämeen Sähkö Oy, Koillis-Satakunnan Sähkö Oy, Pohjois-Karjalan Sähkö Oy, Savon Voima Oy, Tampere City Electric Company, Vaasan Sähkö Oy, Vantaan Sähkölaitos Oy and Vatajankosken Sähkö Oy.

Power companies have been used for expert input in defining functions and basic concepts as well as for testing and demonstrations of new technology. New technologies are also being introduced as product development projects in the electricity industry as far as possible, with special reference to their adaptability to Finnish conditions and the international market.

The projects in the sub-areas are being implemented on a one to three year basis, forming a research framework corresponding to the strategic objectives. Decisions to continue existing projects and to start new ones are taken annually by the research programme Executive Committee. This ensures efficient allocation of resources to the appropriate projects in a rapidly changing environment.

The progress of projects in the research programme is also monitored by four specialist groups consisting of experts in each of the relevant fields. The role of the monitoring groups is to support the research, give advice in problem situations, and liaise with interest groups such as users and industry.

The members of the EDISON programme Executive Committee are

- Esa Pekkola, Head of Development, ABB Corporate Research
- Kari Komulainen, Senior Technical Adviser, Tekes
- Otso Kuusisto, Head of Department, Finnish Electricity Association SENER
- Professor Seppo Kärkkäinen, VTT Energy
- Professor Erkki Lakervi, Tampere University of Technology
- Tauno Leppämäki, Managing Director, Pohjois-Karjalan Sähkö Oy
- Touko Salo, Head of Marketing, Enermet Oy

Research programme director Dr. Matti Lehtonen of VTT Energy has also participated in the work of the management group.

Chapter 4
FFUSION – Fusion energy research programme

Seppo Karttunen
Technical Research Centre of Finland VTT,
VTT Energy

1 Background and objectives

In 1993, the Ministry of Trade and Industry appointed a working group to plan a Finnish fusion research programme. At the same time, the Ministry of Trade and Industry and the Academy of Finland increased the resources allocated to fusion research. A survey of possible ways in which Finnish industry could participate in international fusion research was begun.

The national fusion energy research programme, FFUSION, was launched the following year; its management group was appointed on March 11, 1994. The research input in 1994 was nearly FIM 4 million and ten person-years. The programme just managed to reach a level where negotiations could begin on integrating the programme into the EU fusion programme.

Finland joined the European Union on January 1, 1995, and Tekes signed an association agreement with Euratom on March 13, 1995. This agreement linked the FFUSION programme to European research on fusion energy.

1.1 International fusion research and the EU fusion programme

The aim of international fusion energy research is clear: to achieve a commercially viable fusion reactor. Several fundamental scientific issues must be addressed to attain this objective, and an enormous amount of new technology required by such a reactor must be developed.

The EU is investing about 840 million ECU in fusion research in its fourth framework programme (1994-1998). The largest fusion research installation in the EU is the Joint European Torus (JET) tokamak, which is in Britain. Operation of the JET installation has been agreed on up to the end of 1999. A significant proportion of European fusion research is done in national laboratories that have signed association agreements with the Community programme.

The EU is also financing research into fusion installations alternative to the tokamak. A Wendelstein VII-X stellarator is to be built in Greifswald at a cost of over FIM 1000 million, and will be completed in 2004. There are also a number of medium-size plasma devices and several extensive independent fusion technology research projects in Europe, involving fusion reactor materials, tritium handling, remote maintenance equipment and large superconductor magnets.

The main global research project is the design of the tokamak test reactor ITER (International Thermonuclear Experimental Reactor). The participants are Euratom, Japan, Russia and the United States. The ITER design costs are over FIM 5 billion, and the construction costs are estimated at about FIM 35 billion. The decision on whether to build the ITER test reactor will probably be taken in 1998 or 1999.

1.2 Fusion energy research programme FFUSION

The FFUSION research programme derives from Finland's research policy decision to participate in long-term extensive international fusion research, with particular reference to the coordinated fusion research programme of the EU.

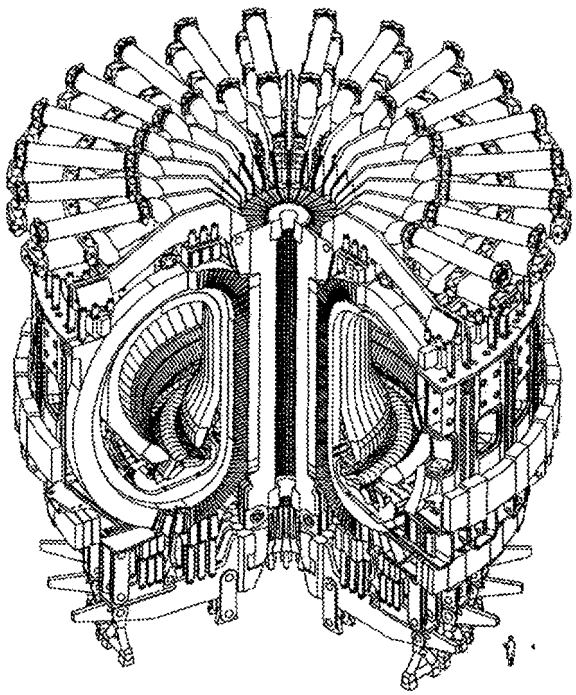

Figure 1. Diagram of the ITER test fusion reactor.

As a participant in the EU programme, Finland is also involved in the global ITER test reactor project. Because of the enormous long-term benefit potential of fusion energy, all industrialized countries are helping with its development. In the short term, fusion research may produce scientific and technological spin-offs, and major experimental reactor projects provide significant export potential for Finland's high-tech industry. While fusion research is an import-based field in Finland, it could conceivably generate exports in certain specific sectors.

The FFUSION programme is divided into three areas:

- fusion plasma research
- fusion reactor materials research
- remote maintenance systems for fusion reactors

Fusion plasma research focuses on the interaction between intensive electromagnetic radiation and plasma, with plasma heating and diagnostics as applications. The work has close links with European experimental work in fusion and plasma physics and with ITER design.

Materials research is a key area in fusion reactor studies. Special materials, superconductors, surface materials and joint technologies are strong areas where the objective is to find joint ventures between industry and research institutions for participation in the ITER project. Industrial applications are also relevant in remote handling and in maintenance and inspection systems for fusion reactors.

1.3 Objectives of the FFUSION research programme

The main objective of the early stages of the FFUSION programme was to bring Finland's fusion research up to European standards. This objective has been attained with excellent success. The association agreement between Euratom and Tekes, the NET/ITER agreement and the Staff Mobility agreement were signed just over two months after Finland joined the EU. Finnish membership of the European JET project was ratified in spring 1996.

Another major objective was to expand the research base to make it more technology-oriented and to increase Finnish industry's interest in the field. Finnish industry is now commendably active in the work on ITER.

Once the FFUSION programme got under way in 1994, the following were identified as main objectives:

- to carry out high-quality basic research in the field and fusion technology development as part of the EU fusion research programme and the international ITER project;
- to promote cooperation between Finnish industry and research institutions in development and planning work related to ITER;
- to focus research and development activities on a few competitive areas.

2 Results in major research areas

2.1 Fusion plasma research

Fusion plasma research is being done by the Department of Technical Physics at the Helsinki University of Technology and at VTT Energy. The fusion and plasma physics research comprises the scientific content of the FFUSION programme, aiming at providing high-quality Finnish input in the EU fusion programme.

The contract of association defines Finland's area of focus as the radio frequency (RF) applications of tokamak plasma, the main points being heating plasma to fusion conditions (temperature range $1\text{-}2*10^8$ K), non-inductive current drive and plasma diagnostics. The theoretical and computational research covers all RF bands used, 20-60 MHz (ion cyclotron waves), 1-10 GHz (low hybrid waves) and 100-200 GHz (electron cyclotron waves), all of which are in use in European fusion installations. Non-inductive current drive with RF waves is an important issue in the European programme, since it would enable steady-state operation of tokamak reactors.

Most of the fusion plasma work in the FFUSION programme is being done in cooperation with the European experiments. These include the Euratom JET tokamak, the German ASDEX Upgrade tokamak and the Wendelstein VII-AS stellarator, and the French superconducting tokamak Tore Supra. Finns are participating in analysis of experimental results and in constructing mathematical models of the experiments. Finns have also been involved in radio frequency heating work in ITER, and an ITER Task involving the ion cyclotron system is under way. An important part of the work involves, developing and applying demanding numerical codes. Industry has only taken part in fusion plasma research related to radio frequency sources; Imatran Voima Oy (IVO) is participating in the ITER ion cyclotron system design work with the Technical Research Centre of Finland (VTT) and the Helsinki University of Technology (HUT).

An extended visit to the JET installation, intended to produce a doctoral thesis, began in summer 1995. The visit is related to a JET Task agreement on the interaction of energetic ions and RF waves. A similar visit to the Max Planck Institute (IPP) in Garching is being planned for 1996, concentrating on the diagnostics of density profiles on the Wendelstein VII-AS stellarator.

Main results of fusion plasma research

Several demanding software applications based on advanced numeric methods have been developed in the FFUSION programme for fusion plasma radio frequency applications. Most of this work has been done jointly by VTT Energy and the Department of Engineering Physics and Mathematics at Helsinki University of Technology. There are several foreign partners, and the codes have been used to analyse experimental results.

FEM (Finite Element Method) codes: Absorption and mode conversion issues in the ion cyclotron area have been analysed with the FEM code. This code can solve full wave equations and is also useful in cases where the plasma has a steep density gradient, as in the edge plasma in a tokamak. The programme has been used in commissioned studies for the JET project, and its results have generated several international publications and a doctoral dissertation.

Monte Carlo simulations: ASCOT, a trajectory tracking program for electrons and ions in plasma, is a Monte Carlo type code suitable for examining several tokamak phenomena. ASCOT observes particle trajectories in a realistic tokamak geometry in which the background magnetic field can be selected to correspond to various tokamaks, such as JET or ASDEX. The code contains collision and RF operations that affect the particle trajectories and energy. The ASCOT code has been applied to several special tokamak issues, such as the losses caused by runaway electrons during current ramp-up, the interaction of fusion alpha particles with RF waves, the determination of current drive efficiency and current profiles and the orbit losses of fast ions. Development work on the ASCOT software is still in progress, and it will remain one of the basic tools of the fusion plasma group. Monte Carlo codes can be run in parallel computers, since the particle trajectories are calculated independently. Parallel processing is able to make calculations significantly more accurate, since increasing the number of particles results in better statistics.

PIC particle simulations: PIC (Particle-in-Cell) simulations can be described as numerical experiments in which the motion of particles and the fields moving them are calculated self-consistently. The motion of charged particles affects the fields in the plasma; this is contrary to Monte Carlo calculations, where the fields moving the particles are given as input values. The fundamental problem with PIC codes is the CPU time and large memory requirement. Parallel processing of PIC codes, which is not as straightforward as for Monte Carlo codes, is being worked on, and a considerable increase in computing power is expected. At the moment, one- and two-dimensional PIC codes are in use and these have been employed to examine electron acceleration mechanisms in the vicinity of plasma wave reflecting surfaces. As an application for Tore Supra tokamak, the generation of fast electrons at the mouth of the lower hybrid grill is being examined. This phenomenon would seem to explain the grill damage occurring in Tore Supra and tokamak de Varennes at high heating power levels. The work is being done in close cooperation with the RF group at Tore Supra. The subject is part of the ITER Task under development concerning current drive by lower hybrid waves.

Vlasov codes: The interaction of RF waves with electrons and ions in the plasma, and understanding this interaction, are essential in optimizing the heating and current drive potential of the various wave bands. At high heating power levels the interaction can become non-linear and lead to completely new phenomena. Analysis of these non-linear properties requires kinetic analysis and self-consistent solution of the Vlasov and Maxwell equations. This is a numerically difficult task, and solutions of realistic cases require a great deal of computing power. The advantage of the Vlasov method over PIC codes is the greater accuracy in processing the tail region of velocity distributions. Vlasov codes have been developed in the FFUSION programme in cooperation with the University of Nancy in France and the CCFM (Centre Canadien de Fusion Magnétique). Vlasov analysis has been applied to fast electron generation mechanisms for various wave spectra suitable for current drive. Fast electrons are of key importance for current drive since, being current carriers, they face low resistance, and the power needed to maintain the current is feasible. Vlasov codes have been supplemented with a collision term, which extends their application to collision phenomena.

Gyrotron research: Gyrotrons are microwave sources used for fusion plasma heating, current drive and diagnostics. This work has been carried out in cooperation with the Forschungszentrum Karlsruhe and the Department of Applied Physics in Nizhnyi Novgorod. Theoretical research on the gyrotron resonance cavity has led to several experimental improvements and innovations in high-power, frequency-tuneable sources. Industrial applications of gyrotrons in Finland have been surveyed. Diamond-coated gyrotron components have been supplied to foreign partners, and component properties have been measured. Previously, there was virtually no knowledge about gyrotron technology and applications in Finland.

Fusion burn studies: The 0D code FRESCO, where the plasma profiles are taken as known, has been developed for simulating fusion burn in a tokamak fusion reactor. FRESCO also exists for PC in a slightly simplified version. FRESCO can be used to make rapid surveys of the power transients related to powering up and shutting down a tokamak and to disruptions during burn. The code has been

used to examine fusion reactor controls - for instance, through fuel feeding speed and impurity injections - to search for optimum operational conditions and to establish stability criteria. Changes in the confinement modes of a tokamak have been simulated. FRESCO has also proved to be a useful tool for fusion burn studies in a tokamak reactor.

International publications on fusion and plasma physics produced in the FFUSION programme in 1993-1995:

- 35 cited articles in international serial publications
- 37 conference papers
- 11 international research reports
- 8 general articles
- 2 patents

One doctoral thesis, two licentiate theses and two diploma theses were completed between 1993 and 1995.

As far as fusion plasma research is concerned, the objective of providing a high-quality basic research contribution to the EU fusion programme has been extremely well achieved. In the selected areas of focus, Finnish fusion physics research is of top European level, allowing Finland rapid access to projects in the EU programme. Several scientist visits within the EU Staff Mobility programme are planned for 1996.

2.2 Fusion reactor materials research

Fusion reactor materials research is being carried out at VTT Manufacturing Technology and VTT Chemical Technology and by the Accelerator Laboratory of the University of Helsinki. Fusion neutronics research has been concentrated at VTT Energy. The industrial partner is the Finnish Blanket Group, which includes Outokumpu Poricopper Oy, Imatran Voima Oy, Rauma Materials Oy, Diarc Technology Oy, High Speed Tech Oy and PI Rauma Oy. Outokumpu Superconductors Oy has been responsible for superconductor development.

Materials research was launched with a preliminary study to survey Finnish competence and the needs of the EU fusion programme. As a result, the following subjects were identified for Finnish fusion materials research to concentrate on: superconductors, special copper materials, dissimilar metal joints, materials and joints testing and characterization, and coatings. Previous efforts have already brought work to a high level internationally in these essential materials technology areas, and there is also strong backing for them from Finnish industry.

Reactor materials and joining technologies

The objective of the fusion materials project is to apply fracture mechanics competence to estimate the radiation damage and damage caused by the environment to the materials in the first wall and blanket of a fusion reactor. The main objective is to integrate fusion materials research and development into the EU fusion energy research programme. Another objective is to work with Finnish companies to improve their competitiveness in the design of fusion reactor components and construction tenders.

Projects concerning Cu/SS joins and fracture mechanics studies on miniature test rods were launched in the EU fusion research programme in 1995, as part of the NET/ITER Technology task T212 and of the EU long-term fusion materials programme.

The first wall structures of the ITER fusion test reactor consist of multimetal structures made of beryllium, copper and stainless steel. Potential first wall element manufacturing methods include hot isostatic pressing (HIP) and explosive welding. The objective of the project is to demonstrate the usability of explosive welding and to characterise the mechanical properties of copper-steel joints. The usability of the technology will be demonstrated by manufacturing a first wall element using explosive welding and by determining its heat transfer properties and thermal fatigue durability. The thermal properties of the first wall element will be determined in cooperation with JRC-Ispra. The explosive welding joints were manufactured by High Speed Tech Oy, with Outokumpu Poricopper Oy delivering the copper alloy needed.

The project defined the tensile strength, shearing strength, fatigue strength, creep-rupture strength

and fracture toughness of explosive welded joints between AISI 316 LN ITER Grade stainless steel and CuCr1Zr copper alloy at different temperatures. The explosive welding joint was ductile, and the ductile fracture occurred in the copper; thus, the explosive welded joint was stronger than the copper alloy used in the joint. In long-term tests at high temperatures, fracture occurred along the joint surface.

Creep properties are expected to be a major design parameter in fusion reactor first wall structures. Creep could lead to a fracture along the joint surface. Heat transfer over the interface between copper and steel is an essential property for the usability of first wall structures, and breaking in this joint surface could lead to uncontrolled heating of the structure.

Outokumpu Poricopper Oy and High Speed Tech Oy have participated in this project. Outokumpu manufactures copper and copper products; the project supports this by using Outokumpu copper alloy in the research work. High Speed Tech Oy has competence in explosive welding; the research will make this method more widely known. The research results obtained in this project will improve the basic characterization of both companies' existing materials and products by generating new research results. There will be several potential applications for both companies in fusion reactor structure design and manufacturing, and this project will improve the companies' visibility, competitiveness and level of technological competence in future tenders.

National networking has been promoted through the founding of the Finnish Blanket Group. VTT Manufacturing Technology is cultivating cooperation with Risø National Laboratories in materials technology and with JRC-Ispra in the thermal fatigue of first wall elements.

An EU Long Term Materials project studying fracture mechanics on miniature test rods focused on what are known as low activation materials such as martensitic stainless steel, vanadium alloys and SiC/SiC composites. These are potential next-generation structural materials for fusion reactors. In particular, martensitic stainless steels are being developed in the fusion materials research programme. The objective of the present programme is to select the primary structural material of the next generation of fusion reactors by the year 1998.

Radiation levels from fusion materials are quite high, so in practice the amounts handled are small, and the test pieces needed for determining fracture toughness required by the standard cannot be manufactured from the materials examined. The qualitative assessment of materials fracture toughness is generally obtained through impact tests, but a reliable direct fracture toughness measurement method is needed to determine the quantitative design parameter. An analysis method developed by VTT Manufacturing Technology reliably determines fracture toughness on 10x10x55 mm^3 test rods, and the aim is to establish whether 3x4x27 mm^3 test rods can be used for direct measurement of fracture toughness.

Present test results on martensitic stainless steel show that the fracture toughness values obtained using 10x10x55 mm^3 test rods and 25 mm CT test rods are mutually compatible. On the other hand, the fracture toughness values obtained using small, 5x10x55 mm^3, 5x5x27 mm^3 and 3x4x27 mm^3 test rods diverge slightly from the above. This divergence may be due to inadequate measurement capacity in the test rods or possibly the poor homogeneity of the material examined.

The divergence in fracture toughness values obtained using different test rods is slight, so there is good potential for establishing the correlation between fracture toughness and the geometry of the test rod. Further experiments will determine which divergence, if any, is due to the poor homogeneity of the material examined. Furthermore, the effect of radiation on fracture toughness will be established. The irradiation will be performed by ECN Petten.

VTT Manufacturing Technology cooperates closely with ECN Petten in research. Also, VTT Manufacturing Technology has attended meetings of the Task Force Materials working group, which designs and coordinates fusion materials research.

Plasma-facing components

One component of the programme is examining the applicability of diamond-like coatings (DLC) in plasma facing components carried out under a

NET/ITER Task. The coatings are being manufactured by DIARC Technology Oy.

The objective of the project is to develop and characterize SiC/DLC coatings as part of the study on the erosion behaviour of fusion reactor first wall materials. The SiC/DLC coatings are manufactured using the DIARC arc discharge method. This method is being developed further for the manufacture of thick DLC/graphite coatings.

Results show that the DIARC arc discharge method can be used to manufacture layered and thick carbon coatings. The coatings have been thoroughly characterized, but use of the coatings in a fusion reactor must be based on tests conducted in fusion-relevant environments. It seems that the coating process can be used to simulate the redeposition process of carbon during fusion burn in the fusion reactor first wall, which will then allow the method to be used for the manufacture of various test samples.

For DIARC Technology Oy, the project has improved visibility and enabled basic research in product characterization. The properties of products are better known, and the fusion project has enabled further development of the DIARC coating process.

Ion irradiation of reactor materials

On the basis of the preliminary survey preceding the FFUSION programme and the research competence of the University of Helsinki Accelerator Laboratory, research has concentrated on trapping of hydrogen in helium precipitations in materials that are planned for use in fusion reactors.

The central objective of the project is to examine the physical grounds for phenomena caused by ion beams. The main focus is on hydrogen-trapping defects in various materials. The research is establishing the concentration relationships between trapped hydrogen and ion-planted helium, the properties of hydrogen-trapping defects and recovery of the background material from various types of defects.

The results are being used in materials research under the national fusion research programme. Their long-term benefit is that the competence gained in research in the Accelerator Laboratory will help improve the potential for Finnish research and industry to participate in the EU fusion programme.

Some of the studies on the recovery of hydrogen-containing inert gas defects and the results of the electronic braking of helium studied in 1995 have been published in international journals in the field.

Cooperation with VTT began in 1993 with a survey in cooperation with the metal laboratory, on ways of measuring light elements in Zr-based compounds. This work has been continued with VTT Chemical Technology in ERD and SIMS studies of copper alloys.

New equipment has also been constructed for the Accelerator Laboratory. A new ERDA measurement system based on the flying time method was constructed in 1994 and introduced in 1995. This enables the examination of more complicated implantation profiles than previously.

Fusion materials analysis with mass spectrometer methods

Materials selection is important in constructing a fusion reactor. Finnish materials research requires the necessary resources, such as materials characterization methods, to be available.

The necessary resources are being jointly developed and applied to the study of copper alloys and martensitic stainless steel in the joint VTT Manufacturing Technology, VTT Chemical Technology and University of Helsinki research project. One of the objectives is to develop mass spectrometer determination methods for metals and to apply these in determining the composition and structure of metals. Researchers are examining how metals can be used in fusion reactor applications and the effect of radiation on metal structure and properties. The objective is to carry out high-quality materials research to promote the use of Finnish materials in fusion applications.

In 1994-1995, mass spectrometer methods to determine trace elements using the ICP-MS method in copper samples from Outokumpu Poricopper, NBS standard reference copper samples and martensitic stainless steel were developed. The

concentrations of over 40 trace elements in steel and copper samples were established.

Surface analysis methods (SIMS, RBS and ESCA) have been used to examine the chemical composition of diamond-like coatings (DLC) unalloyed and alloyed with silicon, the distribution of various elements in the coatings and the bonding of carbon, in cooperation with the Universities of Turku and Helsinki. Also, the effect of the erosion caused by various heat treatments and ion bombardment on the structure of DLCs and the diffusion of deuterium have been studied.

Basic physical phenomena between fusion plasma and wall material have been studied in cooperation with the University of Helsinki. Damage caused by fusion plasma has been simulated by implanting deuterium and helium in F82 steel. The diffusion of these light elements and damage recovery during heat treatment have been examined using the SIMS and ERD methods.

Fusion neutronics

Capacity for neutron and gamma flow calculations for fusion reactors was established at VTT Energy in 1993-1995. Initially, the work was done using SN programs such as ANISN, contained in the REPVICS software created for pressure vessel radiation calculations in fission reactors.

The SN method, in which discrete directions for neutrons are selected, is not very useful in the extremely complicated geometries typical of fusion reactors. The Monte Carlo method would be better, and the MCNP program has become something of an international standard in the field. Because of this, project members acquired MCNP4A and trained themselves to use it.

The program is first being applied to assessing the neutron load on RF antennas, transmission lines and vacuum windows. An ITER Task on this subject and a scientist visit to the ITER design team in Garching are in progress.

By 1996, fusion neutronics calculation had reached a level of competence enabling full-scale participation in the ITER project and the performance of work for the ITER Joint Central Team in Garching.

Superconductor development

Superconductors used in the ITER machine and the Wendelstein 7X stellarator are perhaps Finland's largest potential market in the near future.

ITER uses both Nb3Sn and NbTi conductors, while the Wendelstein 7X uses only NbTi conductors. So far, Outokumpu Superconductors Oy has concentrated on producing a NbTi conductor. When Finland joined the EU fusion programme in 1995, the superconductor development programmes for both machines were so advanced that Finnish participation was not possible.

In order to keep Outokumpu Superconductors in the running as a potential superconductor supplier, a technology project related to ITER was prepared in 1995 and launched in 1996. This project is being carried out by Outokumpu Superconductors Oy.

The situation in the Wendelstein 7X project is very critical. The cable intended for the magnets in the machine could well be developed by Outokumpu Superconductors, but so far the work has been done by competitors. The final conductor and cable will probably be commissioned during 1997.

2.3 Remote-controlled inspection and maintenance systems for fusion reactors

Remote-controlled inspection and maintenance systems for the ITER test reactor have been studied at the Institute of Hydraulics and Automation and the Control Engineering Laboratory at Tampere University of Technology and at the Automation Technology Laboratory of Helsinki University of Technology.

VTT Automation and VTT Electronics joined the project in late 1995. The industrial partner is the Finnish Remote Handling Group, consisting of Imatran Voima Oy, Plustech Oy, Hytar Oy, Tehdasmallit Oy and PI Rauma Oy. Water hydraulics and walking technology are Finnish specialities.

Water hydraulics applications in Reactor maintenance for ITER

The objective of the project studying water hydraulics in the ITER fusion reactor was to study the applicability and potential of water hydraulics for Remote Handling (RH) equipment related to the ITER fusion reactor. The objective was to demonstrate the potential of water hydraulics, to find the pressure medium best suited to the environment and examine the demands and limitations placed on components by this pressure medium, and to help find suitable water hydraulics equipment. The systems being designed in the project are directly usable in the RH equipment testing environment (Diverter Region Test Platform) being constructed by ITER/NET.

The project resulted in establishment of the basic demands imposed by the environment, in cooperation with ITER/NET. The market status of components suitable for water hydraulics remote handling devices and ways of controlling various parameters in water hydraulics were also examined.

Appropriate partners in industry were located during the project, and substantial knowledge was obtained on the market and on the applicability of water hydraulics to a fusion reactor environment.

The overall objective of the project is to gain Finnish water hydraulics know-how an active role in the EU and to obtain projects and deliveries for Finnish research institutions and companies. In practice, the project was divided into three areas: surveying general demands, designing water hydraulics for the maintenance equipment testing environment, and preliminary planning of water hydraulics remote control tool systems.

The main object selected for study was water hydraulic equipment and systems, including a hydraulic unit, for the transport and handling of heavy divertor elements. Also, the controllability of water hydraulics was examined through simulation and measurements, and a water hydraulic servo system was constructed.

Activities in 1994 and 1995 created a foundation for a Finnish consortium of RH companies to respond to requests for tender concerning divertor test equipment. Water hydraulics technology has been established as the most feasible alternative for a number of Remote Handling applications in a

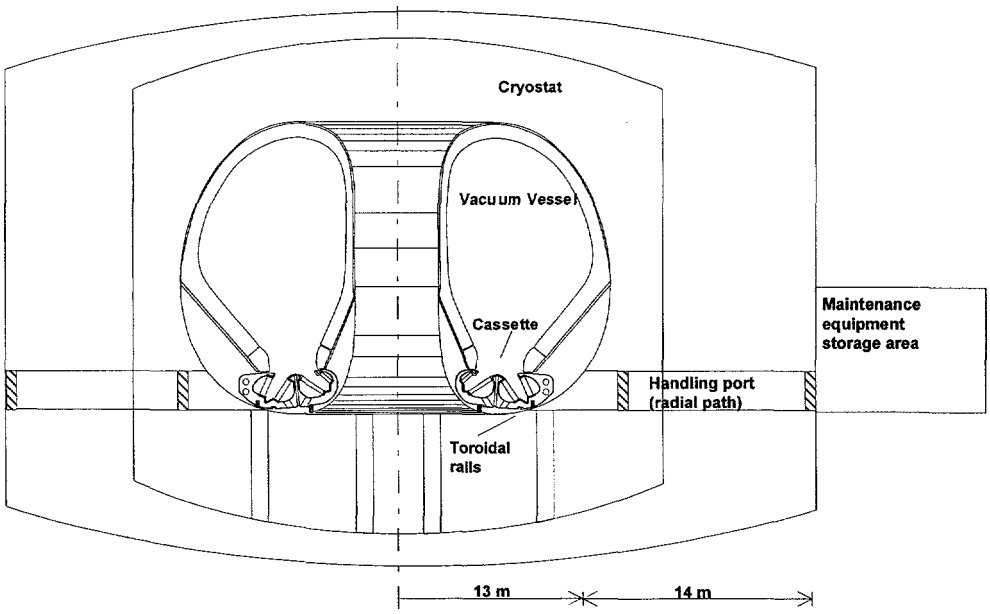

Figure 2. Divertor area of the ITER fusion reactor.

fusion reactor, as is evidenced by the increasing number of research requests and commissions and preliminary agreements for industrial deliveries in 1996-1998.

The divertor area of the ITER reactor consists of 60 divertor cassettes, each of which weighs about 25,000 kg. During reactor maintenance, the divertor cassettes are removed from the reactor and transported to the maintenance area along a track.

Remote maintenance and viewing systems

The remote maintenance and inspection systems in ITER contain potential new applications for interactive machinery systems and moving robot competence developed in Finland. Work on charting this potential more accurately began in 1993-1995, and attempts were made to find work that could be appended to the existing research and development programme. Also, the guidance software for a robot designed for blanket element replacement was developed.

The purpose of the project implemented during 1994 was to establish whether a climbing robot based on walking technology could be used for inspection duties in the ex-vessel area. This work was undertaken by the Automation Technology Laboratory of Helsinki University of Technology, the Regulation Technology Laboratory of Tampere University of Technology and Plustech Oy.

The ex-vessel area of a reactor is complicated, containing various different pipes, ducts and instruments. A number of diverse, often unplanned inspection jobs have to be undertaken in the area, calling for visual observations and measurements with instruments.

This environment should be easily navigable by a fairly small inspection robot, conveying the necessary information to the user and carrying out light repairs that are not part of planned maintenance. The conditions in the area resemble conditions in space; further hindrances include the strong magnetic field and the radiation level, though this is not as high as inside the reactor.

As a result of the project, a detailed preliminary study of the demands and technical implementation potential for such an inspection robot was drafted, determining the feasible concept and seeking potential technical solutions for various subsystems. The project has not proceeded any further so far, since the ex-vessel area maintenance systems in ITER have not yet been opened up to research and development. The concept studied is still a potential object for further research, however, and the aim is to return to it in 1997. The concept developed can also be used for the inspection of more conventional structures.

The test device for the robot designed for blanket element replacement in the ITER reactor (ROBERTINO) is located at the EU Joint Research Centre in Ispra, Italy. The Automation Technology Laboratory of Helsinki University of Technology was involved in research on the interactive guidance methods and software for this device. In 1995, the objective was to seek alternative feasible methods for accurate remote handling in a virtual model, the fundamental problem being the expansion and contraction of flexible materials during operation. The virtual model should at all times correspond to an actual situation, to enable accurate movement planning for unit operations on the basis of the model. The high radiation level of the working space is a particular difficulty, since it excludes nearly all conventional measuring instruments.

In the course of the study, a method was developed for modelling flexible structures in the modelling software used (TELEGRIP), and basic designs were sought for two potential methods that would enable the model to conform to the real world.

At the end of 1995, Finland was offered the chance of participating in development of the IVVS (In-Vessel Viewing System) by studying the functionality of a concept previously designed at JET and by designing the device in detail. A consortium formed by Imatran Voima Oy, VTT Automation, VTT Electronics and the Automation Technology Laboratory of Helsinki University of Technology was launched, and the project started in February 1996.

3 Effectiveness of results

3.1 Industrial competence and potential

The operating strategy of Finnish companies participating in fusion research has been discussed by a separate working group consisting of Matti Kankaanpää and Pertti Pale, with Jorma Routti, Erkki Rantala, Iiro Andersson and Seppo Karttunen in its management group.

On the basis of the industry working group analysis, participation in European fusion research, and particularly in construction of the ITER reactor, offers Finnish industry an enticing prospect. European industry is contributing about FIM 100 million per annum to the design and about FIM 10 billion to the construction of ITER. With active marketing, Finland could well win about 5% to 10% of all ITER deliveries from the EU in 1998-2008, i.e. annual sales of up to FIM 200 million. Then there are the EU fusion programme's internal orders for its own equipment, made on the basis of tenders.

For Finnish industry to capture as large a share of the orders placed with EU industry, the following objectives should be adopted:

- close cooperation between industry and research institutions, increasingly on the terms of industry;
- alliance with EFET, a consortium of six major European industrial companies interested in fusion;
- placing Finnish people in key positions;
- obtaining commissions at the ITER planning stage;
- focusing Finnish fusion research at the planning stage and conducting an aggressive marketing campaign at the construction stage;
- active and coordinated participation.

The strategies of the industrial companies and research units participating in the FFUSION research programme are extremely compatible.

From industry's point of view, the research programme has a special advantage in creating closer cooperation between universities and research centres. Dispelling the prejudices of Finnish companies about fusion has been a major achievement. As industry sees it, the main objectives of Finland's fusion programme are:

- technology transfer, i.e. learning and using the knowledge and skills existing and being developed in the fusion programme;
- obtaining a market position in ITER and other fusion projects.

Successful negotiations with the EFET consortium, making Finnish companies eligible for EU and ITER-EDA fusion deliveries and establishing a call-for-tender practice are the most important ways of improving the potential for Finnish industry to participate in fusion research projects.

Imatran Voima Oy has been accepted as an EFET partner, and its membership became valid in 1996. Industrial orders by ITER-EDA are only placed with qualified industrial companies selected when the EDA stage was launched in 1992. The list was updated with companies from new EU Member States during 1996. Meanwhile, a preliminary call-for-tenders practice has been agreed on with the Commission and the management of the NET Team. This has ensured that Finnish companies, too, have received calls for tenders from the EU programme since March 1995.

Preparing tenders has proved to be a daunting task, particularly for SMEs. Tenders must be carefully prepared, since the selection is made purely on the basis of written tenders. This practice should be developed so that it is not quite so taxing on SMEs. Programme subsidies should also be allocated to the preparation of tenders.

The association agreement has given Finland a good position in the NET Team in Garching, which coordinates participation by the European Home Team in ITER work. Apart from its official committee membership, Finland also has seats on two RF heating coordination committees and expert posts in ad hoc groups discussing special issues in the programme.

Finland has proposed the following groups of companies to be placed on the qualified list by the Commission:

1. Outokumpu Superconductors Oy
2. The Finnish Blanket Group

Outokumpu Poricopper Oy, Imatran Voima Oy, Rauma Materials Oy, Diarc Technology Oy, High Speed Tech Oy, PI Rauma Oy

3. The Finnish Remote Handling Group
   Imatran Voima Oy, Plustech Oy, Hytar Oy, Tehdasmallit Oy, PI Rauma Oy.

All the companies named above have also been approved for the qualified list. The groups have been formed to compete for ITER-EDA projects assigned to Europe. Imatran Voima, Outokumpu Superconductors and Poricopper, DIARC Technology Oy, High Speed Tech Oy and Hytar Oy are already participating in projects in the EU programme. Industrial participation is being coordinated by Prizztech Oy.

The Blanket and Remote Handling groups consist of networks of major companies and small high-tech companies. The company group is also supported by units of VTT and the universities. The arrangement enables excellent flexibility in tailoring projects according to the best know-how available. As an example, in the IVVS project prepared towards the end of 1995, the research institutions involved were VTT Automation, VTT Electronics and the Automation Technology Laboratory of Helsinki University of Technology, with IVO as the industrial partner. The EU partners were the NET Team and JET. The funding consists of contributions, with Euratom providing between 25% and 100%, viz. an overall funding contribution of over 60%.

The benefit of the programme network and the EU programme to small high-tech companies such as DIARC Technology Oy, High Speed Tech Oy and Plustech Oy where technology transfer is concerned is clear. For example, an extensive testing and characterization programme for coatings and explosive welding joins is being carried out, the results of which can be used by the companies. A major proportion of the funding already comes from the EU Commission. By participating in the EU programme, companies can also improve their international recognition.

IVO's membership of the EFET group opens a direct channel for industrial participation in ITER-EDA design work, and there were already clear signs of this in late 1995. It is possible to obtain 100% funding in this way, significantly increasing the degree of EU funding in ITER Task work. At the same time, Finnish industry is getting the best possible preparation in competing for deliveries at the ITER construction stage.

3.2 Scientist training

The FFUSION programme plays an important role in scientist training, since the research areas represent the frontiers of high technology and physics. Close international cooperation and the performance of ITER, JET and technology tasks to tight schedules constitutes the best possible training for those intending to be top scientists.

The technology projects in the FFUSION programme represent distinct entities suitable as components of a licentiate thesis or doctoral dissertation, so the projects offer excellent scope for young researchers. In physics, fusion plasma research has yielded several doctoral dissertations, and more are forthcoming. The code development, testing and application of demanding computer codes has resulted in several diploma theses. Parallel calculation is a new development focus, in which the programme leads the field.

4 Main results of the interim assessment

The two main objectives of the FFUSION programme have been integration of Finnish fusion research in the EU fusion research programme and awakening the interest of Finnish industry in the potential afforded by fusion research. Both objectives have been achieved very well. Joining the EU programme took even less time than anticipated.

On March 13, 1995, Tekes and Euratom signed an association agreement and an agreement on NET/ITER cooperation and staff mobility. The existing agreements are effective until 1998. Finnish membership of the European JET joint venture was negotiated and approved by the JET Council in spring 1995. Confirmation of membership was postponed to 1996. In 1995, the EU already contributed FIM 1.8 million in funding to Finnish

fusion research projects. Finnish scientists have become well placed in EU fusion research organizations, both scientific and technological.

The organization of the FFUSION programme, with clear contact points and responsible people, has met the EU's expectations. The close national coordination and the fairly stable multi-annual funding that the programme provides for are a vital precondition for internationalization.

The FFUSION programme has expanded from pure fusion physics research to more specific subareas of fusion technology involving fusion reactor materials research and remote handling systems. Finnish industry is estimated to have good competitive potential in these fields. Due to FFUSION, overall knowledge about fusion research has clearly increased and gained profundity, and knowledge about the FFUSION focus areas has taken on greater depth.

The FFUSION programme has awakened industry's interest in fusion research. Its contribution to the ITER reactor project could be nearly FIM 100 million at the planning stage and nearly ten times as much at the construction stage. Already, fusion energy research has expanded the scope of application of certain Finnish innovations and thus improved the success potential of the high-tech companies concerned.

The success of Finnish fusion technology projects in obtaining EU funding demonstrates their high quality. Achievement of internationalization objectives more rapidly than anticipated has led to increased specification of research areas and new goalsetting.

Projects in the FFUSION programme are subject to tendering and controlled in many different ways. In the main, projects should fall within the scope of (the) association agreement approved by the EU Commission. This is monitored by the national management group of the programme and the Association Steering Committee, with both national and Commission representatives. Technology projects must be opened to international tendering. Projects funded by the Academy of Finland are being assessed separately for the time being; preliminary research projects must be approved by the national management group and Tekes.

5 Further planning based on the interim assessment

The threat with the programme, as with all long-term programmes, is of progress coming to a halt. In future, attention should be paid to developing projects and to guaranteeing the possibility for new projects to be launched every few years.

Finnish fusion research has quite limited human resources at its disposal, and the programme rests on the work of just a few people. A commendable number of Finns have gone to work abroad, but more visitors should be invited to Finland. The programme must see to it that new researchers are trained.

Each contributing funding party to the programme has its own control mechanisms and reporting obligations. Despite this, the amount of organizational work must be kept as low as possible. For the programme to be effective, it is very important for a single report and plan to cover as many needs as possible. The programme format also offers a clear synergy benefit for fusion research publicity and marketing.

The research plans and reports drawn up for Tekes and the EU Commission in the FFUSION programme are well synchronized with each other. Since the main objective of the FFUSION programme is to participate in the EU fusion research programme, project proposals in the programme are mainly approved by the EU Commission and the international steering committee group of the Euratom-Tekes association.

Major research projects submitted to the Academy of Finland must be submitted in May, which causes a shift of about six months compared with the rest of the programme. The planning period for Academy projects is one calendar year. The EU Commission is at present contributing 25% to Academy-funded projects. The Executive Committee of the FFUSION programme monitors Academy research projects.

A publicity strategy should be drawn up for the FFUSION programme.

6 Research organization and Executive Committees

The research units participating in the FFUSION programme in 1993-1995 were:

- VTT Energy
- VTT Manufacturing Technology
- VTT Chemical Process Technology
- VTT Automation
- VTT Electronics
- Department of Technical Physics, Helsinki University of Technology
- Automation Technology Laboratory, Helsinki University of Technology
- Regulation Technology Laboratory, Tampere University of Technology
- Department of Hydraulics and Automation, Tampere University of Technology
- Accelerator Laboratory, University of Helsinki

VTT Automation and Electronics did not join the FFUSION programme until late in 1995. A dozen companies are also involved in Finnish fusion research. The main European partners are the JET installation and the NET Team, which coordinates European participation in ITER planning.

The FFUSION research programme is coordinated by VTT Energy. The Executive Committee is chaired by Professor Rainer Salomaa of the Department of Technical Physics at the Helsinki University of Technology, and the director of the programme is senior research scientist Seppo Karttunen of VTT Energy.

In spring 1995, the programme was linked to the EU fusion programme via an association agreement signed by Euratom and Tekes. The Euratom-Tekes association is the thirteenth associate member in the EU fusion programme. The chairmanship of the Association Steering Committee rests with the EU Commission and Tekes in alternate years. In 1995, the chairman was Charles Maisonnier, director of the European programme, from the Commission's science, technology and research directorate DG XII.

The members of the FFUSION research programme management group in 1995 were:

- Professor Rainer Salomaa, Helsinki University of Technology, chairman
- Managing Director Erkki Kare, Plustech Oy
- Professor Juhani Keinonen, University of Helsinki
- Senior Technical Advisor Martti Korkiakoski, Tekes
- Head of Product Development Lenni Laakso, Outokumpu Poricopper
- Research Professor Lasse Mattila, VTT
- Head of Development Juha Paappanen, Imatran Voima OY
- Pertti Pate, Prizztech Oy/The NET Team

In 1994, the FFUSION research programme management group included Marja Englund representing IVO, Timo Erkolahti representing Outokumpu, Markku Oikarainen representing Tekes and Jukka Lindgren representing the Ministry of Trade and Industry. Programme director Seppo Karttunen and research scientist Timo Pättikangas of VTT Energy have acted as secretaries.

Members of the Euratom-Tekes Association Steering Committee in 1995:

- Director of the EU Fusion Programme Dr. Charles Maisonnier, EU Commission, chairman
- Professor Hardo Bruhns, EU Commission
- Dr. Janos Darvas, EU Commission
- Dr. Seppo Hannus, Head of Energy Technology, Tekes
- Dr. Matti Kankaanpää, Finnish Academy of Technology
- Professor Pekka Silvennoinen, Research Director, VTT

The secretary of the Steering Committee is Martti Korkiakoski of Tekes.

The research is being funded by Tekes, the EU Commission, the Academy of Finland, the participating research units and industrial companies and, to a minor extent, various foundations.

Chapter 5
SUSTAINABLE PAPER
Energy in paper and board production

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1 Background and objectives

The forest industry accounts for a quarter of total energy consumption in Finland and a third of electrical power consumption.

Energy consumption in the forest industry has grown by an average of 4% to 5% per annum, mainly due to considerable growth in production caused by greater efficiency and new investments. The new paper machines being constructed and already completed will perpetuate this growth. A significant proportion of investments is targeted at paper grades whose raw material is mechanical pulp; this is well suited to Finnish silviculture but highly energy-intensive.

In 1992, the Finnish Government approved an energy conservation programme that sets energy consumption objectives for industry, measured as specific consumption. The objective is to achieve savings of 10% by 2005, compared with the 1990 level. The objective for electricity conservation has a market value of about FIM 220 million per annum. Central organizations in industry committed themselves to this objective in autumn 1992 with an agreement signed by the Government and industry. Practical measures aimed at attaining the objective include the eight second-generation energy research programmes launched by the Ministry of Trade and Industry in 1993. One of these is SUSTAINABLE PAPER.

The programme continues from where the RAINA programme on low-energy paper making and the KUITU programme on low-energy mechanical pulp production ended in 1992. It will last six years, ending in 1998. The title of the programme reflects the need to orientate the production and product structure of the pulp industry towards the principles of sustainable development.

The basic tenets of the programme are:
- the need to cut down the specific consumption of electricity and other primary energy;
- the need to improve the recyclability of products;
- the need to improve production efficiency factors in order to reduce wastage;
- the need to support development of energy-efficient technologies in the paper industry.

The central objectives of the programmes are:
- to develop technology for present manufacturing processes enabling attainment of the world's lowest specific energy consumption and to make use of the internal energy production potential of processes;
- to simplify new process designs and their control systems so as to significantly reduce energy consumption;
- to develop present and future low-energy paper industry products.

On the basis of these objectives, the programme was organized into three areas: the manufacture of mechanical pulp, the manufacture of paper and board, and mill design and process control.

2 Results in major research areas

2.1 Energy savings in the manufacture of mechanical pulp

Mechanical pulp is used primarily in the manufacture of newsprint, mechanical printing papers and board for consumer packagings. These paper grades are of key importance in the Finnish paper industry's product range. Finnish spruce has proved to be the best raw material for mechanical pulp.

The benefits of mechanical pulp include

- opacity and excellent ink absorption;
- z-directional elasticity of paper or board;
- bending stiffness;
- high yield and low manufacturing and investment costs.

Properties limiting the use of mechanical pulp

- poor strength properties;
- low pulp brightness and strong tendency to yellowing;
- low absorbency of pulp, particularly after a period of storage;
- problems with taste and smell;
- high electricity consumption.

Energy issues underlie nearly all research involving mechanical pulp, since changes in manufacturing conditions affect not only the papermaking properties of pulp but the specific energy consumption, too.

A major part of the research carried out in the programme has focused on investigating the theory of pulping. The objective is to lower energy consumption radically. At present, the theoretical energy efficiency of mechanical pulp making is only 0.1% to 0.6%, if the theoretical surface energy increase in the pulping process is compared with the pulping energy needed in practice. Another important object of study is ways of improving the efficiency of existing processes, the objective being for savings in the order of 10% to 30%.

Results in mechanical pulping

Progress has been made in understanding and managing the process, leading to results in what is called 'small step' energy savings. No signs of a major technological breakthrough yielding to radical energy savings have yet been seen, however.

Energy savings in the order of 10% to 15%, measured by specific consumption, can already be attained with a number of changes in the usual mechanical pulp making methods - for example, grinding or refining at a higher pressure and temperature, refining with a shorter residence time in the plate gap zone, and grinding at reduced rpm. In all these methods, pulp quality deteriorates slightly, i.e. there is lower fibre length and poorer brightness.

A better understanding of the process has led to changes in running practices, including better control of quality and process variables. Sorting and fractioning methods have also been improved, and the various fractions can now be used more efficiently. On the other hand, further research is being undertaken to eliminate the adverse effects caused by the process changes mentioned in the previous paragraph. Practical results are expected from the pulp fractionating study, brightness permanence study, and development work on refiner plates and grinding surfaces.

In equipment development, advances in grindstone sharpening equipment, new surface materials for grindstones, refiner plate improvements and the development of process control devices for mechanical pulp making, could be mentioned.

Sufficient control of pulping still requires a lot of basic research. Only a thorough investigation of fibres and the fibre matrix can lead to a radical reduction in energy consumption in pulping.

The national energy balance does not indicate that specific energy consumption in mechanical pulp making has gone down. This is due to simultaneous advances in printing paper quality, which means that the pulp used as raw material for paper is now of a finer grade, requiring more energy to produce. Without the research contribution of the SUS-

TAINABLE PAPER and FIBRE programmes, however, specific energy consumption would actually be far higher than it now is.

Defibration theory

In the area of fibre morphology, work has focused on characterizing methods for thicker latewood fibres and thinner earlywood fibres and the effect of refining on both types of fibre. Papers manufactured from thick-walled latewood fibres have a greater tendency to roughen than those manufactured from thin-walled earlywood fibres. Thick-walled fibres are also more easily blackened during calendering.

A theoretical dynamic pulping model was developed as a result of research begun in the FIBRE programme.

This incorporates the basic physical phenomena essential for treatment of the wood matrix with a variable pressure field and common to both grinding and refining. On the basis of this model, a method has been developed on a laboratory grinder, based on use of a grinding surface with customized dimensions and completely defined. The method developed for the manufacture of a customized grinding surface adds a new dimension to the study of pulping mechanisms. A patent has been applied for.

Grinding process

Tests on the laboratory grinder proved that it is possible to increase production by changing the sharpening method on the stone, enabling the temperature to be raised in the grinding zone at a relatively low spray water temperature. The measured energy saving is about 10%. A new grindstone surfacing technique using a new ceramic material was developed in the same project. The applicability of this material is being studied further on a semi-industrial scale.

To replace the traditional grindstone sharpening device, a sharpening technique using a high-pressure water jet has been developed. This has proved to have significant advantages compared with earlier equipment. A measurement device attached to the finger plate has also been developed which allows continuous monitoring of the surface temperature of the grindstone. A slotted screen technique for screening groundwood has also been developed. These results have been commercialized.

Refining process

The flow properties of a production-scale refiner have been studied in an extensive research project, resulting in a theoretical two-dimensional flow model with energy balance.

The radial power distribution in the plate gap of a single disc mill refiner was established in a study which also evaluated the defibration mechanism by analyzing the pulp samples taken from the plate gap at different radii. These results have already proved useful for refiner plate development.

Ways of lowering refining energy consumption have been studied by changing the operating point of refiners (main refining and reject refining). Results obtained so far show that benefit can be achieved provided that the operating point control in a narrow operating window can be maintained through on-line control technology.

When the rpm of a refiner is increased, it is possible to produce refiner pulp with a particular CSF value at 25% lower energy consumption, but the fibre length decreases and the strength properties of the pulp deteriorate by about 10%. It is hoped that developments in plate segment geometry will offset the decrease in fibre length.

Energy savings of about 20% can be achieved if the fines are removed by fractionation after every refining stage and the grinding process focuses only on the fibre fraction.

The following methods for reducing energy consumption have also been examined:

- moving from single-disc refining to double disc refining;
- increasing the rpm of the refiner;
- Thermopulp, refining at an elevated temperature;
- chemical treatment of the long-fibre fraction.

The reported energy savings were about 10% to 15%, but the methods have their disadvantages. Generally speaking, they produce pulp with a lower

brightness and fibre length, affecting the tear strength of the pulp. Chemical treatment, on the other hand, usually lowers opacity.

Enzyme treatment of the coarse pulp fraction enables 10% to 15% energy savings and produces pulp with normal fibre length and optical properties; in this, it clearly differs from other energy conservation methods. The refining must be a gentle process in order to produce this result. The economy of this method and its applicability to industrial processes have not yet been studied.

Pulp pretreatment and sorting processes

On the basis of pilot tests, a new sorter has been developed with interchangeable rotors for sorting at high or low consistency. A recycled pulp production line based on the new sorter technology has been developed. This line uses 30% to 40% less energy than a similar conventional production line, since the number of electric motors, for example, is 40% to 50% lower.

Chemical treatment prior to refining can be performed either directly on the chips or on the coarse fraction of the first refining stage. An apparatus developed for chip handling removes the air from the porous cavities in the chips by vacuum treatment. The chips are then penetrated with a chemical solution. In grinding after this treatment, the energy saving is about 10% to 15%. This apparatus is ready for demonstration in industry.

2.2 Energy savings in the manufacture of paper and board

In accordance with the main focuses of energy consumption, research has focused on vacuum dewatering on the wire and press sections of the paper machine, the development of web drying methods replacing cylinder drying, and infrared drying of coating.

Extensive mill-specific audits have been carried out to establish the status of wire section dewatering, raw water use, steam and cooling systems. It was established then that the drying sections of the five paper machines examined would yield a realizable annual heat saving potential worth FIM 2.7 million in all. Vacuum system audits or development projects have been carried out on nine paper machines in, or as a result of, the research programme. These demonstrated an annual saving potential of FIM 7 million. In all, control measures and minor investments could probably generate total savings of FIM 50 million in electricity and heating costs in existing paper production lines.

Research into new drying methods has revealed significant potential for energy savings, but realizing these savings requires the methods studied to be developed to the industrial level while also solving the question of how to use the low-grade heat generated as a by-product. This has led to greater emphasis on energy integration and waste heat use than the master plan provided for. The first benefits gained from new drying method development will probably be achieved through better machine manufacturing technology competitiveness, but this will take five to ten years.

A particularly tangible result in this research area is the introduction of a Condebelt dryer in a board machine at Enso Oy's Pankakoski mill this spring. This development work, which took nearly 20 years in all, was supported through both the SUSTAINABLE PAPER programme and its predecessor, the RAINA programme.

Results in paper and board manufacturing

The operation of a paper or board machine, like that of a pulp dryer, consists mostly of web dewatering. The initial consistency in the headbox may vary from 0.3% to 1.5%, while the dry matter content of the finished product on the reel-up is over 90%. The energy consumption of a modern paper machine is between 3 and 5 GJ and 0.4 to 0.9 MWh per tonne of paper, depending on the paper grade. Thus, a large paper machine producing nearly 1000 tonnes per day uses heat in the order of 4 to 5 TJ per day, requiring 30 to 35 MW of electricity.

These figures do not include the energy that may be needed in mechanical pulp making.

For example, on a production line manufacturing coated magazine paper, most of the electrical energy (about 35%) is taken up by the coating machine, particularly for infrared drying. Pulp han-

dling (pumping, refining) takes 25%, vacuum equipment 12%, paper machine drives 12% and other applications 16%. For a newsprint production line, the figures are: pulp handling 31%, vacuum equipment 20%, paper machine drives 30% and other applications 19%.

Most of the thermal energy is used to dry the paper and coating. The problem in conventional cylinder drying is its inefficiency calculated in terms of the paper area unit; this calls for expensive and space-consuming technical designs and causes difficulties in the further use of low-grade heat. The energy consumption for drying steam in Finland is about 55,000 TJ per annum.

Vacuum dewatering

Vacuum dewatering has been examined using the absorption tester developed in the programme. The tester uses high impulse frequency and extremely short vacuum pulses about one millisecond long.

A calculation model was developed to determine the dewatering curves illustrating the development of dry matter content for any headbox stock examined. An Excel spreadsheet was devised to calculate the effect of vacuum levels and changes in vacuum devices in the wire section on the dry content and the energy requirement of the wire section drives, as well as the theoretical need for vacuum. The program is being used commercially by the engineering office that developed it.

Several energy audits concerning vacuum systems and the use of vacuum in the forming and press sections of a paper machine have been implemented within the programme. A pilot machine was used to make vacuum measurements which were then taken as a basis, using regression analysis, in creating a mathematical model on a board machine to estimate the effect of different vacuum levels on dry matter content after the wire section.

In the study, the vacuum systems of two paper machines at one mill were optimized and overcapacity in the vacuum system identified. The energy savings resulting from the measures proposed total 4 GWh per annum, or about FIM 800,000.

The functioning of the paper machines' suction systems was studied using air and water content measurements. Changes were suggested designed to optimize the use of vacuum energy. The annual energy savings on the two paper machines are estimated at 7.9 GWh.

Water volume measurement devices installed in the wire and press sections of the paper machine were used to gather information on the performance of the vacuum system under different running conditions with the aim of establishing the prerequisites for successful control. In conditioning the third felt, a high-speed compressor was used as a vacuum source; contrary to other vacuum sources, its output can easily be controlled.

Wet pressing

Wet pressing, which takes place at a lower dry matter content than at present (about 10% to 20%), enables a reduction in vacuum energy and an improvement in paper machine runnability.

In three part-projects applicable press structures are being studied, a mathematical model of the wet pressing process is being developed and wet pressing tests on a dynamic nip simulator are being carried out.

Drying

In a joint project with the EU, the impingement drying of paper and textiles with superheated steam is being studied. The test apparatus constructed has been used to examine steam recycling and superheating and the technical design of the dryer in drying a continuous web. The integration of a superheated steam dryer in a paper mill energy production system has also been studied. If the problems identified in this research can be solved, the method offers potential for considerable savings in drying energy.

Since the steam used in impingement drying is superheated and the dryer generates low-pressure saturated steam, profound changes must be made in conventional paper mill energy production systems before the method is introduced. Because of this, a study has been made to establish what the best methods would be in terms of technology and energy economy for providing the energy production and heat recovery needed for steam impingement drying; the overall profitability of a paper mill fitted with such a system has also been studied.

The cost of a paper mill built with the new superheated steam concept is of the same order as a mill fitted with an air impingement dryer, but lower than a mill with cylinder drying. If the system is installed at an existing mill, the energy costs per tonne of paper decrease by a few per cent; at the same time, production can be increased by about 5%. In both cases, the profitability depends largely on the potential for using surplus energy.

The Condebelt test dryer has been developed into a demonstration-ready drying system in the research programme. The drying speed with a Condebelt is about 5.5 times that of cylinder drying using the same drying steam pressure, measured by contact area.

The applicability of a new installation design for the infra-red dryer designed in the RAINA programme was examined on five paper machines. Tests to enhance the efficiency of IR drying were continued on four of these.

In an extensive energy survey project, the energy management of the steam and cooling systems of five paper machines were audited and improvements suggested. It was shown that the potential savings that can be profitably achieved amount to about 40 GWh per annum in the case of heat. The savings potential of measures that need further study is about 10 GWh per annum for electricity and 20 to 40 GWh per annum for heat.

WEB FORMING, reducing the amount of water used

A gap former for transport packaging boards has been developed in a corporate project within the research programme. This has been examined in action on a test machine. The first commercial board machine utilizing this concept was delivered in autumn 1995. The former can use higher headbox consistencies than usual, with a 20% to 30% decrease in pumping.

The water use of seven paper machines was studied in order to decrease the amount of water intake and effluent to be treated, and to show potential savings in pumping and water heating. As a result, it was shown that it is possible to reduce water input by 30% on average and to achieve heating savings of 70 GWh per annum. The electricity savings potential was 1 GWh per annum on average.

2.3 Energy savings in mill design and process control

The objective here is to reduce energy consumption by simplifying processes in the paper industry and by improving the efficiency of paper and board machines. This can be achieved by applying unit processes under development and fast-advancing measurement and control technologies in innovative ways.

This area focuses on more effective planning of paper mill energy integration from the point of view of paper making, on simplifying process connections, on reducing the number of machines used and the volume of mass transfer, and on improving the efficiency of paper and board manufacturing.

Mill design and process control results

Two preliminary studies were commissioned from consultants. The first concerned the potential energy savings in processes related to pumping and stock treatment in an SC paper mill. A study has since been done in this area concerning a new type of pressure screen used as a pump, and a new simplified mechanical pulp screening plant concept has been developed.

The second preliminary study concentrated on simplifying the component processes of a pulp or paper mill. At least three of the proposals made have been discussed in various projects in the programme. A simple and efficient new screening plant for recycled paper has been developed as a joint development project.

At the beginning of the programme, especially as work on new drying designs proceeded, the importance of energy and water integration in a mill was established. Projects were included in the programme aimed at developing simulation methods in this area and using them to seek mill designs and individual solutions that would be economical in terms of energy consumption and environmental impact.

Process simplification

A consultancy project was used to study ways of simplifying the processes of an SC paper mill, and mechanical pulp making linked to it. A potential saving of 20% to 40% in pumping was identified.

In a second consultancy project, energy savings potential in pulp and paper mills was studied through process simplification, new process designs and the application of new technology in heat and electricity generation. Eleven separate sites were examined. The results of this survey can be used as a basis for further research.

The sorting capacity and pumping properties of a new type of pressure screen with axial inlet have been studied in a test installation and in mill conditions. It was established that the screen could in most cases be operated without a feeder pump, which would simplify the sorting process. Compared with earlier screening techniques, a saving of about 35% in investment costs and 45% in energy costs could be achieved.

Measurement and control technology

In a study financed by the Executive Committee, shortcomings in measurement and control systems in the paper and pulp industries were examined. The aim was to communicate to machinery manufacturers what the major development needs in the field are. In the pulp industry, only mechanical pulp making was considered. The study presents a list of the measurement needs for which online solutions and/or improved designs are required in various areas.

The objectives of an extensive joint project managed by industry and the universities are to lower specific consumption of energy, control the quality of the refiner process, increase the reliability of measurements and develop simulation and optimization tools for component processes. SER (Specific Energy Requirement) controls have so far been implemented in two major TMP installations; these have significantly improved control over, and the evenness of, the process. One of the two mills involved reported that specific energy consumption had decreased by 2% to 3%, while quality fluctuations in the refiner pulp had decreased. The implementation of fuzzy quality controls is in preparation.

The applicability of pulp high consistency measurement based on infrared light diffusion was studied at various sites. The method has been successfully used for consistency measurement after the TMP grinder. It was established that the most feasible applications were consistency measurements and regulation on post-digester pulp, oxygen-stage pulp, and pulp in the paper machine refiner section.

In pulp, water and liquor flow measurements in the forest industry, flow can be determined on the basis of the setting of the control valve and the pressure differential over it. Equally, it can also be determined on the basis of the pressure differential in the centrifugal pump. The aim is to develop a smart control valve and smart pump to act as flow meters. From project results, it seems that most pumps can be used for flow measurement, probably including all rpm controlled pumps. All the control valves tested were suitable for flow measurement.

Modelling and simulation

The applicability of commercially available simulation software to paper industry balance calculations and flow circuit planning has been studied. The best applications found were WinGEMS and BALAS. A paper production line and waste water evaporator were simulated in tests. Using these tools, models of the grinder room and refiner plant were made and connected to paper machines. The models were used to establish how pulp-making energy consumption could be enhanced and what flow connections should be used to produce low disturbance element levels in a paper machine. The energy pinch analysis was performed on a TMP paper production line and a paper mill complex. The maximum savings potential for a whole complex was established as 11% in winter, or 4.4 MW.

In the second part of the project, simulation tools were used to establish ways in which various process techniques and connections could be used to reduce energy and water consumption in paper making. By adding a multiple effect waste water evaporator to the process, the fresh water needed for the paper machine's shower water circulation could be produced within the system. The economy of the method depends on the quality and amount of surplus heat at the mill.

3 Effectiveness of results

Industrial relevance

The joint development projects, in particular, show results that are immediately usable by industry. It takes longer to apply results from public research projects in practice, and the attainment of results that will eventually be usable by industry is more uncertain.

The programme Executive Committee considers it important for the programme to include not only basic research but also a sufficient amount of applied research, and for the range between the two extremes to be flexibly covered. Industry is more easily interested in solutions to practical problems. Energy conservation objectives can largely be achieved through applied research addressing practical problems.

Competent and active industrial representation on the programme Executive Committee and steering groups has ensured the inclusion of either industry-proposed or otherwise industry-related research projects.

In the case of mechanical pulp, the proportion of basic research has been deliberately kept high, aiming at better knowledge of the cellular structure of wood and its controlled opening. The industrial relevance of the results is, of course, difficult to predict. However, it has been advantageous to organize this particular field of research as a programme, since it is difficult to obtain critical mass in research relying on several different funding sources.

More sophisticated technology

The results yielded by the research programme have high potential for raising technological competitiveness.

The programme has only been running for three years, so the number of new processes or devices improving technological competence implemented in practice is rather small. Condebelt, where development began 20 years ago, has progressed as far as the first production unit commissioning. Component functions in paper machines, such as dewatering in the formation section and better understanding of the drying process and the refining process are expected to improve competitiveness.

Research on new wet pressing technology, on drying in steam atmosphere and on impingement drying with superheated steam, has been launched in the programme. Commercial applications will not emerge for some years, but if successful, these could greatly advance know-how in this area in Finland.

Networking

Cooperation between research institutes has clearly increased in the course of this programme and its predecessor. Individual research projects have been purposefully combined to form joint projects, creating a practical platform for cooperation. New partners and cross-discipline methods have been found for solving problems.

At the same time, research in the field has spread out from the Helsinki area to the rest of Finland. In addition to the Otaniemi 'campus' (the Finnish Pulp and Paper Research Institute (KCL), the laboratories of Helsinki University of Technology and VTT), we must mention Jyväskylä, Tampere, Lappeenranta, Oulu and Turku, where universities and research institutes have taken an active part in the research programme.

Scientist training

The SUSTAINABLE PAPER programme has generated studies from diploma theses to doctoral dissertations. According to information received by the coordinating office, one doctoral dissertation, two licentiate's theses and a dozen or so diploma theses or comparable papers have been written.

4 Main results of the interim assessment

4.1 Feasible structure of project portfolio

Programme implementation deviates from the master plan in two clear respects. In mill design and process control, process simplification and control system development have not proceeded according to the master plan.

Two preliminary studies were conducted in process simplification at the start of the programme, but only a small number of research projects have followed these up. This area falls within the sphere of planning and consultancy offices. Their interest in and financial capacity for investing in development is understandably quite marginal. The area has since been replaced with energy integration, which is considered an important future focus.

Another deviation from the master plan is that research on the fibre line in chemical pulp making and recycled fibre pulp making is virtually non-existent. Only one joint development project, concluded at the end of 1995, has been implemented in this area.

Otherwise, the project portfolio is considered feasible. It includes an appropriate mix of small-step development projects and research aiming at much more radical advances.

4.2 Programme scope

The Executive Committee feels there is no need to make changes in the statement of scope in the master plan relative to other energy programmes. The only other relevant Tekes programme is RENEWABLE PAPER, which ended according to plan at the beginning of 1996. No demarcation problems occurred between the two programmes, since RENEWABLE PAPER concentrated mainly on paper quality research. Tekes is considering how to organize chemical wood processing research once RENEWABLE PAPER ends. The Executive Committee feels that the SUSTAINABLE PAPER programme could include certain new research elements in the pulp and paper industry that are connected with energy research.

The Executive Committee feels, that since the programme was founded as an energy research programme, it should remain one and should continue to be developed as one. However, it should also be possible to study entire research areas relevant to energy use even if these include elements that strictly speaking do not come under energy research.

Supplementing the research programme as proposed above would mean concentrating on energy-intensive processes such as stock handling and refining, pumping and mass transfer and also reducing the use of water in paper making. The main motivation in this area comes from environmental issues and the industry's need to remain at the forefront of progress, if only for image and marketing reasons; rational use of energy is also a consideration, since its importance grows when processes are closed.

5 Further planning based on the interim assessment

The Executive Committee has decided to propose that the research programme for 1996 should focus on the following five aspects:

- mechanical pulp and stock handling;
- web forming, dewatering and drying;
- pumping and mass transfer;
- integrated paper mill energy systems;
- paper making with less effluent.

Since Tekes funding was cut in the State budget for 1996, however, it proved necessary to change the scale of the follow-up plan. Internal coordination in Tekes also caused a change in programme content, mainly in two research areas. A separate research programme was launched for paper making with less effluent, and pumping and mass transfer will be managed in separate projects with no programme links.

Since no acceptable applications were received for the integrated paper mill energy systems area for 1996, the number of research areas was reduced to two: mechanical pulp and stock handling; and web forming, dewatering and drying.

Also taking into account the fact that some projects were turned into joint development projects within the reduced funding framework, the volume of research under the programme was cut by about 20% on 1995.

In future, SUSTAINABLE PAPER will concentrate further on mechanical pulp research. Alongside this, energy issues in paper and board making and energy integration development will be retained. Other problems besides those involving energy technology will also be taken up in mechanical pulp research.

6 Research organization and Executive Committees

The Executive Committee and steering groups have proved functional and competent. The forest industry has experience of intercorporate cooperation in research, so the present cooperation in energy research caused no difficulties. It is considered particularly advantageous for rival manufacturing methods, such as grinding and refining, to be studied in parallel within the same programme.

The members of the steering groups have complained of a shortage of time caused by their own jobs, making it difficult for them to consider matters in detail in the groups. The Executive Committee would like the steering groups to provide hypotheses in their discussion of research topics. The aim of each research project should be to reinforce or refute its own basic premise.

It is difficult to interest operative personnel in the forest industry in energy savings. It has proved easier to involve operative personnel when research has a practical objective. There are exceptions, though. For instance, no such problems were encountered in the TMP research mill tests, perhaps because the problems were widely acknowledged and solutions awaited. Cooperation between the forest industry and equipment manufacturers in the Executive Committees and steering groups has been exemplary.

Two steering groups are enough instead of three. Drawing the line between paper and board making, on the one hand, and mill design and process control, on the other, has been arbitrary. Paper drying falls under the former, while steam and cooling systems, through energy integration, belong to the latter. Using two steering groups will also conserve the industry's expert resources.

In general, SUSTAINABLE PAPER has been kept under better control than its predecessors KUITU and RAINA. The programme is now put together by selecting research applications that aim at objectives selected beforehand. The earlier programmes attempted to select suitable research areas from the proposals submitted by research institutes, and this was a weakness.

The research itself is of fairly good quality, with a few exceptions. These exceptions include projects in which the internal coordination did not work as expected.

Chapter 6
LIEKKI 2 – Research programme for combustion and gasification techniques

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1 Background and objectives

The LIEKKI 2 programme seeks to promote the development of combustion- and gasification-based energy conversion techniques in Finland. Special emphasis is given to research serving the development of new, more efficient and environmentally friendly techniques, but the programme also includes research on conventional combustion techniques.

Another important aim is to maintain and improve the know-how of parties engaged in research, especially universities.

Finland leads the field in many sectors of combustion technology. We have comprehensive experience in using various combustion techniques and fuels in energy production in industry and the municipalities. Moreover, combustion equipment is one of Finland's main export articles; in particular, fluidized bed combustors, pulp mill black liquor recovery boilers, and heavy diesel engines and diesel power plants have been extremely successful on the world market. The market for these products alone is enormous, amounting to tens of billions of Finnish marks according to estimates. At present, the total export of products designed in Finland comes to several billion Finnish marks per year.

New products are also being developed in Finland. Commercial designs, especially for combustion and gasification based on pressurized fluidized bed technology, are just around the corner.

Indeed, the LIEKKI 2 programme aims to support the Finnish combustion and gasification equipment industry. In addition, LIEKKI 2 serves the development work on combustion technology and emission abatement carried out by those responsible for energy production in industry and the municipalities.

The globally targeted reductions in emissions of greenhouse gases, especially carbon dioxide, also require that combustion techniques are improved. The charges payable for carbon dioxide emissions may significantly accelerate the commercialization of new and more efficient combustion techniques giving lower emissions. 'Emission taxes' have also increased interest in expanding the use of biofuels in the generation of electricity. In fact, biofuels are especially suitable for new pressurized techniques due to their remarkable reactivity compared with coal, for instance.

In the following, six combustion and gasification applications interesting from the Finnish point of view are discussed in more detail. The related development work is supported by the LIEKKI 2 programme.

1.1 Fluidized bed combustion

Fluidized bed combustion is a very important sector of Finnish know-how and fluidized bed combustors are one of the most successful Finnish export items. Moreover, Finnish know-how has played a key role in the development and commercialization of larger-scale circulating fluidized bed combustors. These were commercialized in the late 1980s and there are now some 300 such combustors in use, with a total thermal power exceeding 25,000 MW. Approximately half of these combustors are based on techniques developed in Finland.

Development of fluidized combustion techniques concentrates on simplifying the equipment (new cyclone solutions) and reducing emissions. One of the main aims is in fact to bring the emissions of every main component (NO, SO_2, CO and N_2O) below the increasingly strict norms, without separate flue-gas cleaning devices.

Bubbling fluidized bed combustion is another important technique for Finnish suppliers. Its suitability for various fuels, and especially waste, is very interesting. Development of the technique interests combustor technology manufacturers and other process industries. The fluidized bed technique is highly useful for the wood-processing industry, where it can be used for burning different types of wood waste. The main problem with the technique is, again, controlling the flue gas emissions.

1.2 Pressurized fluidized bed combustion and gasification

In recent years, the use of solid fuels in systems called 'combined cycles', which could significantly improve the efficiency of power generation, has attracted considerable interest. In a combined cycle process, the fuel is gasified or burned under pressure. The resulting pressurized product gases are scrubbed and conducted into a gas turbine and further, under normal pressure, to a steam boiler. Combined cycles using solid fuels are, however, still at the development stage. First concepts are being demonstrated abroad. Companies are extremely interested in combined cycles, and there are several versions under development in Finland, based on fluidized bed technology in one way or another:

- pressurized circulating fluidized bed combustion of coal (Ahlstrom, now Foster Wheeler Energia Oy)
- pressurized circulating fluidized bed gasification of biofuels using air (Ahlstrom, now Foster Wheeler, and Sydkraft Bioflow)
- pressurized circulating fluidized bed gasification of biofuels and coal using air (Enviropower, now Carbona Inc., and Institute of Gas Technology)
- pressurized circulating fluidized bed gasification using air, combined with pressurized circulating fluidized combustion of the char residue (Ahlstrom and Foster Wheeler 'topping cycle')
- pressurized gasification of moist fuels (Imatran Voima Oy's IVOSDIG process)

The combined cycle technique for solid fuels has great potential, not only as an important export item but also in generating energy in the Finland of the future. The higher efficiency of combined cycle plants saves fuel and cuts emissions, including carbon dioxide. With processes based on pressurized fluidized bed technology - combustion or gasification - a major increase in power generation could be achieved. Even with first-generation techniques, the increase in the electrical power of industrial back-pressure plants using solid fuels would be hundreds of MW. In district heat generation, doubling the power/heat ratio with solid-fuel combined techniques would increase the present volume of district heat by some 800 MW.

1.3 Diesel power plants

Finland is a leading manufacturer on the global heavy diesel engine market. In 1995, Wärtsilä Diesel delivered heavy diesel engines with a total power of some 2,500 MW. The LIEKKI 2 programme includes research related to the development of power-plant-size engines. The research concerns control of the combustion process itself, minimization of emissions and the special challenges posed by low-quality fuels, such as corrosion due to oil.

1.4 Combustion and gasification of black liquor

The technique used for the combustion of black liquor, a by-product produced by the pulping process, is another area of expertise for Finnish companies. More than half of the boilers sold on international markets during the last few years were designed in Finland.

Recent developments in black liquor combustion mainly involve improved liquor-drying and the optimization of liquor and air feed into the furnace. In fact, the entire combustion process in the recov-

ery boiler has been improved significantly. For instance, sulphur emissions have been materially reduced simply by process-technical means. The control and further reduction of other emissions, especially nitrogen oxides, from the low levels already reached is a challenge for the near future.

Closing the chemical cycle at pulp mills can alter the composition of black liquor and thus the conditions in the recovery boiler. This may also alter the use and design of the boilers.

The black-liquor gasification process, which is replacing recovery boilers, has been studied for a long time. A combined cycle based on pressurized gasification using black liquor is much more complex than one using solid fuels. Because the inorganic substances of black liquor melt at low temperatures, it is very difficult, for instance, to control any fluidized bed process. Moreover, during gasification the liquor releases large amounts of vaporized sodium compounds, whose separation from the product gases before the turbine is very difficult.

The gasification of black liquor is still, nevertheless, an interesting technique, and Finnish industries are very keen to develop it. A gasification process replacing the recovery boiler would revolutionize the pulp industry and mean massive markets for manufacturers. Black liquor gasification is being developed in the USA, Canada and Sweden, in addition to Finland. Most international research concentrates on gasification under atmospheric pressure.

1.5 Waste incineration

The incineration of both industrial and various municipal wastes is attracting increasing interest in Western Europe, mainly because of a lack of areas suitable for dumping and the environmental risks caused by dumps.

Extremely tight emission norms are being set for incineration. In addition to 'ordinary' emission components (SO_x, NO_x), these norms concern a wide range of substances and groups of substances which appear only in very low amounts in flue gases (dioxins, heavy metals, etc.). In fact, the challenges facing waste incineration involve almost solely emissions.

An interesting future prospect is the controlled incineration of waste with other fuels. In Finland, municipal waste is incinerated only in Turku, although plans do exist elsewhere.

1.6 Conventional combustion

Several new challenges also face conventional combustion. Considerable research and experimentation is required, especially in the use of low-NO_x techniques which limit emissions of the nitrogen oxides. Controlling nitrogen oxides in the combustion of pulverized coal or peat by, for instance, staging the air feed can cause new problems. The unburned residue of fly ash or the carbon monoxide level in flue gases may increase, the wall tubing of the furnace may suffer from slagging, and there may be an increase in corrosion, etc.

In conventional combustion, the effect of the fuel type is another current issue in Finland. As the global coal market goes on expanding, a growing range of coal grades is becoming available. Whether a particular coal or peat grade suits, say, the low-NO_x technique used in a particular boiler cannot, however, be solved by means of conventional fuel analysis. Instead, new methods for characterizing fuels are required.

2 Programme structure and main results

The guiding principle in delimiting the LIEKKI 2 programme has been the need for maximum interaction and support between the participating researchers. Maximum coherence in terms of techniques and research has also been sought.

The LIEKKI 2 programme concentrates on phenomena related to the combustion and gasification processes, that is, to the 'thermal conversion' processes. The aim is to promote the development of new (and existing) combustion techniques by better understanding of the process details.

The programme concerns only the actual conversion process and, for example, the technique used to reduce emissions directly. It does not concern post-process cleaning of flue gases (such as selective catalytic reduction of nitrogen oxides), various scrubbers and dust collectors.

The LIEKKI 2 programme does not distinguish between different fuels but seeks to include the thermic conversion of all fuels, including wood, black liquor and other biomasses, municipal waste and other combustible materials.

The inclusion of research on combustion in heavy diesel engines in the LIEKKI 2 programme has led to new contacts between pressurized fluidized bed combustion and diesel engine researchers. The engine research included in LIEKKI 2 concentrates on the largest, power-plant-size engines and especially on the combustion process in cylinders.

The main purpose of LIEKKI 2 is to find new technical applications. Indeed, a major part of the programme involves studying key problems with the new combustion and gasification processes being developed in Finland.

The programme also includes more basic and long-term research with no short-term links to current practical problems.

On the other hand, it is obvious that no rigid demarcations are practicable. Some of the more basic research projects may provide solutions to problems with the development projects, or the applied research may lead to observations or phenomena which are interesting in terms of basic research.

For practical work, the LIEKKI 2 programme has been divided into six review groups. The groups were formed in order to improve contacts between researchers by gathering under one group projects with as much in common in terms of methods and framing of questions as possible. Thus, the principle for forming the review groups was their research method rather than, for instance, the combustion techniques being developed.

The six areas of research under LIEKKI 2 and their chairpersons in 1996 were:

- Modelling the furnace process (Reijo Karvinen, Tampere University of Technology)
- The chemistry of gaseous emission components (Pia Kilpinen, Åbo Akademi University)
- Ash, aerosols and the behaviour of particles (Esa Kurkela, VTT Energy)
- New combustion and gasification techniques (Martti Korkiakoski, Tekes)
- Black liquor (Esa Vakkilainen, Ahlstrom Machinery Oy)
- Conventional combustion techniques and waste incineration (Juha Huotari, SERMET Oy)

In the following, the research carried out by each review group and the relevant results are discussed in more detail. The data are based on the individual projects' annual reports and on the reports by the review group chairpersons.

2.1 Modelling the furnace process

A mathematical model which describes numerically the combustion process of burners, combustion chambers or furnaces is an essential tool in developing combustion techniques. At its best, the model enables the calculation of all features peculiar to a combustion process, i.e. gas flow and temperature distribution at various points of the furnace, concentration distributions of various gas components, heat flux to the walls, etc. This makes it possible to simulate new furnace or burner designs by computer modelling, reducing the need for expensive practical tests.

In practice, however, these calculations involve numerous problems and it is seldom possible to describe combustion processes in detail. Nevertheless, mathematical modelling already plays an important role in practical development work. Modelling allows the effect of various factors on the combustion process to be established even in many complicated cases.

The mathematical model of the combustion process consists of two parts. The first is a numerical solver with which the numerous partial differential equations can be solved iteratively. The other consists of separate descriptions or submodels for each of the significant physico-chemical subprocesses in the combustion process.

The preconditions for both of these parts of the model are much more favourable these days. The calculation power of computers and the available accuracy (number of computational cells) have improved tremendously. The commercial programs on the market (Fluent, Phoenics, Flow-D, etc.) are also better and more user-friendly. The study of physico-chemical submodels has made advances and the submodels are also more accurate.

A total of 30 modelling projects have been carried out under the LIEKKI 2 programme since its inception (1993—1996). The total funding for this period was FIM 25.8 million, the Tekes contribution accounting for some FIM 12.9 million. At the end of 1996, there were 11 modelling projects under way.

The projects concentrate on developing the various submodels of numerical modelling, mainly for pulverized-coal furnaces, circulating fluidized bed reactors, diesel engines and black liquor recovery boilers. They have comprised both theoretical and experimental research. Related industry, research institutions and universities have all played a major role. The fact that many of the projects were already under way before the LIEKKI 2 programme indicates the long-term work required by mathematical modelling. Under LIEKKI 2, much of that work has been applied in practice.

The modelling of pulverized combustion has been improved with the multigrid technique, in which individual burners are modelled using a denser grid, that is, more accurate calculation, than the rest of the furnace (Figure 1). This has made it possible to better describe the phenomena occurring in the vicinity of the burner, crucial especially to emission chemistry, without excessive time being used for calculations of the entire furnace. This modelling technique has already been successfully utilized in, for instance, designing new burner arrangements in coal-fired furnaces.

The modelling has also been applied to the development of diesel engines, although the problems involved in describing the evaporation, ignition and combustion of oil drops have not yet been completely solved. As an example, Figure 2 presents the pressure in an engine cylinder as a function of

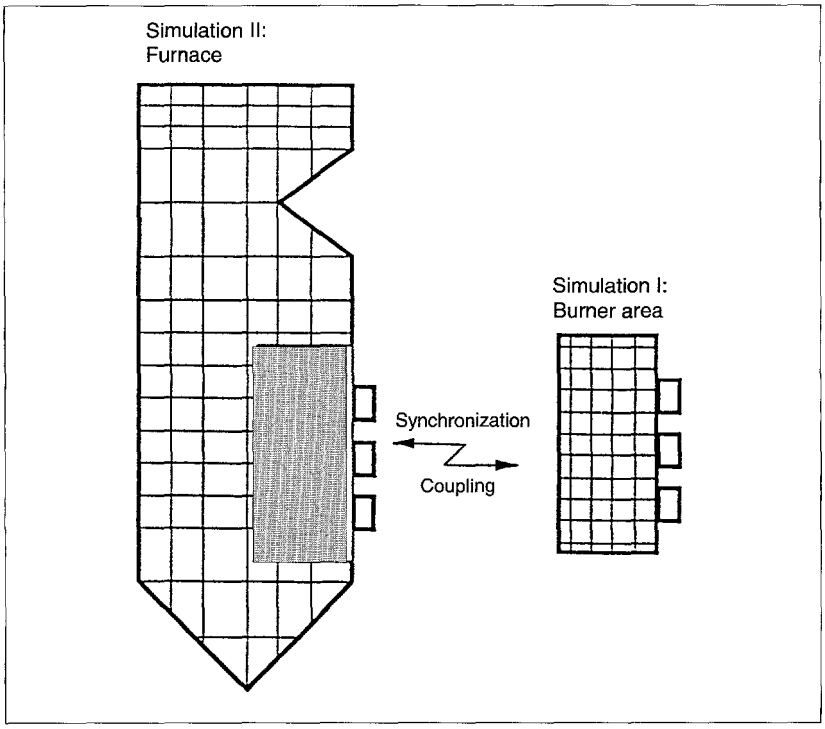


Figure 1. Modelling of the furnace of a large pulverized-coal boiler using multigrid technique

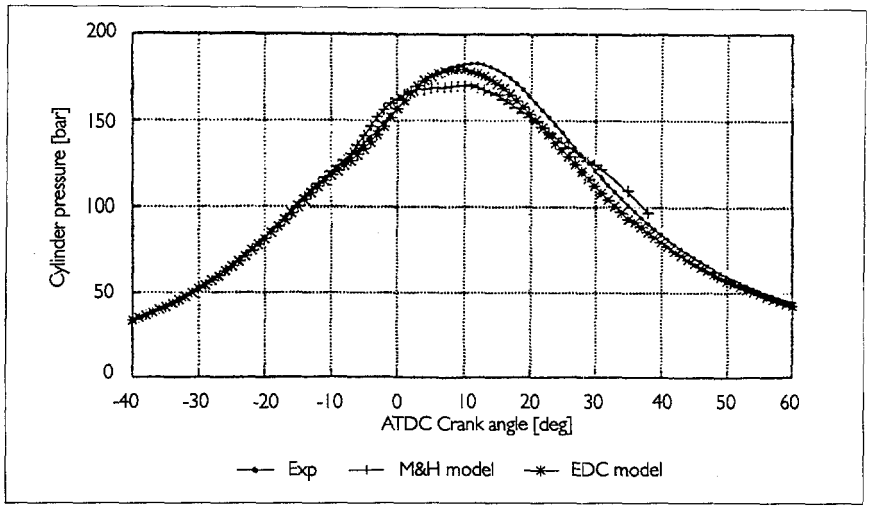


Figure 2. Cylinder pressure in a diesel engine as a function of the crank angle. The continuous line depicts measurement results, the broken line depicts modelling based on the Eddy Dissipation Concept, and the dotted line depicts modelling based on the more recent Magnusen-Hjertager model.

the crank angle, according to measurements and two different gas combustion models.

In the modelling of black liquor recovery boilers, the distributions of temperature and heat flux density can already be calculated quite accurately. Modelling of NO_x emissions is currently being developed.

Modelling of the phenomenon occurring in the furnace or 'riser' of fluidized bed combustors has also attracted substantial interest under the LIEKKI programme. The multidimensional modelling of flows in the riser still faces considerable challenges, mainly concerning the description of particle-to-particle interaction.

The interaction of the turbulent mixing of gases and chemical reactions plays a key role in modelling the formation of gas emissions from combustion processes, and is being studied by a number of research groups around the world. The LIEKKI programme comprises two related projects, which compare different approaches by calculating the relevant phenomena in different ways.

Another important result of the modelling research is that it has increased Finnish industry's confidence in the potential offered by modelling, encouraging it to invest in the necessary research. In fact, a number of experienced researchers have left university research under LIEKKI 2 to join private companies. The programme's good modelling results have also helped to increase interest in the field, resulting in the initiation of the Computational Fluid Dynamics (CFD) Technology Programme in Finland in 1995 to improve numerical calculation and find applications outside combustion processes.

2.2 The chemistry of gaseous emission components

Today, combustion chemistry is crucial to the development of all combustion processes. The flue-gas concentration of many undesirable substances, such as sulphur and nitrogen oxides, gaseous organic compounds and soot, can already be reduced considerably in the furnace during the combustion process. This is almost always a better solution both technically and economically than using separate scrubbers to remove emission components from cooled flue gases.

The LIEKKI programme has included numerous chemistry-related studies, divided into two review groups. Review group two includes projects related

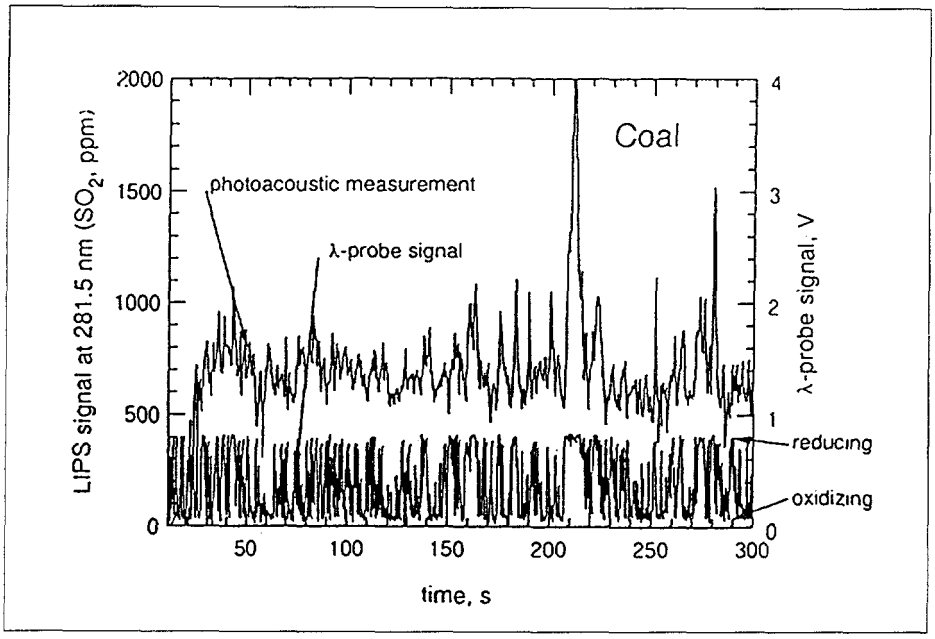


Figure 3. The variation of SO_2 concentration in the lower part of the riser of a 12 MW fluidized bed combustor, measured with a photoacoustic laserspectroscopy-based (LIPS) method and by air ratio measurements using a lambda probe. Coal was used as the fuel.

mainly to the chemistry of gaseous emissions, while studies concerning the behaviour of solid or liquid particles, such as ash, are included in review group three.

During 1993-1996 there were a total of 23 projects in review group two. Their total funding was some FIM 32 million. At the end of 1996, nine projects were under way.

Review group two has been engaged in developing techniques for sampling and analysing gas components and metal fumes in connection with fluidized bed combustion. As an example, Figure 3 presents the measurement results for local variation of sulphur oxide content in the lower part of the riser of a 12 MW circulating fluidized bed combustor. An *in situ* analysis method based on photoacoustic laser spectroscopy (LIPS) was used. In addition, the figure includes the corresponding local variation of the air-to-fuel ratio measured with a lambda sond. The figure shows that the new method is extremely fast and that it is able to monitor the rapid changes in local sulphur oxide concentrations caused by variation of the air ratio.

The nitrogen chemistry of fluidized bed combustion has been studied extensively under the programme, providing a fairly clear overall picture of how fuel nitrogen transforms into nitrogen oxides through various intermediate stages, and an idea of the factors which affect the different reaction routes (Figure 4). The most recent problems have concerned reactions related to the formation and decomposition of nitrous oxide, N_2O, and the relative practical importance they have.

In recent years, the nitrogen research carried out under the LIEKKI programme has concentrated on pressurized fluidized bed processes, requiring considerable experimental and theoretical work. The research carried out in Finland has been groundbreaking, while corresponding work is only just beginning elsewhere.

According to measurements, nitrogen oxide emissions from pressurized fluidized bed combustion in both full-scale and pilot plants are rather low, even lower than in atmospheric fluidized bed combustion. Reasons for this have been sought using various laboratory measurements and model cal-

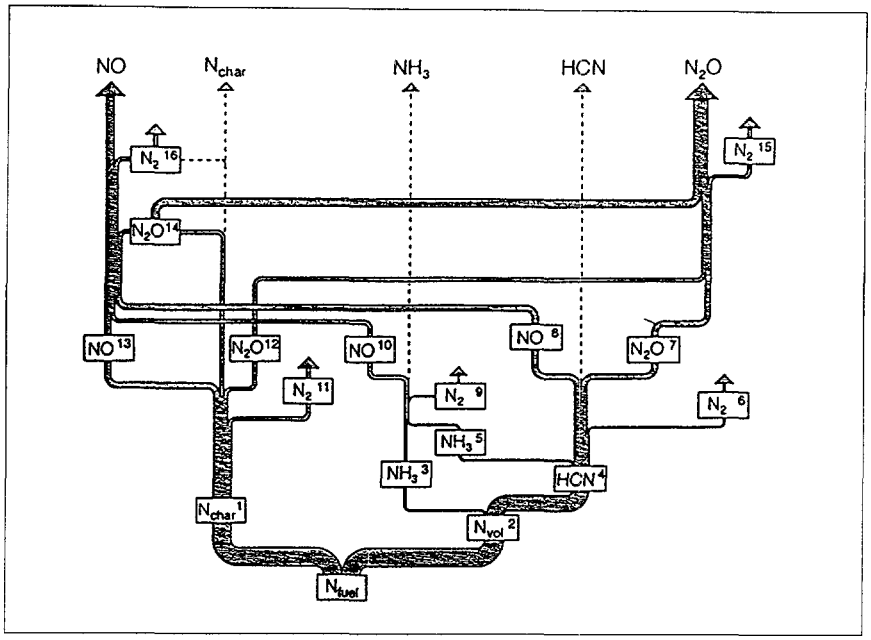


Figure 4. The reaction pathways of the fuel nitrogen in typical circulating fluidized bed combustion. When combustion begins, N_{fuel} (the fuel nitrogen) yields N_{char} (nitrogen which remains in the solid coke residue) and N_{vol} (nitrogen compounds released in gaseous form). As the combustion process progresses, both are further transformed into other compounds such as nitric oxide (NO) and nitrous oxide (N_2O).

culations, but no conclusion has yet been reached. In addition, the formation of nitrous oxide (N_20) in pressurized conditions seems to differ from that in atmospheric fluidized bed combustion. Further studies are required.

During gasification, fuel nitrogen is partly transformed into ammonia, which oxidizes very efficiently into nitric oxide when the product gas is burned out, and is therefore a potential source of NO_x emissions in integrated combined cycle gasification plants. Decomposing the ammonia in gasification gas into molecular nitrogen before combustion by adding suitable reactants and/or catalysts to the gas has been studied under LIEKKI. Very efficient decomposition of ammonia into molecular nitrogen has been achieved with small amounts of oxidizer added at high temperature (900C). In the presence of suitable catalysts, such as aluminium oxide, decomposition has been achieved at even lower temperatures (400—600C). Figure 5 depicts typical ammonia decomposition with oxidizer and aluminium oxide catalyst. The figure indicates that the decomposition reaction can lead to the formation of other nitrogen compounds depending on the conditions.

2.3 Particle behaviour, ash and aerosols

The research being carried out within the third review group concerns, for instance, the combustion and gasification of fuel particles, the behaviour of solid particulates and ash from fuel impurities, evaporation and condensation of alkali metals, formation and decomposition of tars, and the capture of sulphur in limestone. All projects emphasize the behaviour of the various solid particles related to combustion processes. Most of the projects comprise experimental work with laboratory or pilot equipment, but theoretical modelling and sampling from full-scale plants are also carried out.

By the end of 1996, the third review group had covered a total of 32 projects, with total funding of FIM 44.6 million. Of these, 22 projects were car-

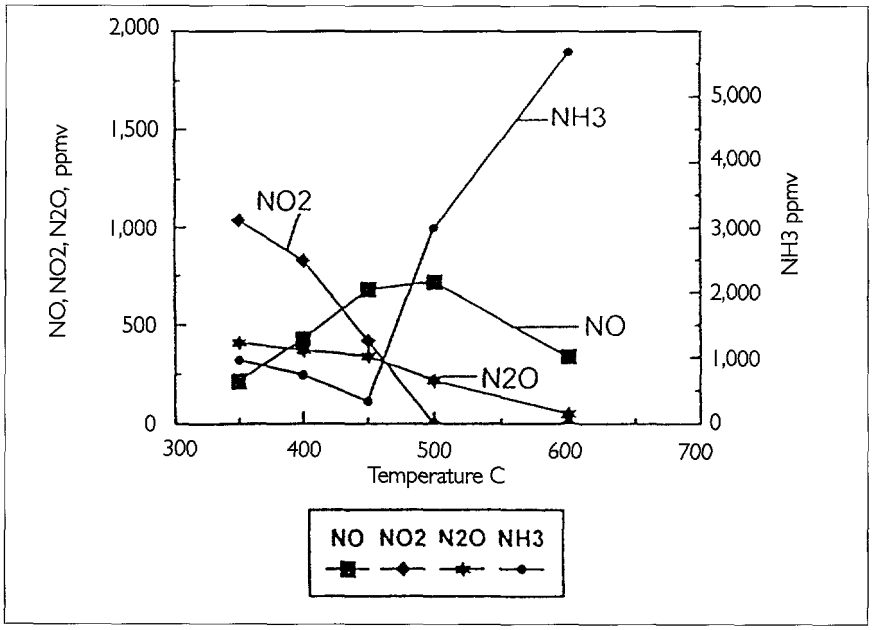


Figure 5. Conversion of gasification gas ammonia with additive. Laboratory test at a pressure of 20 bar and with aluminium oxide as catalyst.

ried out by universities and research institutions, while 10 were product development projects carried out by companies. At the end of 1996, 15 projects were under way.

Different fuels behave very differently in combustors. As the coal market is becoming increasingly international, a wider range of coal grades has become available to power plants, increasing the need to characterize the combustion properties of fuels. Moreover, the co-combustion of various biomasses and wastes with coal is on the increase, especially in many European countries.

The behaviour of fuel particles is being studied in the LIEKKI programme, especially for use in the new pressurized combustion systems. The projects have characterized the combustion and gasification behaviour of various grades of coal, peat and biomass under pressurized combustion or gasification conditions. In this respect LIEKKI has been groundbreaking, while so far only limited research has been carried out elsewhere.

Test equipment includes the following:

- pressurized entrained flow furnace, T_{max} = 1,300 °C, p = 2—20 bar
- pressurized thermobalance, T_{max} = 1,100 °C, p = 2—100 bar
- pressurized grid heater, T_{max} = 1,100°C, p = 2—30 bar
- pressurized laboratory-scale fluidized bed batch reactor, T_{max} = 1,000 °C, p = 1—20 bar
- continuous-operation laboratory-scale fluidized bed reactor, T_{max} = 1,000 °C, p = 1 bar

New measurement and analysis techniques specifically developed in other projects have been used in the test equipment. These included pyrometric temperature and size measurement of particles, a plasma-assisted spectroscopic method for measuring metal fumes and real-time continuous measurement of particle distribution.

The studies have resulted in a vast databank on the behaviour of various solid fuels in pressurized fluidized bed gasification and combustion conditions, and also on the effect of pressure and heating rate on the pyrolysis and combustion of particles, for instance. In addition to standard determinations (rate and total amount of volatile gas release and reactivity of the char residue), these characterization projects study the formation of tar compounds during gasification and the release of fuel nitrogen.

Figure 6 presents an example of unique combustion experiments with coal in a pressurized entrained flow furnace at a temperature of 800C and a pressure of 10 bar. The pyrometrically measured temperature distributions of the fuel particles at six different oxygen concentrations are presented in the figure.

Several projects concentrate on ash-related problems in the combustion process. The behaviour of fuel ash is crucially significant for many combustion applications. Ash may stick to heat-transfer surfaces, weakening heat transfer and causing corrosion problems (slagging/fouling). It can alter the properties of the bed material in fluidized bed combustion, causing the particles to stick together (bed sintering). It can also cause problems in flue gas scrubbers, etc.

The world of ash formation and transformation phenomena has proved to be both varied and complicated, and it has been approached in numerous different ways in projects. The ash-related problems of fluidized bed combustion are addressed in several projects. Both experimental and theoretical methods have been developed to predict the sintering propensity of ash from different fuels. Recently, the emphasis has been on the ashes from various biofuels, which present far more problems for fluidized bed combustion than the different coal grades do. The projects have also studied the distribution of the mineral substances in fuel into different size particles in fluidized bed combustion, using computer-assisted scanning electron microscopes (CCSEM) and advanced techniques for measuring aerosols. In addition to the main elements of ash (Si, Al, Fe, Ca, Mg), the potentially volatile alkali metals (Na, K) and harmful minerals (As, Be, Cd, Co, Cr, Mn, Ni, Pb, Sb, Zn) were monitored in the aerosol measurements. The ash-related problems were also studied in practical experiments under two projects carried out by participating companies.

Theoretical ash research has, for instance, worked to develop multicomponent and multiphase equilibrium analyses for various ash mixes in order to calculate their melting behaviour in different conditions. Development work has also been carried out on an aerosol model of the nucleation and condensation of vaporized compounds and the way they deposit onto surfaces. A model of this kind would allow the order in which compounds condense and the size distribution of condensing par-

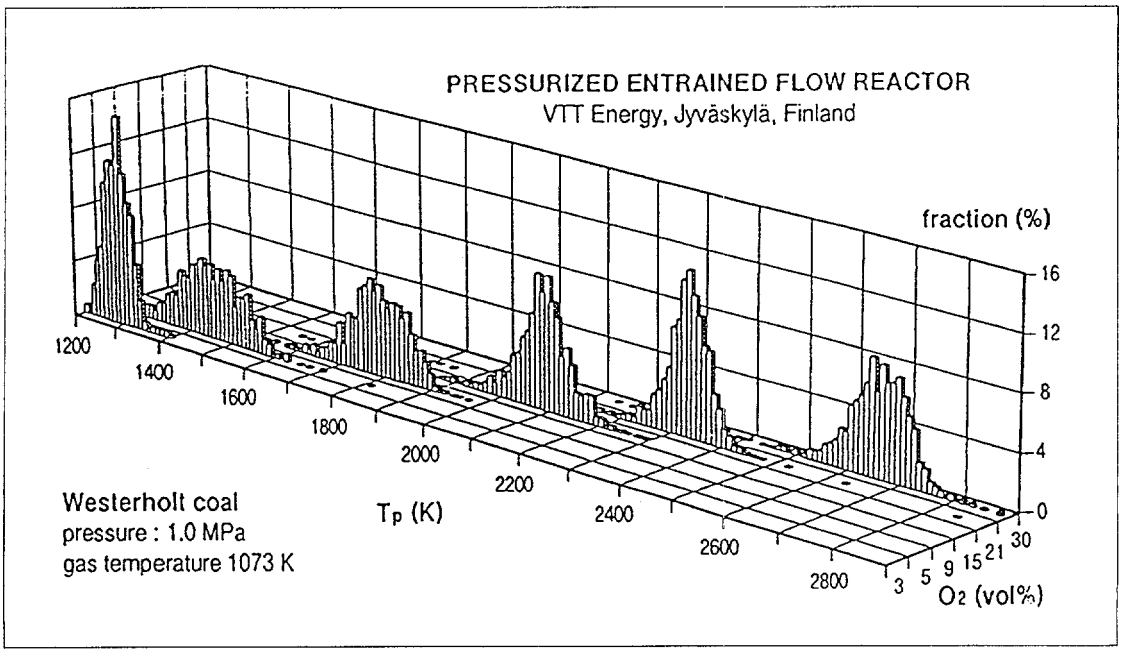


Figure 6. The temperature distributions of burning fuel particles at six different oxygen concentrations in a pressurized entrained flow furnace. Coal (Westerholt) burning at 10 bar and 800C.

ticles in cooling flue gases to be estimated. Both modelling approaches have been applied in describing the processes which lead to corrosion and fouling in the cylinders and valves of heavy-duty diesel engines, as well as in fluidized bed combustion. The study of oil ash behaviour relates to the particulate behaviour of various vanadium compounds.

In integrated gasification combined cycle processes, the solids in the gasification product gases must be removed extremely well before the gases can be led to the gas turbine. The required level of purity can be achieved with various ceramic filters, for instance, but not all the related problems have yet been solved. The filters are sensitive to mechanical damage and tend to clog. Moreover, gas filtration at high temperatures does not always prevent certain volatile metal compounds, especially alkalis, from passing through the filters.

Several studies on ceramic filters and vaporized alkalis are under way, aimed at developing measurement methods, measuring alkali vaporization during pressurized combustion in a pulverized flow furnace and in a pressurized circulation fluidized bed pilot reactor, and testing the adsorption of alkali fumes into a suitable sorbent at high temperature.

In addition, the third review group has studied how sulphur can be captured with limestone or dolomite in pressurized conditions. Research has dealt with the absorption of both sulphur dioxide (combustion conditions) and hydrogen sulphide (gasification conditions). The way limestone reacts with sulphur compounds depends on whether the lime is in calcium carbonate form or whether it has been calcined into calcium oxide. Calcium will not calcine in the conditions typical of pressurized fluidized bed combustion, while in pressurized gasification it may either calcine or remain uncalcined, depending on the conditions. The studies have been able to chart the ability of various grades of limestone and dolomite to capture sulphur in different conditions, as well as to shed light on how to optimize capture in practice. The results have also been generalized as a particle model describing the complex sulphation process of sorbent particles.

2.4 New combustion and gasification techniques

This review group comprises R&D projects which seek to develop new process concepts for combustion and gasification. The group's projects are all very practically oriented.

Figure 7 illustrates how various processes suit different size power plants. The capacity and costs of a conventional power plant process based on atmospheric combustion and a steam turbine are fairly well known. Thus, all new techniques should, after a development and demonstration stage, offer lower power generation costs than existing ones. The projects in this review group concern the processes indicated in Figure 7.

All three projects suitable for the smallest plant-size (less than 5 MW of electrical power) are being developed mainly for biofuels. The target is small-scale generation with local fuels at, for instance, saw mills and farms. According to estimates, these processes will yield roughly the same efficiency of power generation as small steam generation plants (27—30%). This review group contains a study on a gasification-based power plant concept with diesel engine combustion of the gas. It also includes a process incorporating direct combustion of pulverized wood in a gas turbine.

The main emphasis of the applied research carried out under LIEKKI is, however, clearly on the development of processes based on pressurized air-blown gasification, hot clean-up of the gases (simplified IGCC or Integrated Gasification Combined Cycle) and pressurized fluidized bed combustion. These processes use a combined cycle (combined gas and steam turbine process) for solid fuels. This is expected to offer better generation efficiency and lower plant investment costs.

The fourth review group has included a total of 27 projects, 14 of which have been carried out by companies, and the remainder by universities or research institutions. Total funding was FIM 42 million in 1993—1996.

The main task of many of the projects has been to evaluate the technical and commercial feasibility

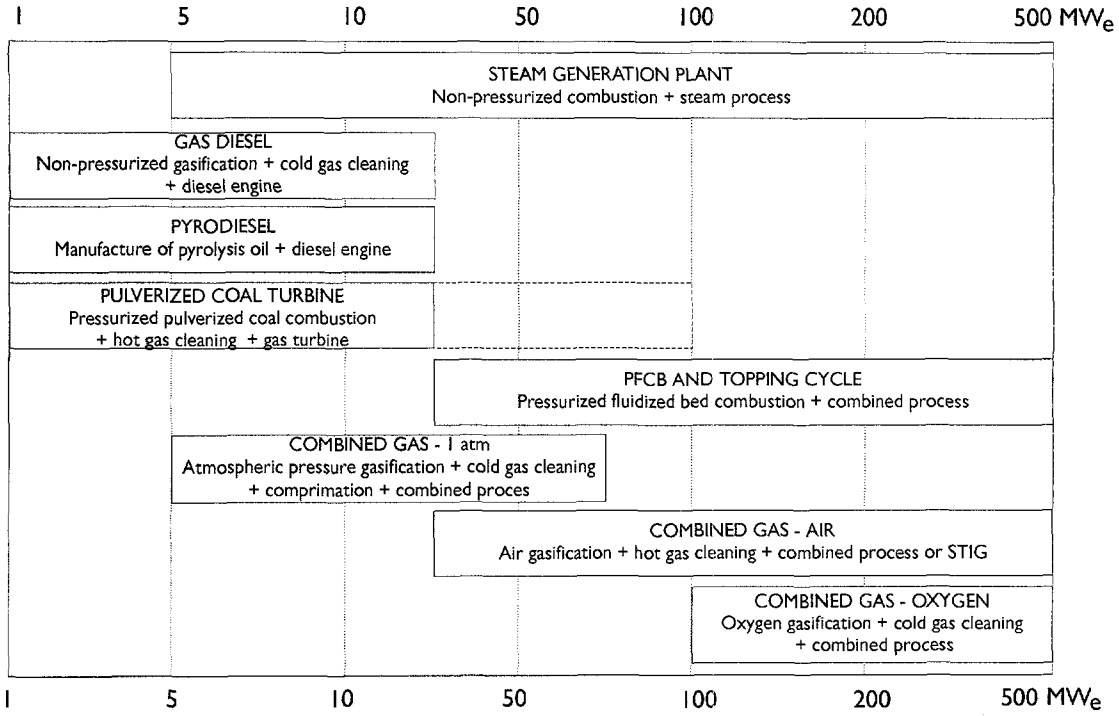


Figure 7. New solid-fuel techniques under development, suitable for various plant sizes and competing with the conventional steam generation process.

and potential of processes and applications competing with conventional combustion techniques. The suitability of various biofuels for gasification processes was studied in a comprehensive project which is also connected to the EU's JOULE research programme. A total of 15 different biomasses were characterized. The results indicate, for instance, that the gasification properties of fastest-growing energy biomasses and agricultural wastes are much more problematic than those of Nordic wood-based fuels. The main reasons for this are the difficulties arising from the melting behaviour of the ash, and the high alkali, chlorine and nitrogen concentrations.

Furthermore, the same project applied process model calculations to study the efficiency of various techniques using biomass in four electrical-power categories: 1) 0.2 MW, 2) 5—10 MW, 3) 20—30 MW and 4) 40—80 MW. The process options were:

- non-pressurized gasification + diesel (categories 1, 2 and 3)
- pressurized fluidized bed combustion + hot gas cleaning + the STIG process (2 and 3)
- pressurized fluidized bed combustion + hot gas cleaning + combined cycle(3 and 4)

The studies proved that, for economic reasons, pressurized processes are not suitable for plants generating less than 30—50 MW_e. When used in plants generating more than 50 MW_e, however, gasification combined cycles appear to be competitive with biomass plants using conventional combustion techniques.

The progress of Finnish companies' pilot and demonstration plant projects was also monitored in this group. The demonstration project carried out jointly by Ahlstrom (now Foster Wheeler Energy Oy) and the Swedish power company Sydkraft AB was especially interesting. In this project, the world's first simplified IGCC biofuel plant comprising all the subprocesses was constructed in Värnamo, a municipality in southern Sweden. The plant, based on circulating fluidized bed gasifica-

tion, produces 6 MW of electricity and 9 MW of heat and has already been tested for about two years. During the test runs, the behaviour of different fluidized materials has been studied and the functioning of a ceramic filter has been demonstrated. According to test reports, carbon conversion in gasification has been extremely good and the heating value of the product gas high.

A combined cycle process based on fluidized bed gasification and suitable for coal and biofuels has been developed by Enviropower Inc., now Carbona Inc. The process was originally developed for coal in the USA (Institute of Gas Technology), but pilot tests under the LIEKKI programme have shown that the process is also very suitable for biofuels. The maximum fuel capacity of the pilot plant used is 15 MW, the pressure 30 bar and the operating temperature 1,100C.

The experimental work carried out within the fourth review group has concentrated around the PFBC/G test equipment at the Helsinki University of Technology in Otaniemi, Espoo.

The maximum operating pressure of the equipment is 10 bar, the temperature 950C and the fuel feed 300 kW in the gasification tests. The equipment includes continuous-operation feeding devices for coal, biofuels and sorbents, the actual gasification reactor (bubbling fluidized bed), a particle recycle cyclone, equipment for testing ceramic filters and a burner for product gas combustion. The equipment allows a wide range of measurements. Under the LIEKKI programme, it has been used in numerous measurement campaigns, concerning, for instance, the gasification conversion of fuels and fuel mixes, alkali behaviour, reactions of the fuel nitrogen, sulphur capture, tar formation and particle removal with ceramic filters.

The equipment at Otaniemi has also been used for measurements of what are called topping cycle processes. In a typical topping cycle process the fuel is pyrolyzed or gasified only partly in the first reactor. The remaining char residue is led to a separate pressurized fluidized bed reactor for final combustion. By combining these reactors in a suitable way a second-generation combined cycle power plant can be constructed, with a power generation efficiency significantly higher than in a simplified IGCC process. Pressurized fluidized bed combustion tests were made on residue char with the test equipment at Otaniemi. The char was obtained from British Coal gasification tests on Kiveton Park coal, which also used limestone for sulphur capture. Thus the coke residue contained large amounts of sulphur in the form of calcium sulphide. Among other things, the tests indicated that in suitable conditions the combustion efficiency was high and that the sulphide captured in the sorbent could be oxidized into sulphate without large emissions of gaseous sulphur.

2.5 Black liquor

The fifth review group in the LIEKKI programme gathered together R&D projects involving the combustion of black liquor, the by-product from pulp production. By the end of 1996, the group had dealt with a total of 24 projects, six of which were product development projects carried out by companies. Total funding of the black-liquor projects came to FIM 23.1 million by the end of 1996.

The black liquor research carried out under the programme concentrates both on improving the conventional recovery boiler process and on developing processes based on the gasification of black liquor.

The key questions pertaining to the operation of the recovery boiler concern the varying properties of liquors, flue gas emissions from the boiler, and fouling of the boiler's heat-transfer surfaces. Projects within the group have developed new laboratory tests for determining the combustion properties of liquors. The tests measure quantitatively the combustion process of a single liquor drop. The tests provide data on, for instance, characteristic combustion time, pyrolysis yield, swelling factors, etc. for each liquor studied. These methods have been used to characterize several dozen liquor samples from various processes around the world. The studies indicate that liquors from different plants have very different combustion properties. This information is of material importance for the design of recovery boiler operation and control. The rather complex connection between combustion properties and liquor chemical composition has also been investigated.

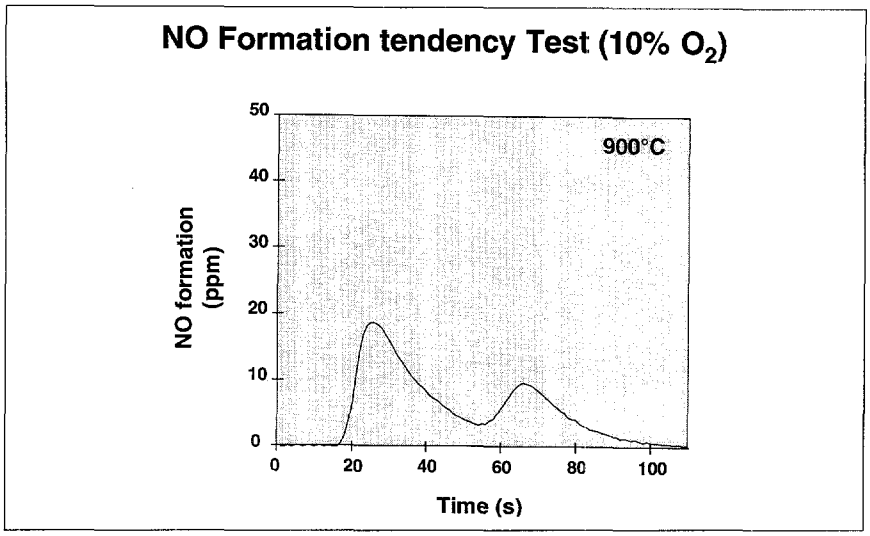


Figure 8. Formation of nitrogen oxide in the combustion of a single drop of black liquor. Combustion conditions: furnace temperature 900C, oxygen concentration in gas 10%, approximate drop size 15 mg.

Extensive work has also been done on the nitric oxide emissions of recovery boilers during the programme. The nitric oxide in the flue gas emitted by recovery boilers originates mainly from the nitrogen originally present in the liquor. The release and transformation of this nitrogen in connection with combustion has been studied by firing single liquor drops in controlled laboratory conditions and analysing the nitrogen compounds released from the drop during combustion. Figure 8 presents the results from a laboratory measurement of the nitric oxide emissions from the combustion of a single liquor drop. The figure clearly shows how the nitrogen in the liquor is released in two stages, first during pyrolysis, together with the devolatilized gases, and then towards the end of coke combustion. In fact, this research has already provided a picture of the main reaction pathways in the recovery furnace followed by the nitrogen in the liquor. At the same time, the study has indicated several potential technological ways to limit nitric oxide formation in the combustion process.

Several projects have concentrated on investigating the flue-gas dust released in liquor combustion. The dust tends to foul the boiler's heat transfer surfaces, and both boiler manufacturers and operators are working hard to find ways to minimize this. Projects in the programme have measured dust formation and studied the composition and structure of dust using various advanced measurement and analysis methods. Furthermore, particle formation has been described using the aerosol models described above.

A key precondition for predicting dust formation is the amount of different elements released during the combustion of a black liquor drop in different conditions. Several research methods have been applied and we now have a much clearer figure of how sulphur, sodium, potassium and chlorine are released, although the quantitative description of the release processes as a function of the conditions is still quite inaccurate.

At the furnace exit, the dust ingredients are almost entirely molten and crystallize slowly as the flue gases cool. It has been suspected that the dust's melting point, or the role played by the molten phase in the dust, is essential in determining the dust's tendency to stick to surfaces at various points in the flue gas duct. A thermodynamic model based on multicomponent and multiphase equilibriums has been under development in the programme. With this model, the melting range of a salt mixture can be determined (initial melting point, sticky temperature, flow temperature, etc.) when the composition of the mix is known. The model has been validated with DTA/TGA determinations of synthetic salt mixes. For instance, the model can be

used to evaluate changes in the fouling of heat surfaces caused by dust, as its potassium or chlorine content increases when a mill's liquor cycle is closed.

The spraying of liquor into the furnace is the most important factor in controlling combustion in recovery boilers. In the programme, the drop formation at different nozzles in different conditions has been measured using video techniques. Studies have been made on injection with full-size nozzles into a trial spraying chamber and, later, also on direct injection into the recovery furnace. These measurements have provided new knowledge about drop formation. It seems that the drop size is maximal when the liquor's boiling point is reached (approx. 120C), after which the liquor probably boils partly in the nozzle, causing the drop size to decrease considerably.

Details related to the process of gasifying black liquor have also been studied in the programme, including the behaviour of liquor in pressurized pyrolysis and gasification. The test equipment included a pressurized thermobalance, pressurized grid heater and pressurized drop tube furnace. The results have provided data on the gasification rates of different liquors, liquor swelling, reactivity of the char residue, etc. at different atmospheres, temperatures and pressures. The studies have concentrated on what is called low-temperature gasification, that is, gasification at temperatures ranging between 700 and 750C. Low-temperature gasification is a process concept where, for instance, a fluidized bed reactor has been proposed as the gasification reactor. This application requires that the salt residue is not in a liquid state, as this might lead to agglomeration of the bed material in the reactor.

2.6 Conventional combustion technology and waste incineration

In this review group, research has concentrated on the development of mainly conventional co-combustion techniques using different waste materials. In co-combustion, waste or fuel refined from waste (Refuse Derived Fuel, RDF, Packaging Derived Fuel, PDF, etc.) is used together with a conventional fuel. In such applications, the proportion of waste is typically 10—30%. The research reflects the prevailing trend, which seeks to utilize as many of the otherwise useless raw materials (wastes) as possible for fuel, or at least to dispose of them without harmful emissions and to reduce dumping.

By the end of 1996, this review group had included 14 projects, eight of them R&D projects carried out by companies. The group's total funding for 1993—1996 came to FIM 30.7 million.

The fluidized bed combustors used in industry or in district heating plants are in many ways very suitable for co-combustion, and the combustion of different waste materials was therefore tested in several different fluidized bed combustor sizes and types. The tests concentrated on observing changes in the emissions from combustion or in the operation of the boiler. In general, the level of conventional emissions of flue gas from co-combustion did not differ from the general level of solid fuel combustion. Tested multifuel boilers are designed for the combustion of fuel grades containing large amounts of volatile substances and a wide range of particle sizes. Blending waste fuel causes no major change in these properties.

The combustion tests also focused on the content of the numerous hydrocarbon compounds. Special attention has been given to compounds of hydrocarbons and chlorine, such as polychlorinated dibentzo(p)dioxins and furans (PCDD/F). Figure 9 presents PCDD/F emissions in flue gas from different-size multifuel boilers and with different fuel mixes. The results are presented as a function of the chlorine concentration in the fuels. The chlorine concentration of the main fuel used was 0.05—0.1%; higher figures indicate chlorine introduced by waste. The measurements show that only when waste had increased the chlorine concentration to more than 0.3% was there a danger that the concentrations weighted by toxicity coefficients would exceed the set limits.

Possible slagging and corrosion of the boiler caused by blend combustion was studied by carrying out long-term tests with an industrial circulating fluidized bed combustor, using 30—40 tonnes of various waste materials each day for more than a year. The use of waste as fuel did not cause any

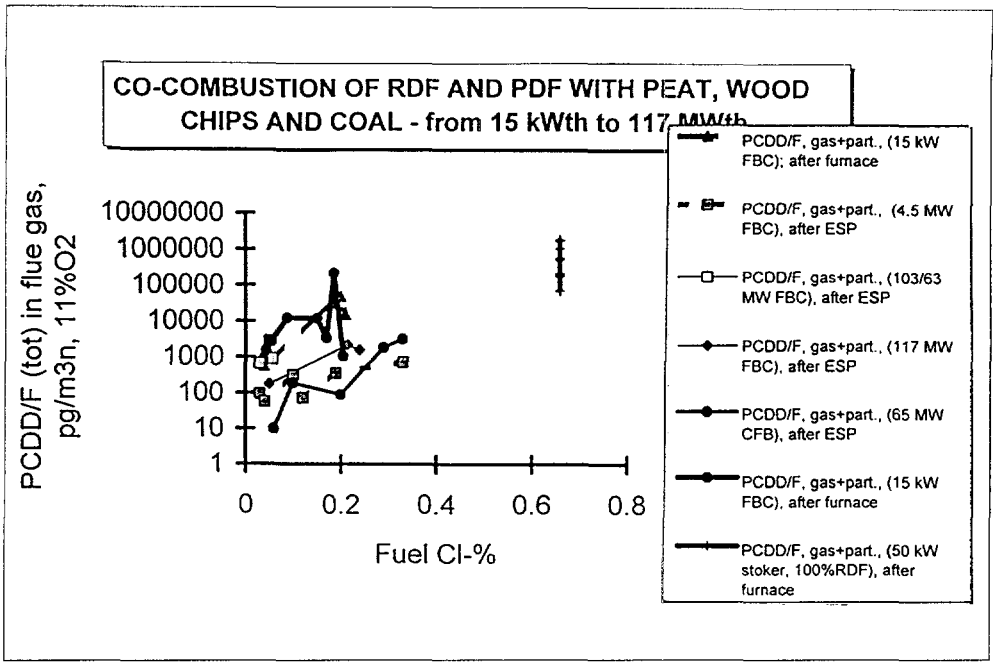


Figure 9. PCDD and PCDF emissions from different size boilers and different fuels as a function of the fuels' chlorine concentration.

particular slagging or fouling problems, nor did it increase the need for soot blowing. Furthermore, the measurements did not indicate any corrosion-induced changes in the thickness of the tube walls, nor did short-term (one month) high temperature corrosion tests with materials at 500 and 550C indicate any signs of chlorine corrosion, for instance.

Factors affecting PCDD/F emissions were also studied in laboratory conditions.

In addition to the blend combustion of RDF and PDF materials, the combustion of car tyres in a cement kiln and the combustion of wood-processing sludge in fluidized bed combustors were studied in corporate development projects.

3 Effectiveness of results

The six-year LIEKKI 2 programme has been operational for four years now (1993—1996). Cooperation in combustion and gasification technology began in Finland back in 1988, with the implementation of the five-year LIEKKI and JALO combustion and fuel-processing-technique programmes. As LIEKKI 2 is a direct continuation of these two, national cooperation in the field has thus continued for almost nine years. Although we are here concerned with the results and effect of the LIEKKI 2 programme, it is clear that these nine years have been crucial for the programme's impact.

Impact is approached from two points of view: the results of the research activity itself, and the usefulness and importance of the results for industry.

The LIEKKI 2 programme's importance for combustion technology research has been decisive. An annual average of 115 researchers have worked on programme projects (Table 1). The programme has covered most of the public research on combustion and gasification technology in Finland. In several fields, the research carried out under LIEKKI has gained a considerable standing internationally. Table 2 presents a list of the international top publications in which LIEKKI 2 results have been reported. The range of publications indicates the multidisciplinary nature of combustion technology research.

Table 1. Man-years in LIEKKI 2 projects 1993—1996.

	1993	1994	1995	1996	1993–1996
Total man-years	125	126	113	94	458
– public projects	67	76	74	64	281
– corporate projects	58	50	39	30	177

Table 2. List of publications in which LIEKKI 2 results have been reported.

Publication (1993–1996)	Articles submitted on projects in LIEKKI 2
Aerosol Science and Technology	1
Appita	1
Applied Optics	1
Biomass & Bioenergy	1
Bioresource Technology	2
Chemical Physics Letters	2
Chemosphere	8
Combustion and Flame	6
Combustion Science and Technology	1
Energy & Fuels	4
Environmental Science & Technology	1
Fuel	17
Fuel Processing Technology	3
Industrial & Engineering Chemistry Research	3
International Journal of Power and Energy Systems	1
Journal of Aerosol Science	1
Journal of Analytical and Applied Pyrolysis	2
Journal of the Chemical Society, Faraday Transactions	1
Journal of Hazardous Waste and Hazardous Materials	1
Journal of Molecular Structure (TheoChem)	1
Journal of Physical Chemistry	1
Journal of Pulp and Paper Science	6
Journal of Radioanalytical and Nuclear Chemistry	1
Journal of the Air & Waste Management Association	1
Journal of the Institute of Energy	1
Nordic Pulp and Paper Research Journal	1
Oil Shale	1
Paperi ja Puu - Paper and Timber	3
Talanta	1
TAPPI Journal	3
Waste Management & Research	1
TOTAL	78

Table 3. Degrees passed completely or partly in association with LIEKKI 2. The table also includes the first five years of the LIEKKI programme (1988—1992).

	Liekki 2					Liekki	Total
	1993	1994	1995	1996	1993-96	1998-92	1988-96
Diplomas	6	11	6	5	28	33	61
Licentiate theses	6	4	5	2	17	14	31
Doctoral theses	3	1	1	2	7	5	12

The programme projects have often included research leading to academic theses. Table 3 contains information on degrees passed during the LIEKKI programme.

Thanks to its review groups, annual seminars and other contacts, exchange of information and cooperation have become increasingly active during LIEKKI 2. In fact, a large number of the programme projects have involved several research groups in recent years.

The success of research activities and cooperation is also attested by the LIEKKI research groups' success in competing for acceptance under EU research programmes. In 1993—1996, a total of 13 Finnish combustion or gasification-related projects were accepted for these programmes, most of which are also reported on under LIEKKI 2.

4 Significance to industry – interim assessment by participating companies

This chapter discusses the LIEKKI 2 programme's importance to Finnish industry and energy economics on the basis of the evaluation made by the participating companies in autumn 1995. This interim assessment has been published in its entirety in Finnish in the programme's 1996 yearbook (LIEKKI 2 Vuosikirja-Årsboken 1996, part III, Åbo Akademi University 1996, ISBN 951-650-711-5).

The LIEKKI 2 programme in its entirety and all its research areas serve the product development, design and marketing of companies committed to the programme very well.

The programme has generated internationally highly competitive know-how in combustion and environmental technology. Not only does this know-how benefit the companies committed to the programme, it also has wider significance for Finland's energy economics, environmental management, forest and other process industries, and research and educational institutions and consultancies operating in these sectors.

The programme offers very good international contacts, which means that in an international forum Finland appears as a leader in combustion and environmental technology. Moreover, the contacts also put Finnish researchers in touch with relevant research institutions worldwide.

Every company committed to the programme operates internationally, although a significant part of their operations takes place in Finland and their research and development is concentrated here.

The Executive Committee believes that programme activities so far correspond well to the aims set.

As combustion technology will remain important in energy management well into the future, LIEKKI 2 will remain central to Tekes' energy technology research programmes.

Finnish companies and equipment suppliers in the energy sector are very committed to the pro-

gramme. As they serve both the domestic and the international market, the programme has been designed, and its projects selected, with both the Finnish and the international energy market in mind.

Good combustion technology know-how allows new applications to be developed to serve an increasingly wide range of companies. In addition to the main concern - the special needs of the forest industry - this involves the needs of SMEs engaged in developing small-scale combustion.

Although participation in EU research programmes is important, the substance they offer is not sufficient to replace Finnish combustion research. Sectors vital to Finland - wood-processing energy, for instance - are poorly represented in EU programmes, which is why it is important for Finland to have its own national research programme concerning combustion techniques.

In the Executive Committee's opinion, aims set for the LIEKKI programme are largely satisfactory. Attention must, however, be paid to all external demands caused by changing markets or scientific or technical advances.

The Executive Committee believes that a considerable part of the programme's emphasis must focus on projects which best improve the competitiveness of existing products on the global market. Although cooperation between companies and research institutions does function smoothly, it should be further improved.

In view of the above, the Executive Committee proposes that the programme be continued with the present volume of funding and without any major changes in its content.

In 1996, the Executive Committee had the following members:

- Chairman: Lars Gädda, Neste Oy
- Stefan Gros, Wärtsilä Diesel International Ltd Oy
- Reijo Kuivalainen, Foster Wheeler Energia Oy
- Kauko Janka, Kvaerner Pulping Oy
- Reijo Karvinen, Tampere University of Technology
- Martti Korkiakoski, Tekes
- Markku Raiko, IVO International Oy
- Esa Vakkilainen, Ahlstrom Machinery Oy
- Sirpa Salo-Asikainen, Ministry of the Environment
- Mikko Kara, VTT Energy

LIEKKI 2 research areas (chairman in 1996):

- Modelling the furnace process (Reijo Karvinen, Tampere University of Technology)
- The chemistry of gaseous emission components (Pia Kilpinen, Åbo Akademi University)
- Ash, aerosols and the behaviour of particles (Esa Kurkela, VTT Energy)
- New combustion and gasification techniques (Martti Korkiakoski, Tekes)
- Black liquor (Esa Vakkilainen, Ahlstrom Machinery Oy)
- Conventional combustion techniques and waste incineration (Juha Huotari, SERMET Oy)

Chapter 7
MOBILE
Energy and the environment in transportation

Nils-Olof Nylund, VTT
Juhani Laurikko, VTT

1 Background and objectives

Traffic and transportation are essential to a developed society. Societies based on global market economies and world-wide distribution depend on transportation services. Traffic is all too often seen as an obstacle and an environmental risk, while the production and business activity it makes possible is forgotten. According to estimates, the indirect gain generated by traffic in Finland is some FIM 200 billion each year (Kallberg, Tieliikenteen Tietokeskus Oy). The direct transportation costs of final industrial products are some FIM 24 billion each year; following employment costs, they are the second highest variable cost item. Revenues from fuel, engine, machine, vehicle and vehicle component exports are estimated at FIM 10 billion annually.

Of course, traffic, and especially its growth, does cause problems. Although traffic's share of total energy consumption (some 15%) and contribution to carbon dioxide emissions (some 18%) are lower in Finland than in any other industrial country, it still accounts for some 40% of consumption of oil-based energy in Finland. The use of other than oil-based forms of energy is more difficult and expensive in traffic than in other sectors, and traffic will most likely continue to be dependent on fossil fuels for a long time.

Traffic's contribution to total carbon monoxide, hydrocarbon and nitrogen oxide emissions in Finland is significantly greater than its share of energy consumption; approximately 75% of carbon monoxide and 50% of hydrocarbon and nitrogen oxide emissions are traffic-originated. Particulate emissions correspond roughly to the share of energy consumption. However, the impact of traffic emissions is intensified by their health-related effects; traffic's contribution to air impurities in urban areas is even higher than to emissions.

In a global perspective, however, traffic congestion and the quality of urban air are not very bad in Finland, although the cold winters do increase emissions, especially from petrol-powered cars. A firm reminder of the fact that problems of air quality do, nevertheless, affect us was last received in December 1995, when the quality of air in the Helsinki region was satisfactory at best. For three days in late December, air quality was very bad in Helsinki and several other cities and urban areas in southern Finland as well, because of profuse emissions and exceptional weather.

Before 1991, energy research on the traffic sector and other traffic-related research lacked any logical structure. In 1991—1992, traffic was included in the first stage of the Ministry of Trade and Industry's SIHTI programme. As this stage of SIHTI covered a rather extensive field, it proved impossible to set up a strong network of know-how and contacts. A substantial improvement took place when the traffic sector was given its own research programme, called MOBILE.

The MOBILE programme was given the following mission statement: To show how goods and people can be transported in Finnish conditions with the lowest possible consumption of energy and volume of harmful emissions. Promoting the development of exportable products in Finnish industry was included as an additional aim.

The planning of MOBILE was based on the premise that it would be a technology programme which

Table 1. Points of emphasis.

Type of traffic	Small pass. cars/ delivery vans	Buses	Trucks	Off-road applications	Trains	Ships	Air traffic
Contribution to domestic emissions	+	o	+	+	o	o [1]	o
Potential impact on emissions in Finland, during the programme period							
• utilization rate	++	+	+	+	-	-	-
• optimization of use	++	+	++	+	-	-	-
• technical development	-	+	+	++	+	++	-
• fuel	++	++	++	++	+	++	-
Need to re-inventory emission volume	+	o	+	+	o	o	o
Product development potential (domestic and international markets)							
• vehicle/engine	-	+	+	+ [2]	++	++	-
• components	+	++	++	++	++	++	-

++ significant + limited - some o small
[1] significant sulphur emissions, however [2] tractors, working machinery, etc. ++

would not address questions related to community structure, allocation of activities and the formation of traffic demand.

Although the energy technology programmes were originally designed for the Ministry of Trade and Industry, traffic does involve the activities of other ministries as well. This is why the Ministry of Transport and Communications and the Ministry of the Environment were also included in the planning stage, in the Executive Committee's work and in interim assessment.

During the planning stage, the various sectors of traffic were studied systematically and the relevant demand for research and potential for product development were assessed. Because of its limited production of passenger cars, Finland has little influence on the development of passenger-car technology. On the other hand, Finland is strong in fields such as fuel development, off-road and marine engines, exhaust gas aftertreatment components and certain customized heavy-duty vehicles. Finding solutions to problems concerning operation in cold conditions is important to Finland, and no significant international emphasis can be expected in the field.

It was realized right at the beginning that the traffic research programme should not be restricted to technical development alone; traffic systems should be covered more comprehensively in order to ensure a properly functioning programme. The programme was therefore divided into two main sectors, technical development and systems research.

Funding has laid emphasis on technical development, which has received some 70% of the total available. Under the 1993 general plan, the technical development sector conducted research on motor fuels, engine technology and development of equipment, as well as demonstrations and trial runs.

The systems research sector of MOBILE includes research related to the use of vehicles and the loads carried by them, traffic flow, exhaust gas measurement and emission inventory. According to the general plan, the sector focuses on vehicle usage and load patterns, strategic planning, emissions, air quality and assessment of costs.

Fuel production is central to traffic-related use of energy and its environmental impact. Thus, the fuel-engine-aftertreatment axis for exhaust gases was given special emphasis. For instance, the technology of lightweight structures and aerodynamics was excluded, despite its significance for the use of energy and the high level of related expertise in Finland. The inclusion of general vehicle technology in future programmes should, therefore, be taken into consideration.

The following were listed in MOBILE's general plan as the principal research areas:

- different fuels, their use and performance
- engine-technology-related methods for reducing emissions/low-emission diesel engines
- development of exhaust catalysts and other technical solutions for emission reduction
- development of low-emission vehicles for urban services
- reducing the consumption of energy by improving the internal efficiency of traffic systems
- effects of conditions particular to Finland.

During the programme's first three-year period, the general plan was followed quite closely. The evaluation carried out in autumn 1995 showed that the plan was still up-to-date and serviceable, and it has therefore been adopted as the basis for planning the second period.

Work related to modelling and application of models has, however, grown more important and should now be included among the principal areas of research. One especially interesting and important application is the use of models related to air quality in urban areas. They offer completely new potential for assessing everything from the effects of reductions in traffic-originated emissions to air impurities. This is very significant, as the calculations of mere emission volumes and reductions do not always provide accurate data.

2 Results in major research areas

Technical development has concentrated on engine fuels and diesel engines. On the other hand, development and demonstration projects concerning various alternative fuels and technologies have received considerable publicity.

Even the systems sector of the programme has generated a large number of products, comprising different kinds of models and the information needed for their application. They are important tools for determining the properties of actual commercial products and for product assessment. Another product of a kind is the readiness to carry out very extensive exhaust gas analyses which has developed and improved gradually during the programme.

2.1 Motor fuels

Both petrol and diesel fuels can be improved significantly, reducing the environmental impact caused by their use. Key terms include reduction of aromatic compounds and sulphur, control of distillation ranges and a more discriminating selection of fuel components. The fuels produced with the above methods are often known as reformulated (petrol or diesel). The development of a fuel has considerable impact, since it affects all vehicles using the fuel almost immediately, contrary to improvements in vehicle technology, which only yield benefits gradually as old cars are replaced by newer models.

The reformulation of fuels typically reduces what are called regulated emissions (carbon monoxide CO, total hydrocarbons HC, nitrogen oxides NO_x, particulates) by 10—30%. It thus represents only a partial solution to traffic-related emission problems. It is nevertheless important, since it can reduce the amount of certain extremely harmful, e.g. carcinogenic, exhaust components by as much as 50—70%.

Because of the solid foundation SIHTI provided for research and product development conducted

under MOBILE, reformulated diesel and petrol already appeared on the market during MOBILE's first three-year period. It is largely thanks to MOBILE that Finland is a European pioneer in reformulated fuels. Oxygenated petrol was introduced as long ago as 1991, and actual reformulated petrol in 1994. Low-emission diesel, almost completely sulphur-free, has been available since 1993.

Neste Oy's reformulated petrol contains less than 1% benzene, while petrol sold elsewhere in Europe contains an average of 3%; as much as 5% is still allowed. Ethers are used in reformulated petrol as oxygen-containing components to improve combustion and knock resistance. At present, the ethers used are MTBE and TAME, which are methanol derivatives, since ethanol-derived ETBE is too expensive.

During 1993—1995 petrol research included the following:

- effect of sulphur and benzene content
- effect of aromatic compounds, olefins and the T90 temperature
- comparison of various reformulated petrols
- TAME as a fuel component
- development of special exhaust gas analyses (GC technique, aldehydes, PAH compounds in particulates and semivolatiles).

The principal factors affecting the exhaust emissions from diesel fuel include density and viscosity of the fuel, cetane number (ignition quality), chemical composition and sulphur content. During 1993—1995, the research programme included the following:

- the effect of the composition of diesel fuel on emissions (16 different fuels were included in the preliminary study)
- comparison of various reformulated diesel fuels
- optimization of low-emission winter and summer grades of diesel fuel
- aftertreatment of diesel engine exhausts
- exhaust gas and particulate emission measurements, by test stage
- mutagenicity of particulates, nitro-PAH compounds and distribution of particulate sizes.

As a diesel fuel's sulphur content decreases, the diesel engine's particulate emissions fall. In Europe, the maximum permissible sulphur content is being lowered to 500 PPM (parts per million), from 2,000 PPM. The use of effective exhaust aftertreatment devices, especially with heavy-duty engines, requires an even lower sulphur content, however. Thus, the Citydiesel produced by Neste Oy contains less than 50 PPM. Other properties of Citydiesel include its low aromatic content (under 20%), good ignition and cold operability properties, rather low final point of distillation, small density range and good lubricity, achieved with additives. Furthermore, Neste Oy has optimized the availability and properties of this low-emission diesel fuel by marketing separate winter and summer grades.

By merely changing the fuel, the particulate emissions from a typical heavy-duty engine can be reduced by 30%, and NO_x and CO emissions by some 10%. Hydrocarbon (HC) emissions remain roughly the same, however. With a catalytic converter, the CO and HC emissions can be reduced even further. The total emission reduction achieved is roughly 60% of the original level. The hydrocarbons in particulates can be oxidized with a catalytic converter, so that a total reduction in particulate emissions of roughly 50% is achieved with the correct fuel and a catalytic converter. Measured by the AMES bacterial test, the mutagenicity of the particulates is reduced by some 70% merely by changing the fuel, and a catalytic converter reduces the mutagenicity even further.

Projects concerning Neste Oy's reformulated fuels are one of MOBILE's principal areas of research. Such environmentally less harmful fuels are also being promoted by the government, through tax reductions. For low-emission petrol the reduction is FIM 0.05 per litre and for diesel, FIM 0.15 per litre.

The MOBILE programme has also included studies on the performance of alternative fuels, carried out mainly by VTT Energy, and largely concerning gas-powered heavy-duty vehicles. Contrary to reformulated fuels, most alternative fuels require both new or converted vehicles and a new distribution system. Thus their applications must be selected carefully to optimize cost effectiveness. Primary applications would include heavy-duty urban vehicles operating from depots, such as city buses, garbage trucks, municipal road-management vehicles and delivery trucks, because these usually already have centralized fuel supply systems.

A total of ten heavy-duty LPG-powered vehicles have been monitored under the MOBILE project. One of them is a city bus and the remaining nine SISU trucks. The results have mainly been positive. An LPG bus which originally operated in Espoo was transferred to Helsinki City Transport (HKL) in 1994. Mainly on the basis of the positive experiences from this vehicle, Helsinki applied and received funding from the EU Thermie programme to convert five diesel buses to LPG by installing new engines. In addition, the City has made a commitment to purchase services from a private operator which has recently acquired two completely new natural-gas-powered buses. A fast-fill-type natural-gas filling station has been built for the buses in Pirkkola by Gasum Oy, Helsinki. HKL's environmental programme includes promoting the use of both catalytic converters for diesel vehicles and vehicles run on gaseous fuels.

The MOBILE programme has helped to establish the use of gas-fuelled heavy-duty vehicles in Finland. Alternative fuels have been promoted by, for instance, the safety analysis of LPG (VTT Safety Engineering) and the study 'Electric and gas vehicles in delivery traffic - Case Tampere' (TUT Transportation Engineering), partly funded by the MOBILE coordination project.

In 1990—1995, under IEA's 'Alternative Motor Fuels' programme, VTT Energy conducted an extensive study related to MOBILE on alternative fuels for light-duty vehicles named 'Performance evaluation of alternative fuel/engine concepts'. The study, widely endorsed within the IEA, measured both regulated and 'non-regulated' emissions from 14 vehicles. The total number of different vehicle-fuel-test temperature combinations was 143. VTT purchased three test vehicles (two alcohol and one

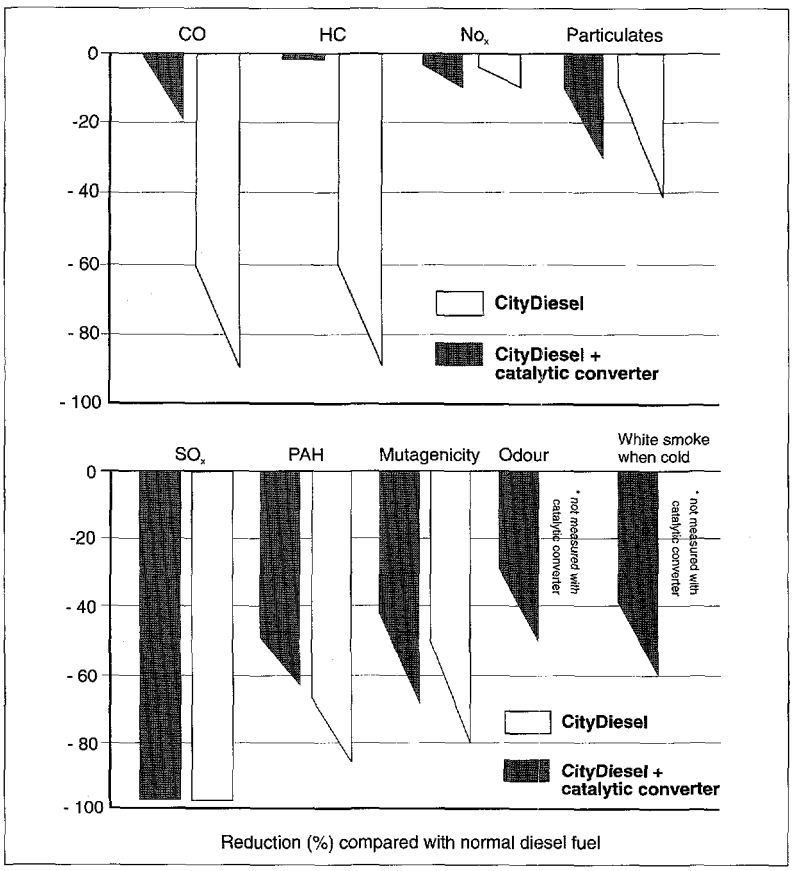


Figure 1. Emission reduction resulting from Citydiesel, compared with normal diesel fuel.

natural-gas-powered) for the study with IEA funding. The long-term tests performed with these vehicles are being carried out under VTT's MOBILE projects. The results support the view that in Finland, use of alternative fuels should be concentrated on heavy-duty vehicles.

The use of rapeseed ester as a diesel fuel has also been studied under MOBILE. Mildola Oy's joint development project 'Rapeseed esters as diesel engine fuel', carried out in 1993, mainly supplemented earlier studies. Practical engine and vehicle tests were carried out at Neste Oy, VTT and HUT. The necessary basic knowledge regarding the performance of rapeseed esters as fuels and fuel components is, therefore, available. In addition, rapeseed esters have been used as a reference in, for instance, certain IEA and EU projects comparing various fuel options and their properties.

2.2 Engine development

Finland is a significant manufacturer of medium-speed marine and power-plant engines (Wärtsilä Diesel) and of high-speed engines for off-road applications (Sisu Diesel). In fact, with its 20% share of the global market, Wärtsilä Diesel leads the medium-speed segment.

Sisu Diesel's 1995 engine deliveries came to 12,000 engines, or 1.1 MW of total power. The company's main markets, in addition to Finland, include Europe, South America and, a new region, North America.

Regulations concerning marine and off-road exhaust emissions change more slowly than those concerning road traffic. Emission restrictions were already imposed on heavy-duty vehicle diesel engines in the 1980s, while the first IMO regulations on NO_x emissions from ship engines still lack final ratification, and will probably not come into force until the turn of the millennium. The same applies to EU directives on off-road applications. Products with lower emissions than the regulations require could provide a significant competitive edge, as there is already demand for them on progressive markets. Moreover, many developed countries take a favourable view of economic instruments and the promotion of Best Available Technology (BAT). If the additional costs of more advanced technology are compensated with taxation or other advantages, its price will not be an impediment.

Minimizing fuel consumption is especially important in the development of marine and power-plant engines. When NO_x emissions are reduced, fuel consumption usually increases. This also applies to off-road diesel engines. Further challenges are posed by demands for the restriction of particulate emissions.

In a MOBILE project, Wärtsilä Diesel has developed a 'Low NO_x Combustion' solution for its VASA engines which meets the upcoming IMO regulations without increasing fuel consumption. The solution is based on delaying ignition so that maximum cylinder pressure is reached at the end of the compression stroke; combustion then occurs solely during expansion. So that the engine's fuel economy will not deteriorate, the compression ratio must be increased at the same time.

Delayed injection sets special requirements for fuel spray formation and for duration of injection, and these in turn, require higher injection pressure. Thanks to the MOBILE project on low-emission marine diesels, Wärtsilä Diesel was already able in 1995 to offer its customers versions of its 20, 32 and 46 engines complying with the coming IMO regulations.

The ignition properties of the fuel are crucial to combustion in a diesel engine and to the resulting emissions. Wärtsilä Diesel has studied the ignition and combustion properties of various heavy oils with laboratory equipment and engine tests. The demands set for ignition properties are emphasized when NO_x emissions are reduced by direct water injection into the combustion chamber.

The Kotka Polytechnic (now Kymenlaakso Polytechnic) initiated a project on marine diesel emissions which involved measuring the emissions of different ship types. Later on, the project concentrated on developing various techniques to reduce emissions. With considerable success, the Polytechnic applied its own EGR technique to scrub the exhaust gases of the training ship M/S Katariina. The project has also studied the use of water emulsion technology and SCR catalytic converter technique for reducing NO_x emissions.

The aim in Sisu Diesel's project is to develop the Valmet series of diesel engines to meet the oncoming emission regulations for both on- and off-road applications. In the case of on-road applications, the project seeks to develop versions of the 612 and 420 engines which surpass the Euro II emission limits. The aim will be achieved by, for instance, optimizing the compression ratio, fuel injection equipment, injection timing and turbocharging.

The main emphasis is, however, on engines for off-road applications. Although emission regulations are less stringent off-road than on-road, customers are not willing to pay a high price for an off-road engine, and solutions which meet the required low emission for on-road vehicles are usually considered too expensive.

Demand for off-road engine development derives from the transition from in-line injection pumps to rotary-type injection pumps with better flexibility for adjustments. An extensive study was made of naturally aspirated engines to chart the alternatives with which EU Stage 1 emission levels can be achieved.

VTT has been developing Valmet gas-fuelled engines since 1988. During the research stage now under review, optimization of the 612 and 634 gas-powered vehicle engines continued and the results and experiences were presented in a doctoral dissertation. In addition, Sisu Diesel implemented a project defining the technical product specifications and manufacturing principles for a stoichiometric natural-gas-powered generator engine. A 1,000-hour durability test run was also conducted with the engine.

The flow of fuel in a diesel engine was modelled at the Helsinki University of Technology's internal-combustion engine laboratory. For this project, which is internationally significant, an in-house computer code was created, and the work proved to be much more complex than expected. The original plans had to be revised and some of the aims were not reached. As the calculation and modelling of engine processes is considered highly important, however, more emphasis will be given to this during MOBILE's second three-year term.

2.3 Vehicle technology

In vehicle technology, research has concentrated on developing components, studying various technical alternatives in reducing exhaust emissions, and developing vehicles for special services.

Kemira Metalkat Oy implemented a project aimed at developing a catalytic converter for diesel engines. Work began with an investigation of the related chemistry and a study of the reactions of various hydrocarbons in the catalytic converter. The latter was carried out jointly with Neste Oy.

The technical challenges facing diesel catalytic converters include their use with sulphur-containing fuel, as sulphur-free fuel is not available in most market areas. Restricting the formation of nitric oxide (NO_2) is also important. The project developed to commercial level a revolutionary oxidizing catalytic converter for diesel engines, which contains only low amounts of precious metals.

VTT Energy is studying the operation of various petrol-engine catalytic converters in cold conditions and evaluating the suitability of commercial and precommercial technical alternatives for reducing cold-operation emissions in the Finnish climate, which is often very severe.

ELCAT's electric-car projects conducted under MOBILE, aimed at developing a hybrid-engine solution for electric cars and optimizing lead batteries experienced a setback. The manufacturer of the VW Transporter van, which was chosen as a base for the hybrid, refused to approve the increased axle loads needed for the hybrid solution. Thus only an electric prototype of the VW Transporter, without the hybrid engine, was constructed. ELCAT launched negotiations with new customers for deliveries of the parallel hybrid application components developed in the project.

The battery project ran aground when the owner of the participating battery-manufacturer changed, and the new owner was unwilling to make the necessary equipment investments. ELCAT continues to manufacture and sell the ELCAT Cityvan 200, based on a Subaru minivan, as well as com-

ponents for electric cars. Its largest customer is Finland Post Ltd.

In 1994, a separate study was made on the potential for developing electric cars. Electric cars and their charging stations were demonstrated in Hämeenlinna in a parallel project. In addition, a project implemented later on in Tampere also greatly helped to promote research on the use of electric cars.

The potential of different hybrid solutions was charted in two preliminary studies carried out by the HUT Laboratory of Automotive Engineering. The studies showed that, for instance, a high-speed flywheel based on existing technology cannot be used as the energy reserve for a hybrid car. The best potential would probably lie in using it as a regenerating power reserve, so that it could reduce the demand for peak power on the energy reserve proper.

Gas-fuelled special vehicles have also been developed, viz. the Sisu LPG trucks already mentioned. The first truck was finished in autumn 1992, six in 1993 and two in 1995.

The largest user, the Helsinki City Public Works Department (HKR), is now operating four LPG-powered trucks. Regular monitoring of these has provided vital information for product development. The exhausts of some of the trucks and the MAN LPG-powered bus operated by HKL were measured on a roller-type test-stand to assess the stability of emission levels.

In the follow-up study on the MAN LPG bus, it was observed that the original catalytic converter lost efficiency. It was therefore replaced with a converter manufactured by Kemira Metalkat, which proved to have superior efficiency and durability. Thanks largely to this study, Kemira Metalkat subsequently signed delivery contracts with the vehicle manufacturer MAN and the City of Vienna, which operates numerous LPG-powered buses.

A prototype of a mid-sized low-floor bus was completed in a Finnish cooperation project led by Valmet Automotive. The bus was registered under the product name 'Ecobus'. Valmet Automotive designed the bus, built the bodywork and was in charge of overall realization, Oy Sisu Auto Ab provided the axles and the dashboard, Sisu Diesel Oy the engines and Kemira Metalkat Oy the catalytic converters. The prototype has two engine alternatives, a diesel engine with a catalytic converter and an LPG engine with a three-way catalyst.

The prototype was bought for Finntech Oy, to be used by VTT as a test platform and demonstration tool in MOBILE. The prototype was funded by several companies, the Ministry of Trade and Industry, the Ministry of the Environment and VTT. In terms of its technology, the Ecobus has been extremely successful. The bus has been demonstrated in the Nordic countries and in Central and Eastern Europe. It has also been tested by bus operators, including HKL (Helsinki Transport) and Tampere City Transport.

Although MOBILE played a key role in developing this exportable vehicle and the product itself is a success, manufacturing a preliminary series of 10–20 buses before actual mass production has proved to be more difficult than expected. Negotiations on funding and on various manufacturing site and licensing alternatives are still under way. The research programme does not, however, cover this stage of the process, which concerns mainly venture capital, initiation of new business activity and making market evaluations.

The main purpose of the demonstrations attached to the research programme has been to promote the implementation of commercially viable techniques and to simultaneously gather data for product development. The demonstrations carried out under MOBILE have mainly involved alternatively powered vehicles, such as electric and gas-fuelled vehicles, and the construction, although small-scale, of related infrastructure. Valuable information on the usefulness of alternative techniques in Finnish climatic and operating conditions has been provided by various follow-up studies on the usefulness of new techniques and by systematically gathering and analysing user comments.

2.4 The use and duty cycles of vehicles

Projects studying the use and duty cycles of vehicles have yielded information on traffic volumes, conditions and the use of various transportation vehicles.

The results have already been used for various energy and emission balance calculations. In the future, the results will be utilized in creating a more detailed picture of traffic conditions in Finland and their special characteristics. In addition, the uses of telematics applications such as vehicle navigation have also been studied.

2.5 Emission inventories and measurement of emissions, model calculations

A study has been initiated in joint projects by the Finnish Meteorological Institute and the Helsinki Metropolitan Area Council (YTV) in which models are used to calculate the dispersion of traffic emissions and assess impurity contents. Although parts of the system, which consist of numerous models, are still rather simple, significant advances have already been made towards the goal: a tool for assessing the environmental impact of regional traffic solutions.

Results from YTV's air quality measurement network have been used in assessing the calculation results. Encouragingly, the assessments have shown that the results are of the correct magnitude. The calculation system will probably be first applied in practice in the assessment of the Helsinki region's traffic plans to be carried out during 1997.

2.6 Cost assessments and life-cycle analyses

The harmful effects of emissions should be priced in order, for instance, to justify economic controls and gradually include environmental protection within the sphere of market mechanisms. This is an extremely challenging task and requires the use of a wide range of methods in order to take different values and opinions into account objectively.

The exploitation and application of international research and its results has been one emphasis in Finland, and here Energia-Ekono Oy has been most active. Some guideline indicators of harmful impacts and 'prices' for them have already been defined for the principal emissions, and these have been used by the Finnish National Road Administration, for instance, which has applied them in calculating the externals costs arising from traffic. The harmful impact value of individual substances can vary greatly, however, depending on the method or source of data used.

3 Effectiveness of results

3.1 Industrial significance

Within the MOBILE programme, more than 60% of Tekes research funding goes into development projects run by enterprises. Tekes' maximum contribution to these projects is 40%, which guarantees that the projects are meaningful to industry. Private contributions from industry help to ensure efficient implementation of the programme's joint projects.

The following table shows products and product improvements generated by MOBILE directly and indirectly. In addition to businesses, VTT Energy has played an important role in developing gas-fuelled engines and special vehicles.

In addition to concrete products which can be manufactured and sold, the programme has generated what could be called immaterial products, which provide companies with vital support in product development, as well as important information. The main immaterial products are:

- cooperation in physico-chemical and biological analyses of non-regulated exhaust emissions. A consortium comprising Neste Oy, the National Public Health Institute and different units of VTT (Energy, KEM (Chemical Technology), Biotechnology and Food Research)
- assessment of traffic emission impact on atmospheric impurities by applying a combination of

traffic and dispersion models and comparing calculation results with those from air-quality measurements. Joint project between the Finnish Meteorological Institute, YTV and VTT Energy.

3.2 Improvements in technical standards

Thanks to the MOBILE programme, technological standards have improved in Finland. The programme, especially its fuel development sector, has generated high-quality technological know-how ranging from products to manufacturing technology. The programme has allowed participating companies to further expand and diversify their own product development and given them a better picture of their sectors, the demands set for their products, and client expectations.

The programme has promoted the emergence of more comprehensive and multidisciplinary research groups with in-depth know-how and it has also tightened cooperation between research groups working in different sectors. New, concrete and successful cooperation has also evolved in product development between companies as a result of the programme.

Table 2. Products and product improvements realized under MOBILE or with its support.

Product	Company	Special feature	Commercial maturity
Reformulated engine petrol	Neste Oy	reduces CO and HC emissions (no catalytic converter), reduces CO, HC and NO_x emissions (catalytic converter), reduces toxicity of exhaust and volatile emissions	on the market (also exports)
Reformulated diesel oil	Neste Oy	reduces NO_x, sulphur, particulates and non-regulated emissions, toxicity of exhausts, enables the use of catalytic converters	on the market (also exports)
Low-emission marine diesel engine	Wärtsilä Diesel	a series of marine diesel engines which meet the coming IMO norms	product definitions/ on the market
Low-emission diesel engine	Sisu Diesel	for agricultural (off-road) applications , meets the EU Stage I/EPA 96 requirements	on the market (also exports)
Oxididation catalyst converter for diesels	Kemira Metalkat	studies on the optimization of fuel and converter combinations, new product concept	on the market (mainly exported)
Low-emission gas engine	Sisu Diesel	low-emission engine for stationary use (generators, CPH, LPG or natural gas + catalytic converter)	product specifications/ prototype
LPG truck	Sisu Auto	extremely low-emission vehicle for urban areas (street maintenance and refuse collection)	on the market (preliminary series)
Mid-size urban bus	Valmet Automotive	low-emission bus for urban areas (gas and diesel-powered)	prototype

3.3 Networking

During its operation, the programme has helped to build the infrastructure needed for research. This infrastructure consists of research groups with in-depth and multidisciplinary know-how, and cooperation between them, as well as the research facilities and other material resources required for high-quality research.

The following are examples of research cooperation based on and strengthened by the MOBILE programme:

- cooperation in the physico-chemical and biological analysis of non-regulated emissions
- cooperation in calculating traffic emissions and comparing calculation results with air-quality measurements
- cooperation in modelling urban traffic volumes
- cooperation in developing traffic models with practical measurement results.

The programme has also helped to provide resources for research. Research institutions have been prepared to invest in equipment when they have a client providing research funding from the programme. Examples of this are the diversification of VTT Energy's exhaust gas research unit and the equipment for measuring emissions from small engines acquired by VAKOLA. Programme-related projects have also supported creation of the test run site for medium-speed diesel engines operated jointly by VTT Energy and Wärtsilä Diesel.

The cooperation of bodies under various ministries (Ministry of Trade and Industry, Ministry of Transport and Communications, Ministry of the Environment and Ministry of Education via universities) is characteristic of MOBILE. In its class, MOBILE is a good example of the cross-sector cooperation much discussed and sought after in government.

Thanks to the critical mass generated by MOBILE, Finnish traffic-related research has won international attention. The programme has been publicized in several international contexts by the coordinator of MOBILE (VTT Energy), including the research organizations of the EU and the IEA. As an organization, the MOBILE programme was invited to help create a new structure for IEA's traffic sector projects. The MOBILE programme and its projects have featured in some 30 international conferences and publications.

Table 3. Companies and research units participating in the MOBILE programme.

Code	Company/unit	Research and operation sectors	Cooperation unit
Y1	Neste Oy, R&D	reformulated motor fuels (petrol and diesel oil)	T7, T16, Y2
Y2	Kemira Metalkat Oy, R&D	catalytic converters	Y1, T7
Y3	Wärtsilä Diesel Oy, R&D	medium-speed marine diesel engines	T7, T12
Y4	Sisu Diesel Oy, R&D	high-speed diesel engines	T7, T1
Y5	Elcat Sähköautot, R&D	electric and hybrid cars	T4
Y6	Valmet Automotive, R&D	mid-size urban bus (ECOBUS®)	T7
Y7	Oy Sisu Auto Ab	trucks	T7
Y8	LT-Konsultit Oy	traffic systems and energy consumption in transportation	
Y9	Suunnittelukymppi Oy	analyses of traffic and traffic congestion	T3
Y10	Finnair Oy, tuotetekniikka	emissions from air traffic	T15

Table 4. *Public sector entities participating in the MOBILE programme.*

Code	Department/unit	Research and operation sectors	Cooperation unit
T1	HUT, Laboratory of Automotive Engineering	vehicle navigation, alternative sources of power	T7
T2	HUT, Internal-Combustion Engine Laboratory	mathematical engine modelling, high-speed diesel engines	T7
T3	HUT, Laboratory of Transportation Engineering	traffic simulation, signalized control	Y9
T4	TUT, Transportation Engineering	life-cycle analysis of vehicles, planning, management, analysis of vehicle demonstrations	T8
T5	TUT, Occupational Safety Engineering	emissions from working machines in various situations of use	Y4,T7
T6	MTT/VAKOLA	emissions from small working machines and their reduction	T5
T7	VTT Energy, Engine Technology	motor fuels, alternative fuels, emission-reducing techniques, emission measurement techniques	Y1,Y2,Y3, Y4,Y6,Y7, T8,T9,T10
T8	VTT, Communities and Infra-structure, Transportation Research	cold operation of vehicles, drive cycles, distance travelled in urban areas	T4
T9	VTT Chemical Technology	physical and chemical analysis of exhaust gases	T7
T10	VTT Biotechnology and Food Research	biological analysis of exhaust gases	T7
T11	HTOL/Test-Center Tiililä	the effect of traffic situations and driving on energy consumption in traffic	T7
T12	Kymenlaakso Polytechnic	measurement of emissions from ship engine, reduction of emissions from existing ships	Y3
T13	Finnish Meteorological Institute, Air Quality Department	modelling of the dissipation of emissions, emission contribution by traffic	T14,T7
T14	YTV	air quality measurement, emission calculation	T13,T7
T15	Finnish Civil Aviation Administration	emissions from civil aviation	Y10
T16	National Public Health Institute	biological analysis of emissions (mutagenicity)	Y1

3.4 Researcher training

Steering groups and annual seminars have been included in the programme to serve continuous researcher training and exchange of information between researchers.

The programme has promoted research projects by arranging two meetings between steering groups each year. The purpose of these meetings is to direct research projects and assist project managers. In addition, the steering group meetings are important providers of training. They promote the

dissemination of information and active discussion between projects and researchers. It has, for instance, been a challenge to motivate engine and air-quality researchers to discuss emissions and their volumes in a common language.

The steering groups have been arranged into technical development and systems research sectors in line with the programme's main sectors. In addition, projects have been encouraged to participate in the other sectors' steering group meetings to improve both dissemination of information and training.

The annual seminars held in April 1994 and March 1995 during the research period under review have acted as vital forums for demonstrating project results. In 1994, an extensive exhibition called 'Clean urban vehicles from Finland' was arranged in connection with the seminar. The exhibition comprised low-emission vehicles developed within or in connection with the programme.

The programme has also included 'theme seminars', designed to study a more closely defined area of the programme and to function as a tool in researcher training. In 1993, a theme seminar was organized on exhaust gas measurements and, in the same year, MOBILE researchers also participated in an international seminar on life-cycle analysis, arranged by UETPEE and SIHTI2. In 1994, a theme seminar was arranged on alternatives for local traffic in cooperation with the Finnish Bus and Coach Association and the Local Traffic Association.

The MOBILE research programme's general plan states that the programme promotes researcher training and graduate studies. During 1993—1995, five diplomas and one licentiate and one doctoral dissertation were completed under the programme.

4 Main results of the interim assessment

In autumn 1995, an interim assessment was carried out as a combination of the Executive Committee's internal and external evaluations. The Committee was asked to give an opinion on the programme.

There were also four external evaluators: Reino Lampinen from the Ministry of Transport and Communications and Antero Honkasalo from the Ministry of the Environment from Finland, and Sweden's Stig Ericsson from Scania and Professor Erik Egebäck from Luleå University of Technology.Companies were generally of the opinion that the MOBILE programme had been beneficial to them. In a statement issued in connection with the interim assessment and dated June 13, 1996, Neste Oy's Product Development Manager, Markku Laurila, summarizes MOBILE's activities as follows:

"The majority of the MOBILE joint development projects aim to improve competitiveness. In fact, such improvement is already attested by the projects concerning reformulated fuels, engine technology and exhaust gas aftertreatment. Although the research institutions' projects have no direct commercial aims because of their nature, many of them seek to improve Finnish know-how in a way which may, for instance, have an indirect impact on the competitiveness of Finnish industry.

"The MOBILE research programme's impact on the environment is both direct and indirect. The effect of projects regarding fuels, engines and catalytic converters on traffic emissions have been indicated by studies and partly realized through commercialization. The most concrete example is the reformulation of petrol and diesel oil. Emission measurement capacity meeting international requirement has been created under these projects, and the awareness of the emissions of domestic traffic and the ways to influence it have been enhanced materially. Moreover, tools for environmental impact assessment, such as life-cycle analyses, emission evaluation and models on the dissipation of emissions have been developed in several projects.

"Some of the joint research projects have created export potential for technology. The majority of Neste Oy's traffic fuel exports already consists of reformulated fuel, and it is very probable that the projects developing engines and catalytic converters will create further export potential.

"All in all, the MOBILE programme has generated a very good return on the investments made in it. While some of the benefits might have arisen with-

out MOBILE, the results can be applied more easily and quickly thanks to the programme."

In its statements related to the interim assessments and reports, Wärtsilä Diesel International Oy states that it hopes the programme will place more emphasis on industrial research and product development projects. New ways to ensure that products reach the markets should be developed. The Executive Committee should be strengthened by the addition of an expert on international marketing. Wärtsilä Diesel also suggests that the rule of 40% maximum funding should be extended to research institution projects.

In the light of these opinions, there seems to be general satisfaction over MOBILE's success. The Swedish evaluators especially praised the good structure of Finnish energy research. The interim report summarized the evaluation as follows:

"During its three years of operation, the MOBILE programme has found its place in the field of energy technology research. Thanks partly to the solid foundations inherited from the SIHTI programme, MOBILE activities have been high-quality, productive and, for the most part, well-focused. As the programme's research field is rather extensive, proper focusing of resources has been - and still is - essential. The use of expert assistance to back up the Executive Committee's visions in preparing research plans has been very helpful.

"The programme's general plan and overall aims are still extremely useful. The definition of the field of enquiry and its delimitations can be considered up-to-date, although slight adjustments are necessary from time to time. In focusing research and resources, the Executive Committee should continue its policy of moving from open applications and tenders to contracted research, where the Committee defines the demand and aims, and then seeks researchers. There is good potential for this because of the comprehensive and highly-skilled Finnish research community which has emerged largely thanks to the programme and its predecessor.

"Programme activities and the added value they generate for productive research and publicity concerning it have provided a solid return on the resources invested. Activities must, nevertheless, be renewed constantly; the evaluation has already suggested ways to go about this.

"All the evaluators favour continuation of the programme. Industry has received the support it needs from research projects oriented towards product development, and some of the results have already found an application in products whose market standing has improved because of modifications which have made them more environmentally sound. The objective information provision channelled through the programme has also been helpful. Reformulated traffic fuels are surely the most successful example, as they are known to have reduced emissions.

"It is certain that national research programmes will continue to provide a good format for promoting public R&D. The versatile executive committees with comprehensive vision, and the other expertise accumulated under the programmes are an excellent way to ensure the efficient and objective focusing of limited resources. Finnish and foreign research - and funding - must be kept separate. While international projects and open international cooperation in research are needed, maintaining and promoting national competitiveness must always be given priority."

5 Future planning based on the interim assessment

The programme's original general plan was still considered useful for the second stage. Although the work already carried out has followed serviceable guidelines, the interim assessment led to certain suggestions for improvements that will fine-tune the existing plan.

While the programme's principal goal of reducing emissions was achieved at least reasonably well, a few evaluators proposed that the other subgoal, reducing consumption of energy and emissions of carbon dioxide, should be given greater emphasis when future research is planned.

The external evaluators (Lampinen and Honkasalo) recommended that the programme target be set, at least in some respects, much further ahead,

perhaps 5—7 years from now. This could be done in the case of projects involving the maturity and long-term usefulness of various technologies. These could be made to include analysis of the possible alternative strategies for the future. At the same time, these projects would generate indicators for the course of future product development.

Reviewing MOBILE as part of Tekes' activities opens up new vistas and an opportunity to create a more comprehensive system of programmes covering the technology of passenger and goods transportation vehicles and off-road machinery. At the same time, projects could be incorporated from fields now outside MOBILE, including lightweight structures and aerodynamics - traditionally strong fields in Finland - and the energy consumption of passenger and goods transportation vehicles. As an increasing number of product development projects were incorporated, the programme's present emphasis on energy consumption and, especially, reduction of emissions would decrease.

Although traffic and transportation are not actually an independent sector of production or industry, they form an integral part of a modern society based on an open market economy. Their importance will increase all the time as European integration expands markets and mobility, leading, almost inevitably, to more demand for transportation and traffic. Moreover, transportation is growing into an important factor for competitiveness, especially for Finland. Thus, in the future, companies offering transportation services could become the programme's 'clients', in addition to existing industrial enterprises.

Without exception, all the evaluators considered internationality and the dissemination of information a vital part of the programme's activities. At the same time, however, concern was indicated about the future of national research funding.

National research programmes such as MOBILE were especially favoured by companies because in their experience, large, multinational programmes usually suffer from cumbersome bureaucracy and poor communication, and much of their resources are wasted in administration. Experience has shown that in international cooperation, there is often a danger of information leaking to competitors. It would not, therefore, be practicable to channel nearly all of Tekes' future research funding into projects which are part of EU or other international research programmes, as has been suggested.

Internationally, we should try to develop special areas of research serving our own needs, as a part of some international project. This would help to increase our know-how and could open up demand for direct research services. An example of such a useful and international project, and one closely related to MOBILE, is the Annex V project, which is being realized under the IEA's Alternative Motor Fuel Agreement. In Annex V, Finnish know-how in research on fuel and exhaust gas emissions in cold climates has been both developed and utilized. The project has received considerable praise from the IEA and is viewed as a good example of how international research cooperation should be carried out under the IEA.

In view of the wide range and versatility of the problems MOBILE addresses, its funding has been rather limited. This has had a direct bearing on the average size of projects; in order to achieve even reasonable coverage, the programme contribution to funding has had to be limited to FIM 100,000—150,000 on average. In fact, the total budgets of the smallest projects have been less than FIM 100,000, which should be considered an absolute minimum for any research project. Thanks to good cooperation and efficient use of the available resources, however, the research has been productive. The programme itself has made possible the existence and efficient operation of such small projects by giving them a clear frame of reference and its full backing. In a sense, the programme has operated on a 'project-within-a-project' principle. It would be wise to increase project size at least somewhat, of course, but if the programme gave more emphasis to contracted research in which the Executive Committee defined the problems and aims and then made a contract on the research project, small-scale problems and projects would surely be most suitable and efficient.

6 Research organization and Executive Committee

The Executive Committee directs research and defines its content, decides on the projects to be admitted into the programme and distributes Tekes funding in the case of research institute projects. During 1993—1995, the following persons nominated by either the Ministry of Trade and Industry or Tekes took part in the work of the MOBILE research programme Executive Committee:

- Antti Saariaho, HUT (chair)
- Arto Haakana, Elcat
- Göran Hellén, Wärtsilä Diesel Int. Oy
- Timo Korhonen, Sisu Auto (1995)
- Tarja Lahtinen, Ministry of the Environment
- Pekka Lappi, Kemira Metalkat Oy
- Markku Laurila, Neste Oy-Öljy (Oil)
- Mikael Rehula, Ministry of Transport and Communications (1994–1995)
- Sampo Siiskonen, Oy Sisu-Auto Ab (1993—1994)
- Raisa Valli, Ministry of Transport and Communications (1993)
- Mauno Ylivakeri, Sisu Diesel Oy

Raija Pikku-Pyhältö has been the programme monitor and also a member of the Executive Committee.

Actual programme activities are the charge of VTT Energy/Engine Technology, which has functioned as coordination unit. Nils-Olof Nylund was nominated as director of the research programme and Juhani Laurikko as main coordinator. Other programme coordination was in the hands of experts from the very beginning: head of research Ari Juva (Neste Oy; technology sector) and Associate Professor Jorma Mäntynen (TUT, traffic and transportation; systems sector), who are in charge of evaluating the scientific quality of research conducted under the programme. In addition, Professor Kai Sipilä (VTT Energy) has provided expertise on biofuels. The experts' role in monitoring the programme's implementation has proven extremely valuable, as the main coordinator would not have been able to manage all the technical aspects of a programme as extensive as MOBILE. Since the coordination unit, VTT Energy, is itself engaged in projects, the experts also evaluate their quality.

Results of individual projects are reported to the Executive Committee through the steering groups. In practice, this is done by the experts, some Committee members, the programme director and the coordinator participating in steering group meetings. On the basis of these meetings, the experts then draft situation reports on their respective sectors and the reports are handled at Committee meetings. The steering groups have proved very efficient and productive. Thanks to this structure, there is no need to set up a separate executive committee for each project. Of course, such a system is still possible, and is indeed used for the largest projects. In addition, the work done at steering group meetings ensures that information is efficiently disseminated between the researchers and also to the Executive Committee.

Chapter 8
NEMO 2 – Advanced energy systems and technologies

Peter Lund, HUT

1 Background and objectives

NEMO 2, a research programme on advanced energy systems and technologies, was begun in 1993. It was based on the main results of the Ministry of Trade and Industry's NEMO programme, the 1992 memorandum of the Ministry of Trade and Industry's energy research working group, and its own preparatory work.

A general plan for 1993—1998 was drafted for NEMO 2, comprising the following main aims:
- to promote the development of Finnish technology;
- to promote technology exports;
- to increase utilization of wind and solar energy in Finland.

Increasing the utilization of wind and solar energy is vital, since development of the home market is crucial to attainment of the programme's purpose - the commercialization of Finnish technology on the global market.

The programme's operations are directed on the basis of corporate interest, the markets and the programme's own strengths. In terms of content, this translates into market-oriented development of technology. The energy research working group's memorandum (Ministry of Trade and Industry, 1992) set wind and solar energy as the main emphasis for research. In the general plan, this research is supplemented and backed by technologies for energy storage and other small-scale generation.

The Executive Committee has brought the programme's broad aims up to date annually and focused research on those fields of technology and application which appear most promising from the point of view of the parties exploiting the research results. The programme's main emphases are the following:
- arctic wind power;
- components of wind power plants;
- integration of solar energy into applications, including thin-film solar cell techniques.

The development and practical demonstration of solar and wind energy and supporting basic and production technologies are the programme's aims, in line with the master plan.

In practical research, emphasis has been given to potential usefulness, market potential, cooperation between companies and international cooperation, and high quality.

In 1993—1995 the programme included 22 research projects and 30 joint development projects. Total funding came to FIM 73 million, of which Tekes' contribution was 49%. The private sector contributed half of the total funding. From its 67% contribution in the first phase of the NEMO programme (1988—1992), public funding fell to 49% in NEMO 2, with a corresponding increase in contributions from industry.

1.1 Global situation

Advanced energy techniques (solar electricity and heat, wind power) is one of the fastest-growing sectors of energy technology in the world. Although its impact on the generation of energy is still small, it has considerable potential.

On a local scale, advanced energy techniques already have an impact on energy production; in Denmark, 4% of total electricity is wind-generated, and in certain regions of the country the figure exceeds 25%. In some Mediterranean countries solar heating is used to produce nearly 10% of all

hot water services. Globally speaking, wind power generates some 12 TWh/a, solar heat 13 TWh/a and solar electricity 0.6 TWh/a. In a scenario drafted by Shell International, solar and wind energy play a key role in long-term global energy production. They are expected to be economical relative to other energy sources by 2020, leading to a 30% market share by 2050.

The global market for the advanced technologies is expanding by more than 20% each year. At present, the annual volume of business is some FIM 12 billion. By the year 2000 it is expected to reach FIM 15-18 billion, and by 2010 FIM 50—70 billion. The main research areas of NEMO 2 coincide with those of the EU's energy and energy research policies. For instance, nearly a third of the EU's energy research, other than nuclear, corresponds with NEMO 2. The research areas in advanced energy technology are of international importance.

In 1995, the total capacity of photovoltaics installed in Finland was 1.5 MW_p. Some 6,000 m^2 of solar collectors had been installed at that time, and wind power capacity was 7 MW.

At present, Finnish companies have a 2–3% share of the sector's global market and some have even acquired a solid foothold in their own niches. 20% of wind power plant power transmission components and 10% of thin-film solar arrays are Finnish. In fact, Finland is Europe's leading industrial manufacturer of thin-film applications in solar technology. In solar heating technology, Finns are forcing their way into the European markets.

2 Results in major research areas

2.1 Commercial significance

Wind power

Within the arctic wind power project, an icing/freezing-sensor was developed which is also being sold to foreign weather stations and wind power plants. Corresponding new products are being developed jointly with industrial partners. The principal long-term advantage is the extensive utilization of wind power in arctic conditions, in northern Europe, for instance. Finland is clearly the international technology leader in the field. The research area also involves joint development and EU projects.

One of the projects is developing key technologies to enable the exploitation of offshore wind power potential. Cost-efficiency at the construction stage and best possible solutions are being sought with

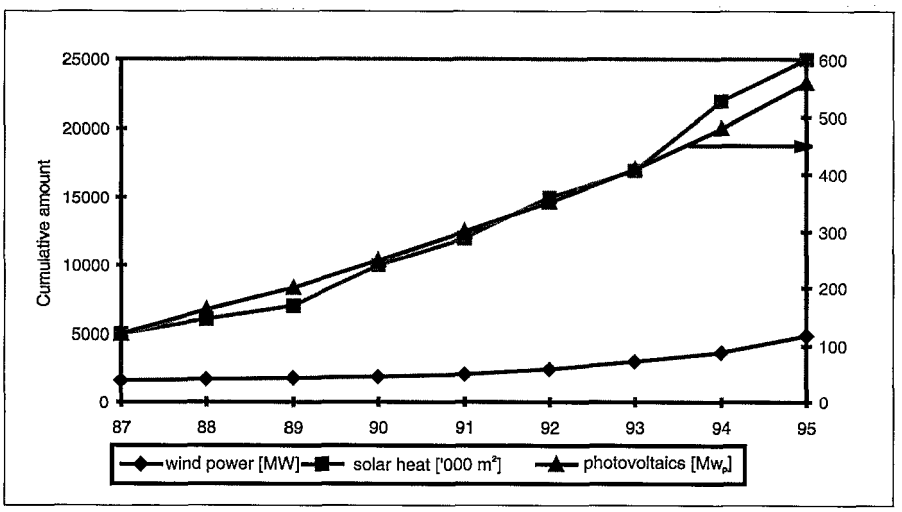


Figure 1. The development of the global advanced techniques market (Wind power MW, solar heat, surface area of collectors (1,000 m^2), photovoltaics MW_p).

a pilot project. In the short-term, 300 MW (FIM 1.5—2 billion) could be constructed. In the longer term, the potential is 3—10 TWh/a.

A new wind power plant based on advanced hydraulic transmission has been developed under the programme. The aim is to launch a 100 kW wind turbine which can compete with conventional plants. The product's success will derive from the simplicity of its structure (reducing investment costs) and its improved efficiency (increasing annual income).

At present, the annual global wind power market is 1000 MW. This is expected to double within five years, reaching a market of FIM 5.5 billion. Of this, power components (generator, gearing, inverters) comprise some 20%, or around FIM 1 billion each year.

Today, most plants are based on a generator and gearbox. A gearless generator equipped with a permanent magnet and an inverter for larger plants has been developed under the programme. The solutions can generate 10—15% more power than previous techniques, leading to a 5–10% reduction in the cost of wind-generated electricity.

Solar energy

The solar panel prototypes and know-how in systems design created under the project on the integration of solar energy have provided the technical preconditions for commercializing solar power systems and launching them onto new markets, and have enormous long-term growth potential. The project's development work has included thin-film solar power facades for buildings, offering a 30% cost reduction on the crystalline silicon technology dominating the market at present. Finnish know-how is of a high international level. Solar energy includes joint development and EU projects.

The main commercial significance of the project on developing solar heating technology is to develop related components so that they can be manufactured industrially. The project's results include new absorption surfaces for solar collectors. In addition, it has generated industrial production and exports of solar collectors to European markets. They have considerable short-term commercial importance.

The project developing hydrogen-based energy storage techniques was one of the first in the world to find efficient solutions to long-term storage of solar energy. The project has also resulted in a competitive special product for small-scale electricity applications in remote rural areas.

Other technologies

The results of the programme's small ORC plant project will be utilized in a demonstration plant. The ORC (Organic Rankine Cycle) method is based on a low-temperature cyclical process. The software developed in the project can be used for optimizing the ORC process, yielding considerable commercial advantage in planning actual plants.

The main obstacle preventing electric cars from becoming common is insufficient battery technology. The project on air and metal hydride electrodes has developed a new battery type with a storage capacity several times greater than that of conventional lead batteries.

The aim of the project on high-temperature superconductors is to demonstrate the use of new materials in a 1.5 kW synchronous machine. Large-scale and long-term application in transformers and electric appliances, for instance, reduces size and weight by 40—70% compared with conventional generators, cutting raw-material costs. In the Finnish electricity grid, the potential savings generated by superconductivity could reach some 1.2% or FIM 3.5 billion.

2.2 Principal projects

Arctic wind

The development of wind power technology suitable for arctic conditions was initiated during the first stage of the NEMO programme in the late 1980s. Wind measurements were carried out in Lapland's fell region and other measurements at a small test plant on the Pyhätunturi fell. The test plant on Pyhätunturi in Pelkosenniemi was constructed in October 1993 in cooperation with VTT, the Finnish Meteorological Institute and Kemijoki Oy.

Measurements showed, already at an early stage, that the wind conditions on fell tops were extremely good. On most fells, the annual average wind speed is more than 8 metres per second. During winter months the average speed tops 10 m/s, sometimes even 12 m/s. In coastal areas, the maximum annual average wind speed is 7 m/s, and at open sea 8 m/s, measured at the height of a wind power plant's hub. Thus, wind conditions alone can cause 50% higher gross production at a wind power plant located on top of a fell, compared with a corresponding coastal plant.

The principal problem in generating wind power in arctic regions is the formation of ice and rime on the plant's structures. The icing of rotors reduces power and increases load, which causes instability and flexing. Icing and the resulting excess mass also cause problems when a plant is restarted after a stoppage.

The wind energy research conducted by Kemijoki Oy has been part of the NEMO programme from the very beginning. Its aim has been to study wind conditions and power generation in fell regions. In addition to wind research, ways of preventing the icing of rotor blades, the frequency of conditions where rime occurs and the possibility of operating wind power plants in arctic conditions have also been studied. Kemijoki Oy has cooperated with VTT and the Finnish Meteorological Institute. The purpose is to achieve the technological standard required by commercially viable wind generation in arctic conditions.

At the moment, the test plant on Pyhätunturi and the measurements carried out there are an essential part of arctic wind energy research. The purpose is to develop, measure and test techniques which will enable the operation of modern wind power plants in Lapland and other arctic regions. Research and development concentrates on:

- instrumentation: wind meters and indication of icing/freezing conditions;
- development of heating systems for wind power plant blades;
- wind power plant ice loads.

There are two wind power plants in existence intended for research use. The plant on Enontekiö's Paljasselkä generates 65 kW and that on Pyhätunturi 220 kW. Both plants are connected to a low-voltage grid and feed electricity to local distribution networks. The plants are used to monitor and measure the stress caused to a standard mass-produced wind power plant by an arctic climate. On the basis of one year's operating experiences and theoretical studies, components and functions have been modified at both plants. The number of wind measurements in Lapland has increased during the programme and measurement equipment has been improved to suit the conditions better.

Both the Paljasselkä and Pyhätunturi research stations have antifreeze systems, which are tested during the winter. On the basis of these tests, a new heating system was developed for the winter of 1995—1996. The system is also used at the first arctic wind farm, located at Lammasoaivi in the municipality of Enontekiö. Other key modifications have involved hydraulic systems, lubrication materials and the selection of component materials.

Other companies have also participated in developing arctic wind power generation in addition to Kemijoki Oy, VTT and the Finnish Meteorological Institute. They include Vaisala Oy (wind meters and weather stations), Labko Ice Detection Oy (ice detection and heating systems) and Wind World and Nordtank, the suppliers of the Pyhätunturi and Paljasselkä power plants.

Future plans include the development of an integrated heating system in cooperation with blade manufacturers.

The research system has implemented Vaisala Oy's new heatable wind meters at wind metering stations located on fells, and for controlling the Pyhätunturi test plant. In addition, Labko Ice Detection Oy's ice detector was modified for controlling the heating of rotor blades, and a detector-based heating control system was developed. With ice detectors the number of hours a heating system is used can be cut significantly, leading to considerable energy savings over mere temperature-based or manual control.

The commercial version of the heating system comprises:

- heating elements;
- freezing sensors which start the heating system only in freezing conditions;

- a control system which turns on only the required heating elements on the basis of blade geometry, heating element configuration and wind speed.

This commercialized heating system will be installed on Pyhätunturi and at the Lammasoaivi arctic wind farm.

The Pyhätunturi plant also includes instrumentation for measuring loads. The results have been compared with simulations made with ADAMS software. The software produced for the project is especially suitable for calculating loads in changing situations.

The importance of maintenance has become clear during operation of the test plants. Distances are long in Lapland and transporting heavy equipment to fell tops can be very difficult, especially in winter. A maintenance programme will be developed for arctic wind farms, providing short downtimes and low operating costs.

The environmental impact of wind power plants has also been studied. Kemijoki Oy has commissioned an environmental report on the impact of power plants on local inhabitants and fauna.

Integration of solar energy

The optimal use of active and passive solar heating and solar electricity requires both the development of respective technologies and their combination in a way practicable to each application.

The benefits of systems integrated into buildings are as follows:
- system installation does not require extra surface area;
- solar panels can replace construction elements, thus having an architectural functional;
- the electricity produced by such systems is of more value to consumers than to power companies.

Integrated solar electricity systems differ crucially from power plants. As components replacing construction materials, the solar panels' surface-area cost will probably be more important than the cost of the power they generate. The price of photovoltaic panels manufactured from amorphous silicon (a-Si) already corresponds to that of certain facade material used in commercial and office buildings. For small houses, however, solar heating, together with passive solutions, will most likely remain the primary form of utilizing solar energy.

Neste Oy Advanced Power Systems (NAPS), Neste Oy Technology Center and Helsinki University of Technology (HUT) have conducted the research in cooperation.

In component development, a-Si panels have been modified for integration in buildings, installation techniques have been improved and DC solutions have been developed as an alternative to grid-based ones. In addition, full-scale pilot tests have been conducted for evaluating the practical functioning of system concepts. In equipment development, measurement instructions have been drafted and test equipment has been developed for component assessment.

The project's main results include a new solar electricity product and several component prototypes. The facade solution based on amorphous silicon developed under the project is materially cheaper than conventional panels. A full-scale pilot system was built at the Pietarsaari housing fair on the basis of this solution.

Hydrogen storage

Solar electricity systems are often used in small-scale applications outside the power grid, e.g. as power sources for telecommunications. In the north, seasonal storage is also necessary and is not possible with lead batteries.

In a solar hydrogen system, the excess solar energy produced in the summer is conducted to pressurized electrolysis apparatus, where water is broken down electrochemically into oxygen and hydrogen, which is then stored in a pressurized tank. In winter, the hydrogen is used in a fuel cell and the water produced can be conducted back to the electrolysis apparatus. As a result, the system's circulation is closed.

Solar hydrogen systems have been studied jointly by Helsinki University of Technology (HUT) and Neste Oy's research centre since 1990.

Both HUT and Neste now have full-size test plants, and a prototype plant is nearing completion. H2PHOTO software was developed for dimensioning and optimizing the systems. The development work led to five international patents, related to pressurizing the electrolysis cells, adjusting pressure and feeding pressurized service water. Several international publications have also been produced.

Neste has constructed a prototype of a solar hydrogen system. The first commercial applications are expected within a few years. Seasonal hydrogen-based storage solutions for daily power consumption of 1—10 kWh are the eventual aim.

Component development has concentrated mainly on solid-polymer electrolysis cells (SPEL) and their pressurization systems. Various methods of hydrogen storage have also been compared. In small systems, pressurized tanks and metal hydride storage are applicable. Metal hydride solutions are suitable for very small applications, as their pressure and thermal properties are selected so that an electrolysis cell can be used to charge the hydride and the hydride can be decharged to the fuel cell without additional heating.

The solar hydrogen system under review is also interesting economically, compared with a conventional system using diesel generators as an auxiliary power unit in places where maintenance is difficult. Special attention must be paid to minimizing maintenance. A small system based on gas cylinders and a fuel cell as an auxiliary power unit is also a promising alternative.

The project's main result, a prototype of a seasonal storage system, is being exploited by Neste in expanding the market for solar power systems to new areas and applications.

3 Effectiveness of results

The NEMO 2 programme has had a positive impact on the development of advanced energy technology in Finland. Its principal aims and effects are:

- to increase business activity;
- to develop new technological know-how;
- to initiate new business activity;
- to transfer technology to Finland.

In terms of aims, the main result is the programme's positive impact on business. During the programme the volume of business activity in the sector has grown to FIM 200 million per annum, of which more than 80% is exports. The strong growth of advanced energy technologies is a result of developments in top-level technology, favourable trends on international markets, availability of venture capital and related publicity directed at Finnish target groups.

Activities under the NEMO 2 programme and its projects in 1993—1995 may also generate some FIM 50—60 million a year in new turnover, even after the programme ends in 1998. Long-term potential is some FIM 350 million per year.

The NEMO 2 programme's main result in terms of energy economy is the introduction of wind power to Finland; in 1989 only 0.3 MW of wind power was generated, while in 1995 the figure was 7 MW. Moreover, the programme has been crucial to the creation of the Ministry of Trade and Industry's wind power programme, which aims to construct 100 MW of power by the year 2005.

The NEMO 2 programme has generated new research and technology products and new business activity. The production stage has been reached for the following products:

- launching of solar heating systems business (Neste Oy);
- initiation of solar collector development and manufacture (Neste Oy);
- a control unit for solar power systems (Coronel Oy);
- a cathode protection device based on solar power (Savcor-Consulting Oy);
- a prototype of a small-scale wind-diesel power plant (Neste NAPS Oy, HUT)
- a wind scanner prototype (Vaisala OY, Finnish Meteorological Institute);
- a gearbox for large MW wind power plants (Kumera Oy)

Other product plans include:

- an absorber solution for solar heat collectors (P. Koskelan Vesi ja Lämpö Ky, HUT);
- two solar power facade prototypes (Neste Oy Technology, Länsilasi Oy, HUT);

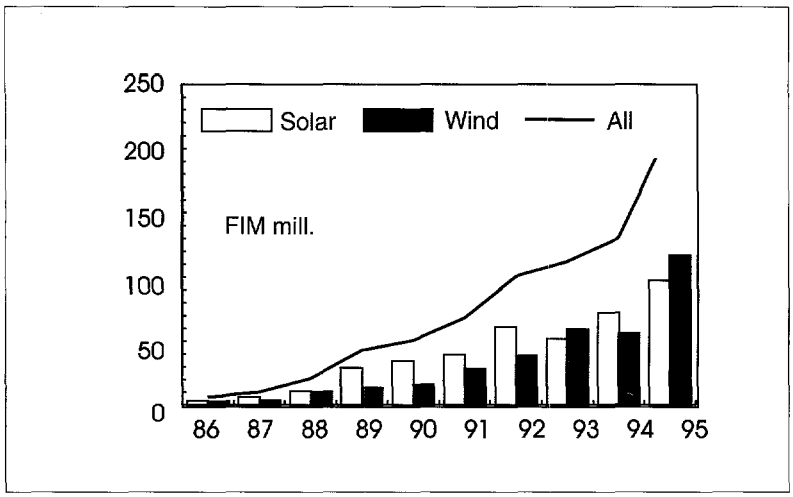


Figure 2. Development of advanced energy technology business in Finland.

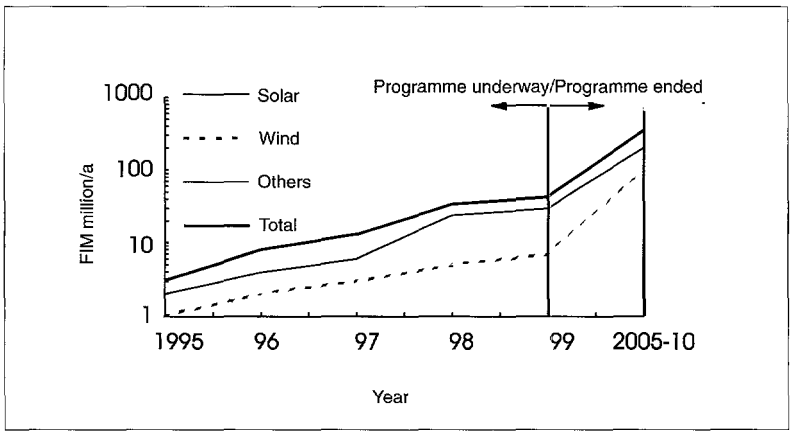


Figure 3. An estimate of the impact on manufacturing business of the projects carried out under NEMO 2 during 1993—1995.

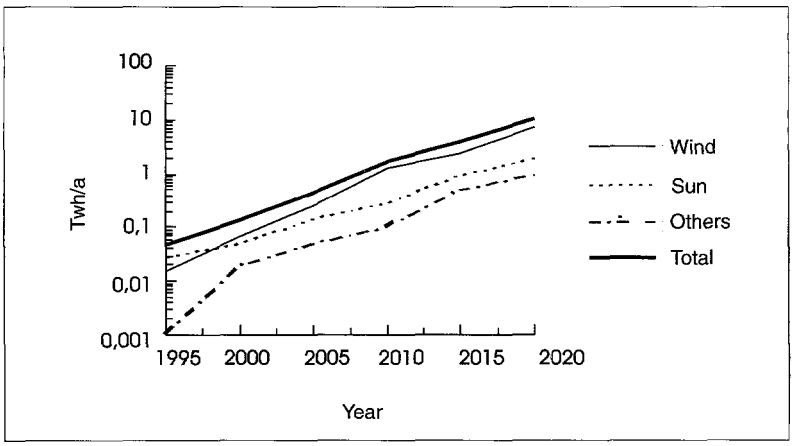


Figure 4. A scenario of the NEMO 2 programme's impact on the Finnish energy economy.

- a prototype of an autonomous solar hydrogen system (Neste Oy Technology, HUT);
- an arctic freezing sensor and blade (Labko Ice Detection Oy, Kemijoki Oy, VTT);
- a prototype of an arctic wind power plant (Kemijoki Oy, VTT);
- a hydrostatic wind power plant, two prototypes (Tmi Kone-Sampo, Imatran Voima Oy);
- a gearless generator prototype (TUT);
- a hydrogen battery for electric cars (Elcat, HUT);
- a prototype of a small-scale ORC power plant (High Speed Tech Oy, HUT).

A large number of product improvements and know-how products also exist, including planning of wind farms and instructions for planning solar electric buildings.

Several pilot plants have been constructed to promote the aims of technology and energy policies. The most important ones are:

- the arctic 225 kW wind power test plant on Pyhätunturi;
- the arctic wind farm on Lammasoaivi (1996);
- the 500 kW offshore plant (planning begun in 1995);
- the 50 kW hydrostatic wind power plant in Kopparnäs (completed in 1996);
- the 52 m^2 solar heating system in Leppävaara;
- the 100 m^2 solar heating plant in Orivesi (monitoring only);
- the 200 kW fuel-cell plant in Hämeenlinna (monitoring only);
- the 195 m^3 high-temperature water storage in Sjökulla.

Actual clusters of know-how with high scientific standards and sufficiently large research groups have formed in the following fields:

- integration of solar energy (i.e. control, structures), thin-film technology and storage;
- wind power technology and components for difficult conditions;
- systems and electrical techniques in advanced energy technology.

The solar energy cluster comprises some 20 researchers and 10 companies. Roughly 50% of the products and product ideas generated within the programme originate in these clusters. Indirectly, they are involved in 80% of all new products.

A total of 3—4 strong clusters of know-how have formed at VTT and at universities of technology. Their functions include researcher training. The research groups have a key role to play in training experts in the sector. At present, the groups comprise some 50 people, two thirds of whom are in researcher training. A graduate school in energy technology has been founded at the Helsinki University of Technology, open to project researchers and post-graduate trainees. In connection with researcher training, 16 first degrees and 8 advanced degrees, 5 of which are doctoral dissertations, have been completed.

An additional advantage generated by the programme for companies is the researcher transfers (approx. 10) from universities to demanding product development and commercialization work in the private sector. Another advantage is the 10—15 products and product ideas created within the programme.

The programme activities themselves have had a positive impact on the sector's businesses, according to which it often brings added value and improves competitiveness. The commitment of companies is also demonstrated by the growth in the business funding provided since the inception of the programme. In 1995, companies contributed one half of the programme's funding. Compared with the start of the programme, the volume of joint research projects in terms of Finnish marks has grown nearly twenty-fold. Moreover, many of the joint projects are long-term (more than 3 years), requiring firm commitment to the programme (i.e. Neste Oy, Neste Oy NAPS, Mikrokemia Oy, Kemijoki Oy, Imatran Voima Oy, Prizztech Oy).

The programme's indirect influence (i.e. via publicity and contacts) on those companies which are indirectly participating (such as ABB Motors Oy, Valmet Voimansiirto Oy) can partly be seen in the changes in these companies' product ranges. It seems that advanced energy technology is switching its emphasis more clearly to specialized products. For instance, instead of an ordinary power generator, a company may develop a generator intended specifically for wind power plants.

The programme has a positive effect on companies and on joint development projects. In fact, close cooperation between research activities and com-

panies has been typical. Each research project includes a company that intends to utilize the project's results. In addition, research coalitions comprising research and joint development projects have been formed between companies and research institutions (arctic blades, photovoltaic facades, solar hydrogen, hydride batteries, etc.). The programme has a significant influence on the content of these projects and their focus. Results from international cooperation are put to practical use most effectively through these programme channels.

International networking has also been central to the programme. NEMO 2 has included a total of 17 EU research programme projects, contributing nearly 20% of NEMO 2's total R&D funding. The programme is actively participating in the OECD/IEA Solar Heating and Cooling, Photovoltaics Power Systems and Wind Energy programmes. Nordic cooperation has also been active.

The programme's information and publicity activities have improved awareness of advanced energy technology and promoted realization of the programme's aims. Each year, the programme has, for example, organized a research seminar and several information sessions, participated in fairs, published the NEMO bulletin (2—3 each year) and a yearbook, and created a multimedia presentation.

4 Main results of the interim assessment

According to the interim assessment conducted by the Executive Committee and a foreign evaluator, the programme had complied well with the research plan's aims.

The principal observations made in the assessment are given below.

- The programme has clearly promoted the development of advanced energy technology and related business activity in Finland.
- The programme has generated considerable added value for companies in the sector.
- New clusters of know-how have formed in research institutions and companies.
- The programme has introduced the utilization of wind energy to Finland and increased power companies' interest in wind power.
- The programme's scientific standards are high. In certain areas they are of the highest standard internationally.

According to the interim assessment, the NEMO 2 research programme's contents and emphases have been chosen correctly, and the main segments, solar and wind energy, form an excellent, market-oriented and environmentally sound technological whole.

Advanced energy technology is global and its sectors of research are international. For example, of the EU research, other than nuclear, nearly a third concerns NEMO 2's research areas. It is obvious that international cooperation is vital to solving the key problems in advanced energy technology. At the same time, attention must be paid to the considerable commercial interests involved, even in the short term, emphasizing the importance of our own national research in support of Finnish companies.

The areas which have strategic importance for industry (such as know-how clusters) should be given strong emphasis in research and investment. National funding enables research to be directed in a way not always possible in international programmes. International cooperation must, however, be given emphasis. According to the interim assessment, the NEMO 2 programme has been very successful in this. National research must often also be considered as a necessary input in international cooperation and a precondition for international funding.

In less specialized areas, generic research could be better covered by, for instance, EU funding. The NEMO 2 programme's model for international cooperation, into which companies are closely integrated, is an efficient basis for an international division of labour.

The various partners in NEMO 2 have participated closely in the different stages of commercializing advanced energy technology. Cooperation between research institutions and companies is close and smooth, allowing the programme's results to be transferred to practical applications.

With regard to new product ideas, generated largely by research projects, the interim assessment suggests that the added value provided by cooperation could be increased by founding small development companies in which the actual work would be carried out by researchers, while venture capital would be provided by larger companies. University-based science parks and their researcher and technology companies are one possible option.

The NEMO 2 programme has participated actively in the research programmes of the Nordic Council of Ministers, the IEA and the EU, each of which has generated added value for the programme itself as well as for the private sector. Which form and forum of cooperation will become the primary one will naturally depend on the content of the cooperation and the advantages that this offers the programme. It is likely that participation in EU research programmes will increase. Linking these projects more closely with the programme would be sensible in terms of national research and resources. EU research funding would mainly involve generic research in which the typical participants are larger companies and research partners. In the future, EU funding should be actively sought in order to gain international information and publicity for the NEMO 2 programme.

5 Further planning based on the interim assessment

The interim assessment proposes no major modification to the programme's contents. The programme's focus is in place and there is little need to adjust it.

A majority of the programme's projects have been long-term (at least three years), which means there is a need for updating and new projects. In addition, new SMEs entering the sector may introduce new needs, as the research and cooperation assistance they require has proved considerable. This can be anticipated particularly with regard to innovative wind power plants and solar heat systems.

The programme's main segments, wind and solar energy, make up a practicable technological whole, as do the know-how clusters formed within the programme (integration of solar energy, including thin-film techniques, arctic wind, wind power components). The following provide support for business-oriented research projects, in compliance with the master plan and the needs of the know-how clusters:

- energy storage: solar and wind energy;
- multifunctional solar collectors based on thin-film technology;
- improvement of the efficiency and stability of amorphous silicon;
- improvement of the cost-efficiency of solar heating;
- wind in cold climates and models for a technical solution;
- effects of increased use of wind power in the energy system, including environmental impacts.

In these areas, there is theoretical potential for improvement of some 50% on the present technological level. Part of this potential can be realized through the programme.

Public financiers such as Tekes have an important role in promoting advanced technology. Without Tekes' input, the development of advanced forms of energy and energy technologies and their exports would have remained at a modest level in Finland.

At the moment, what justifies advanced energy techniques is technology and its commercialization. These generate new industry, technology exports, top-level R&D and jobs. Although their impact on Finland's energy economy is not significant at the moment, this could well change in the future. In this respect, wind power has advanced the most; wind power could well be given a production target in energy policy. For wind, a suitable target level could be the Ministry of Trade and Industry's wind power plant programme's 100 MW target for 2005.

Public funding will remain vital to technology research and development. Limited 'smart energy technology programmes' with concrete technological aims, such as cutting systems costs, are a potential new programme format. Such programmes would include the development of technology and markets at the same time. The competitiveness of new products on global markets could be achieved more quickly if a small niche were

created for them on the Finnish market; there are several successful examples of this abroad. As such, smart programmes do not require additional funding, merely some degree of reorganization between financiers and other partners.

6 Research organization and Executive Committee

The NEMO 2 research programme has been coordinated by Helsinki University of Technology. The Executive Committee is chaired by director Tapio Alvesalo from Neste Oy NAPS. The director of the programme is Associate Professor Peter Lund, HUT, department of technical mathematics and physics.

During 1993–1995, the Executive Committee comprised the following:

- Dr. Tapio Alvesalo, Director, Neste Oy NAPS, chairman
- Mr. Iiro Andersson, Director, Prizztech Oy
- Mr. Markku Autti, Managing Director, Kemijoki Oy
- Dr. Mikko Kara, Research Director, VTT (Technical Research Centre of Finland)
- Mr. Kari Komulainen, Special Researcher, TEKES Technology Development Centre
- Dr. Yrjö Laiho, Director, Research Department, Imatran Voima Oy
- Dr. Rainer Salomaa, Professor, Helsinki University of Technology
- Dr. Peter Lund, Associate Professor, Helsinki University of Technology, director of the programme

The project secretary, Ms. Satu Isokoski, has also acted as secretary to the Executive Committee.

Chapter 9
RAKET – Energy use research programme for buildings

Markku Virtanen, VTT

1 Background and objectives

The goal of Finnish energy policy is to increase the efficiency of energy consumption by 1% over what could otherwise be attained. The target for savings in specific energy consumption by sector for the year 2005 is 10-15%. Energy conservation is also expected to reduce emissions by 15-20%. Reaching this goal will require major changes in the energy economies of buildings.

It is essential for the achievement of environmental and energy policy targets to reduce the use of non-renewable fossil fuels. In the building sector this will, for example, mean more extensive use of solar energy. Indeed, the coming decades must be seen as a period of transition from the use of fossil fuels in the heating and cooling of buildings to renewable forms of energy.

Application of the best commercial and prototype technology will allow savings of 30-70%. Introduction of prototype technology will require a significant rise in energy prices from present levels (100-200%) to make them profitable. According to the International Energy Agency (IEA), the greatest long-term potential for energy savings in the building sector is found in advanced control and automation technology, heat recovery and heat pump technologies, new insulation materials and structures and in improved glass technology. These are also priorities of the RAKET research programme.

The results of research on energy use can be exploited by making construction and energy technology a competitive factor for companies in the sector. Energy research on buildings has focused on areas in which there is commercial interest on the part of companies in developing technologies and products. This approach has succeeded in committing companies more strongly to research.

One trend in the building construction sector has been to seek overall solutions in which energy saving components can be combined to form functional entities. The emphasis has been on the development of approaches to be applied to the existing building stock, because construction has shifted increasingly from new build to maintenance of the existing building stock.

The equipment systems of buildings have developed with respect to technology and function at a very fast rate and will continue to do so, placing great demands on the professional competence of operating personnel. Building equipment systems are often so complex that it is difficult to understand their correct use, functioning and control. Removal of this obstacle is one of the major goals.

The goal of the research programme is to develop energy saving methods based on new equipment, structure and regulation technology and to promote the commercialization and application of new approaches to improved energy use in buildings. To implement this objective, the research programme will

- develop energy conservation technology - equipment, structural approaches and eventually competitive solutions that represent a high standard of construction and meet demands for a good indoor climate.
- develop building automation systems, support systems and software tools for design and real estate maintenance with which the proper operation of technical systems can be achieved and maintained.
- promote practical application of energy conservation technology by encouraging compilation of the applied knowledge of company consortia and the best existing technology for use in the organization of test building and demonstra-

tions and for informing consumers and decision-makers of energy conservation technology.
- produce information for officials and other decision-makers for use in the preparation and pursuit of energy and research policy.

2 Results in major research areas

2.1 Low-energy buildings

Finnish low-energy buildings are based primarily on reduction of heat loss. Insulation, windows and heat recovery from ventilation have been improved. In the research programmes preceding the RAKET programme (Energy-economical buildings and building components and Energy and automation systems for buildings) model solutions for buildings and their equipment were determined. Many of these were realized or are being realized in the test building projects of the RAKET programme.

Rapid commercialization has more priority in the targets of test building ventures than the actual research projects. Key factors are overall economy, practical guidelines for planning, reference material on the functioning of the solutions obtained with measurements and comprehensive dissemination of information. Synergy between test building and research in the programme was created with support systems that have included comments on plans for test building and various analyses elaborating on the plans.

The goal is to develop economically competitive model solutions in which the consumption of purchased energy would be less than a quarter of the rated level. In single-family dwellings this would correspond to 50 kWh/m^2 or less in total annual energy.

The results of theoretical research begun at the end of the 1980s were measured in the RAKET programme. The room heating energy consumption target in the first test buildings was set at 60 kWh/m^2 per year. The future level of consumption was reduced to 40 kWh/m^2 per year. The ordinary heating energy consumption of a single-family dwelling is 120 kWh/m^2 per year according to follow-up studies.

Single-family dwellings in Finland consume 22 TWh of energy per year. At a consumption level of 40 kWh/m^2; single-family dwellings would consume some 5 TWh for heating. The energy savings per year would be 17 TWh, which would be equivalent to FIM 3 billion.

To date, ten single-family dwellings have been built. Most of them are new, although some were renovated. Increased insulation thickness, improved windows, heat recovery from ventilation and building of air-tight structures without cold-bridging are means of energy conservation. The increase in building costs is less than 5% compared with a conventional single-family dwelling.
The solutions by structural part were as follows:
- thickness of wall insulation 250-300 mm (U value 0.16-0.13 W/m^2 K)
- heat insulation for the roof slab 450-500 mm (U value 0.10-0.08 W/m^2 K)
- heat insulation for the floor slab 200-250 mm (U value 0.20-0.16 W/m^2 K)
- heat insulation for the windows (U value 0.70-1.20 W/m^2 K)

The target value of n50 for natural ventilation, which depicts airtightness, was 1.0 1/h and the realized values 0.8-1.6 1/h. The temperature efficiency of heat recovery from ventilation has been 60-80%.

Systems based on oil, electricity and solar technology have been developed for the single-family test dwellings. Storage systems were sought to minimize heating costs. The benefits of heat-storing fireplaces for heating of the entire building were also studied.

The consumption of heating energy measured in the houses was some 40-70 kWh/m^2 per year and the total energy 95-135 kWh/m^2. The normal total energy consumption of a single-family dwelling in southern Finland is approximately 200 kWh/m^2 per year. The quality of the indoor air proved good and residents have been satisfied with it.

In seeking even further reductions in consumption of purchased energy than those presented above, use of high efficiency heat pumps and active exploitation of solar energy are needed as well as

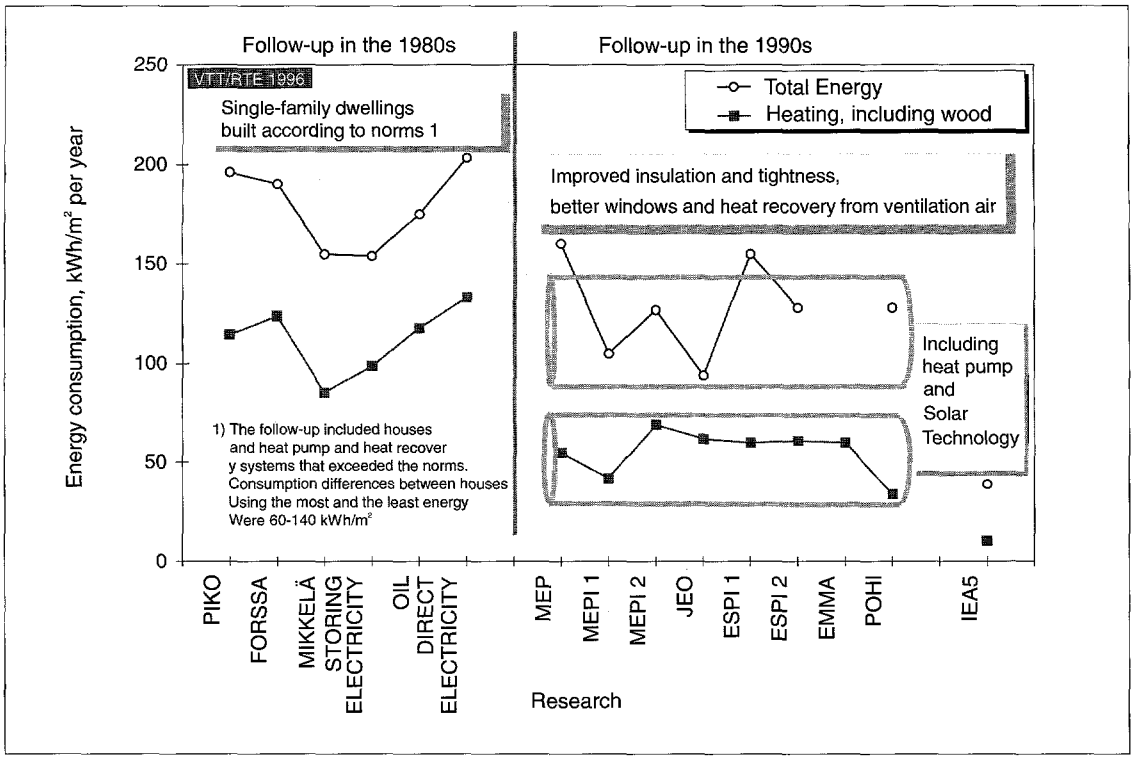


Figure 1. Energy consumption in the test single family dwellings.

from good insulation of the outer shell and heat recovery from ventilation. A single-family dwelling was built in Pietarsaari, Finland, within the framework of the RAKET programme and IEA energy research co-operation. Consumption of purchased heating energy is only 10 kWh/m^2 per year, which is substantially below the present normal level. Total energy consumption in the house is 40 kWh/m^2 per year.

The consumption target for heating energy in the test apartment blocks is half the present norm, which is typically some 120 kWh/m^2 per year. Heating of apartment buildings in Finland consumes 17 TWh of energy per year. At a level of 60 kWh/m^2 heating of apartment blocks would consume 4 TWh per year. The monetary value of energy savings would be some FIM 2 billion per year.

Savings in heating energy in Apartment House 2000 was achieved without appreciably increasing building costs. The energy conservation technologies used included a well-insulated shell, windows and heat recovery from ventilation. Low-temperature room-specific floor and air heating was used. The technology was designed to ensure that occupants would be disturbed as little as possible during maintenance and repairs. The equipment could be maintained and repaired via the stairwell.

In the low energy office buildings control of internal and external heat load and the need to minimize or eliminate mechanical cooling altogether were emphasized, apart from good insulation and heat recovery from ventilation. The METOP test office building consumes 60% less heating energy than a typical office building, and no mechanical cooling is needed. A solution based on the METOP office building was demonstrated at the Lappeenranta student union office building. Technologies such as structural protection from the sun, control of internal heat loads, integration of structures and equipment systems in short-term energy storage, use of outside air in cooling and a high degree of building automation were tested there. The project encountered many difficulties and the targets were not reached in full.

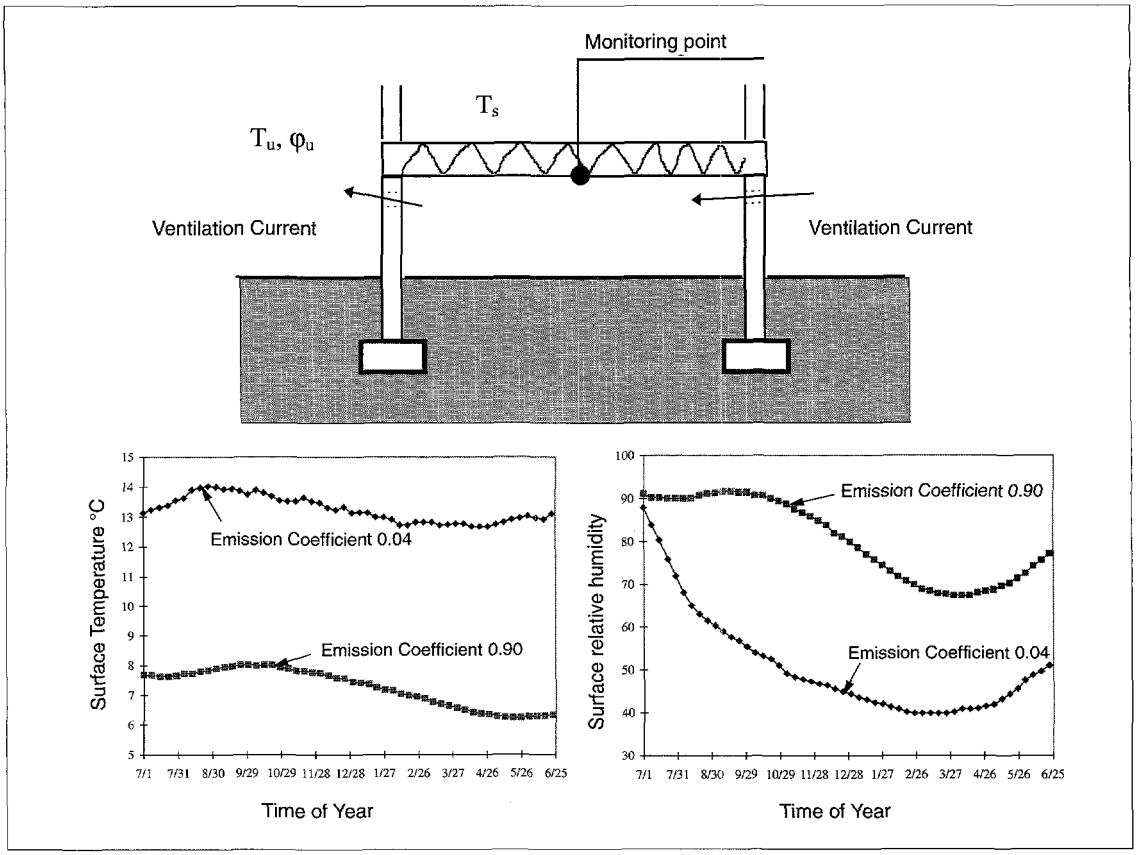


Figure 2. Temperature and moisture content on the lower surface of crawl spaces.

The low emission coefficient for long-wave radiation on the lower surface of the crawl space below a floor slab will raise the temperature of the lower surface of the crawl space and substantially reduce the potential for fungal attack and condensation. The outside conditions represent the weather in Helsinki in 1979 and the inside temperature is a constant 22 °C.

2.2 Building systems

Research on structural systems focused on insulation structures, new window and glass structures, equipment systems integrated with structures and on structural solutions for renovation.

Prototypes for thick insulation structures are based on light-weight mineral wool and films coated with low-emissivity material. This eliminated convection currents and long-wave heat radiation inside the structures.

The effect of air currents could be eliminated almost entirely with 'convection barriers'. For example in the case of a 300 mm mineral wool wall structure the increase in heat loss caused by convection was insignificant when the insulation comprised three 100 mm layers and convection barriers were placed between them. At inside and outside temperatures of 20 °C and -20 °C the increase in heat loss would have been 5-19%. Building paper that permits diffusion of water vapour is a suitable convection barrier.

Film insulation structures comprise air space and films in which long-wave heat radiation can be eliminated almost entirely by using films with a low-emissivity surface on one side. The free water collecting on the roof in self-drying roof structures could be removed by capillary action using thick water-repellent and moisture-resistant cellulose-fibre paper and then evaporated.

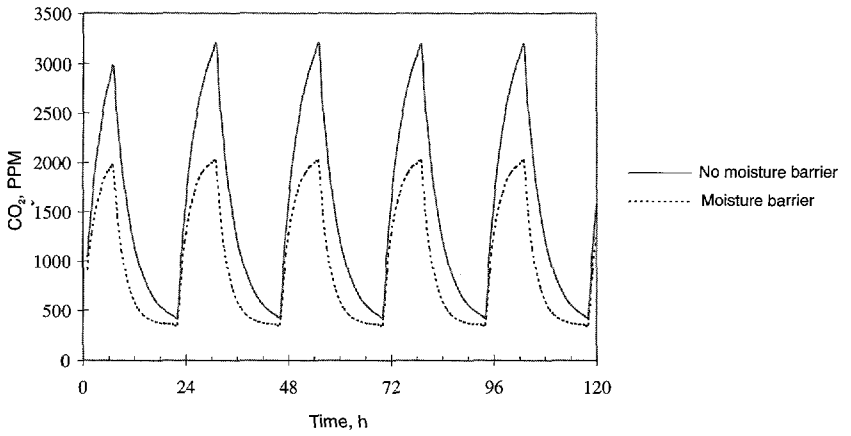
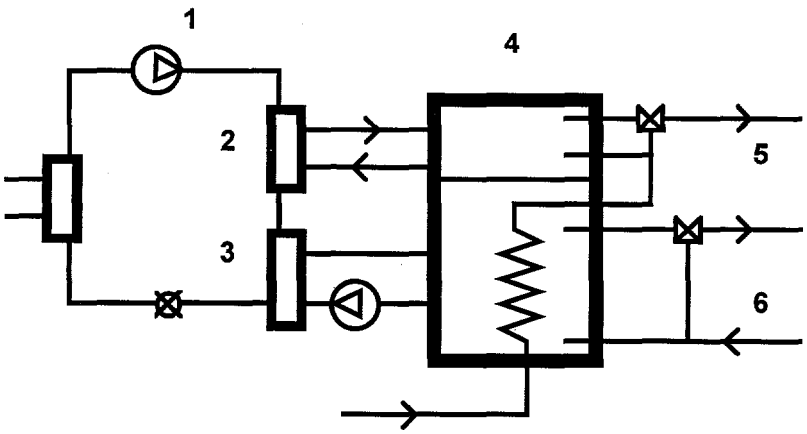
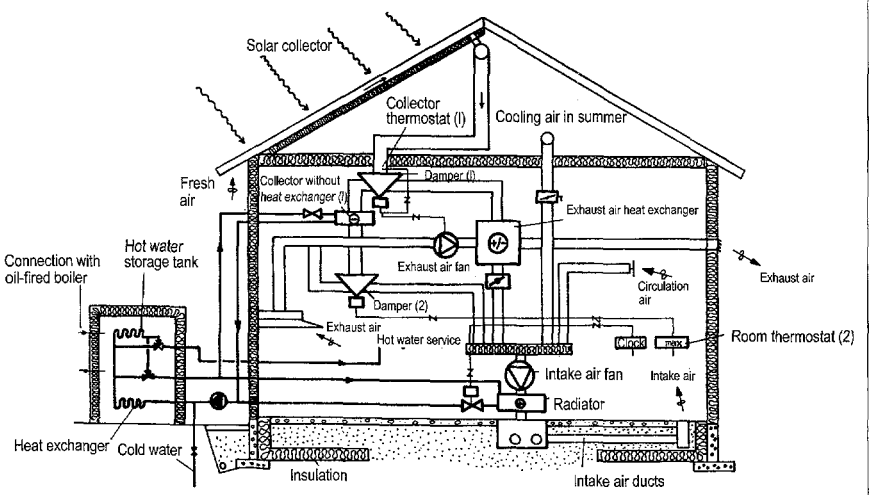


Figure 3. The carbon dioxide concentration in a 12m^2 bedroom. The diffusion of carbon dioxide through the wall structures (42 m^2) of a bedroom without moisture barriers considerably lowers the carbon dioxide content of the inside air and improves its quality. Two adults are in the bedroom between 23 and 07. The air circulation coefficient is 0.25 1/h. Moisture barrier: plastic vapour barrier in the wall structure through which carbon dioxide is not diffused. The structure of the bedroom walls beginning with the inner surface: porous wood fibre board (12 mm), building paper (no moisture barrier) or plastic vapour barrier (vapour barrier), pulp fibre insulation (150 mm), porous wood fibre board (12 mm) and ventilation gap and timber cladding.

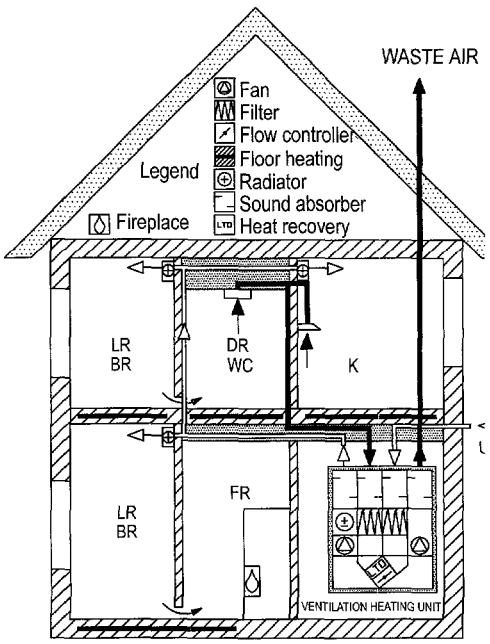


1 heat pump compressor
2 cooling radiator for generation of hot water service
3 condenser for heating hot water
4 two-part storage tank
5 hot water service network
6 heating water network

Figure 4. Connection of heat pump to the hot water storage tank and heating network.



Solar and air heating system for a low-energy house in 1978. Total energy consumption was 43 kWh/m^3.



Ventilation heating system for a low energy house in 1996. Total energy consumption is 35 kWh/m^3.

Figure 5. Equipment systems for low-energy houses have been simplified over the years.

Internationally pioneering work was done in modelling and developing experimental research methods for cellular plastic insulation. The methods will be used in the future to develop polyurethane structures based on CFC-free propellants.

Research on window and glass structures has international significance. Co-operation in the sector was carried out in IEA projects. The goal was to design a window suitable for Finnish conditions which would be optimal both thermally and optically. The windows underwent a comprehensive energy analysis. Via technology transfer, information on the heat and radiation transmittance of adjustable glass and windows was obtained, as was information on the properties of aerogels and vacuum glazing.

The research programme developed a prototype of a solar air collector based on translucent insulation. Solar energy is collected in the absorption layer behind the translucent layer. The heat is then transferred by means of natural closed air circulation from the absorption layer to the structural parts of the building that store heat. The volume of heat obtained with the air-collector system may be double that of a structure based on passive translucent insulation. A prototype was tested in the PASSYS (passive solar components and systems testing) outdoor test chamber developed in the research programme.

Repair concepts for the external shell were analyzed for different apartment block types. The emphasis in repair solutions for the external shell is on the application of new window technology and the use of balcony glazing in energy renovation. The company projects developed products suitable for renovation; commercial applications of the new window technology and additional ventilated insulation for outer walls.

2.3 Equipment systems

Research on equipment systems focused on air conditioning, heating and renovation.

The research programme took part in the development of the TermoNet and Merki air-conditioning systems. Thanks to efficient heat recovery, considerable savings in energy and power were achieved with the ThermoNet system. Cost savings are also achieved by using low-temperature return water from the district heating system. Used extensively, the system will reduce heat loss from a district heating distribution network and improve the operating economy of co-generation.

A commercial application of the cooling beam used as the room unit in the Merki air-conditioning system has been developed. The concept of the system has been demonstrated and converted into a commercial planning guideline. Heat recovery instead of postheating can be integrated with the room unit in the solution intended for renovation. The system developed saves a considerable amount of mechanically produced cooling energy in office buildings (30-40%) compared with conventional arrangements.

The need for mechanical cooling in office spaces can be reduced substantially with cooling equipment at individual work stations. The most efficient approach proved to be a ceiling fan, which kept the work station comfortable even when the room temperature rose to 28 °C. Since an average air flow velocity of 1 m/s on the surface of the body can be obtained with a ceiling fan, the body experiences a temperature 3 degrees lower.

The research programme developed two economical low temperature pump prototypes. One is for 5 kW, and is meant for new buildings. The 8 kW heat pump is meant for renovated premises. Considerable improvements over existing equipment in the capacity for hot water production, the heat coefficient and the control system were achieved in the prototype developed by the programme. The structures were also kept simple. Work on development of ground heat pumps continues in a product development project.

In advanced solar heat equipment the heat from the solar air collector is stored in the earth under the building. The temperature of the earth mass storage is raised with a heat pump to the level required for heating and hot water services. The system is at the demonstration stage.

In developing wood as a fuel for heating single-family dwellings, the aim was easy use, energy efficiency (measured boiler efficiency in the neigh-

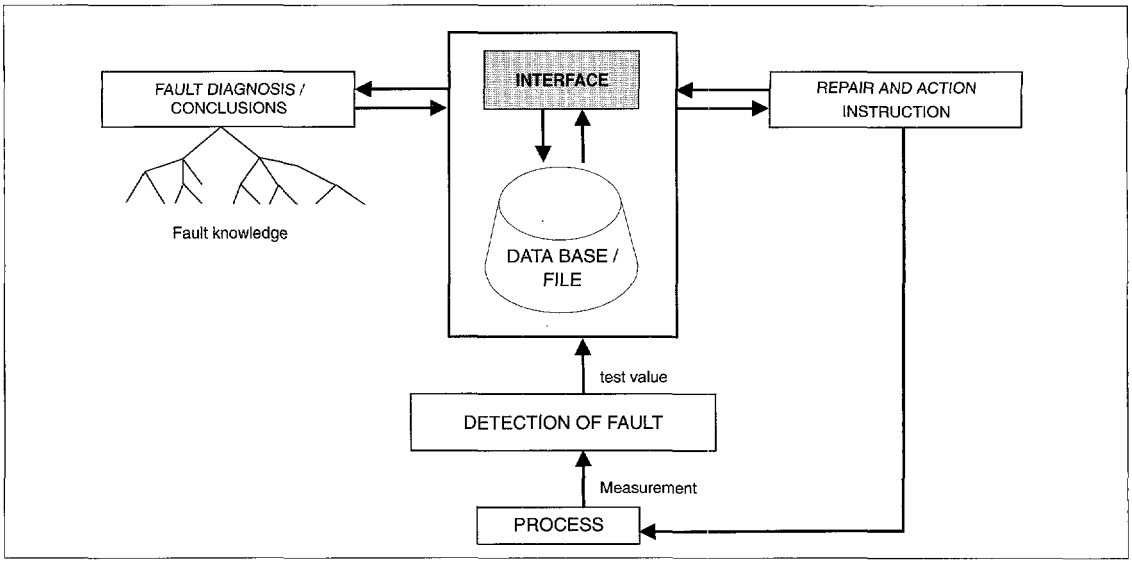


Figure 6. The fault diagnosis system provides information on the basis of which the reason for the fault can be determined.

A fault detection tree. The desired process can be restored after diagnosis. A database is used to record and store fault data.

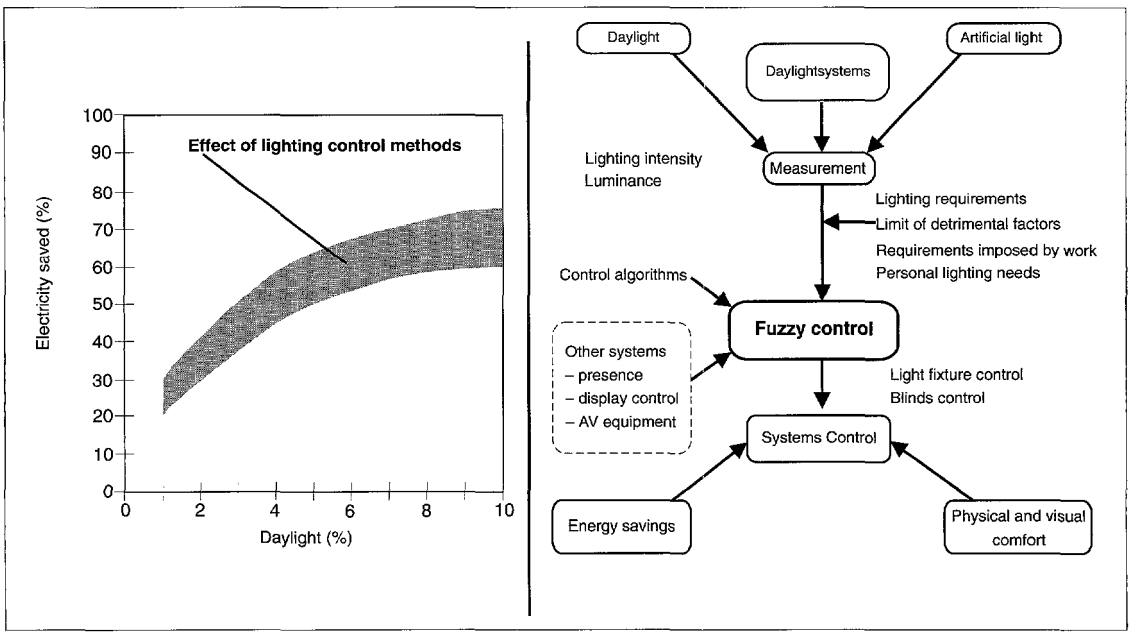


Figure 7. The electricity consumed in lighting can be reduced with effective controls.

Lighting control can be implemented for example with fuzzy logic. The daylight ratio is the ratio between the interior lighting intensity and the external horizontal lighting intensity under the open sky.

bourhood of 80%) and low emissivity. The system developed is based on a wood-fired boiler with a rated output of 40 kW, a hot water storage tank of 1.8-3.0 m^2 and water-based heat distribution. A number of manufacturers are developing heating systems based on the use of wood and solar energy. The main objective is to use the heat from a fireplace throughout the building and integrate solar technology with water-based heat distribution.

The research programme developed model solutions for renovating and improving the ventilation systems of apartment blocks built in the 1950s-1970s with various technologies. Drying equipment (Esteri) based on heat pump technology was developed to alleviate the moisture problems of apartment block bathrooms.

Ways have also been sought to improve the energy economy of air-conditioning cooling equipment. The main problems in the operations of cooling systems (direct vaporization systems, water coolers and standard air-conditioning machines) have been overdimensioning of plants and operating problems in winter. Both problems can be tackled effectively in the design stage. Views on systems design, dimensioning criteria, output control and solutions for the renovation of cooling systems with respect to most malfunction and disturbance situations were presented.

2.4 Operating technology and building automation

Research on building automation systems concentrated on energy control systems and data systems for operations, optimization of the use of HEPAC processes and diagnostic methods, control ja regulation of lighting and integrated systems regulation.

The research programme developed an energy management system that serves as a frame of reference in R&D on building maintenance, use and automation systems. The concept was applied in a company project that developed an intelligent connection between the electric company and households (Hemis). The concept has now advanced to the prototype stage.

The research programme developed several real-time fault diagnosis systems for district heat exchangers, oil burners and air conditioning. A fault diagnosis method for the building level was also developed within the framework of IEA co-operation. The research also developed an inspection method for the operation of heat and air-conditioning control systems.

The lighting criteria developed in the research programme created the basis for development of a control algorithm for lighting. Room lighting need not be kept constant. A comfortable volume and distribution of lighting depends on natural light. Measurements made with the help of test personnel showed that lighting could be balanced, that is the formation of shadows and brightness differences between various parts of a room could be reduced. The necessary control of lighting could be achieved for example with a learning intelligent control system based on fuzzy logic. The electronic interface for the fluorescent light fixtures was developed in a company project.

The programme also analyzed the effect of integrated lighting and air-conditioning systems on measurement and energy consumption in a typical office building. Model solutions for the design of controls for lighting and air-conditioning systems were devised on the basis of the analysis.

2.5 Design technologies and data systems

Development of design methods concentrated on data management and systems and on tools and analysis methods for design.

The RAKET programme developed an energy-economy model for building and HEPAC and automation design in which the design stages are depicted in terms of energy economy. The model includes a need survey, project planning, building design, construction and commissioning. The model is to function as a frame of reference in development of data system applications for the design process.

The research programme developed a HEPAC and electricity feedback system model and database on

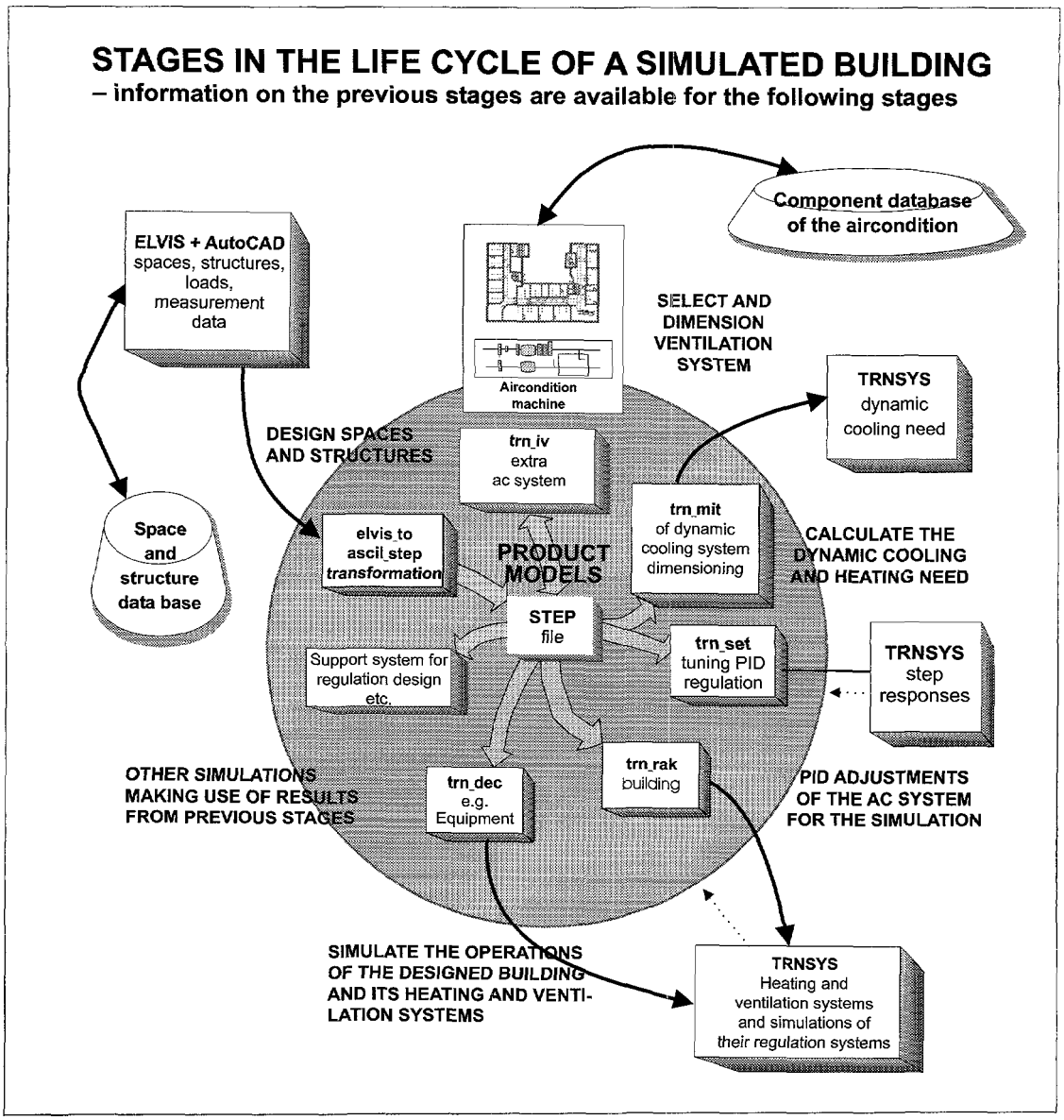


Figure 8. Building air-conditioning systems can be simulated with PROMISE software.

the internal climatic conditions of office buildings and the sources of impurities and emissions in them. The former contains data on the energy consumption of office buildings, flows of outdoor air in office rooms, symptoms of employees and the chemical and physical values of indoor air. Information from 56 office buildings in 9 different countries was compiled for the database.

Before energy-saving building systems can be widely applied, design methods and the infrastructure for the design system must both be developed. Management of knowledge-based instead of document-based design data is the basic requirement for integrated design tools and computerized building. The RAKET programme adopted a product data model based on the 'RATAS' concept for use in documentation. The basic solutions of the integrated design environment based on the product model were developed for the prototype level in the COMBINE project of the EU JOULE programme.

A prototype of an integrated simulation environment(PROMISE), in which simulation and design tools were combined with a commercial CAD system using the same product information, was developed for national commissioning of the design environment. The product data technology used parts of the ISO/STEP data management technology. Product data technology will be a key element in the core of data transfer in the building process and in the long-term for data management throughout the life cycle of the building.

Individual methods were developed for analysis of energy, internal climate, and environmental and cost effects. An important aspect of the national energy-saving programme is the introduction of an energy technical classification for buildings. It would promote efficient energy use of buildings and application of energy-saving technologies. The classification will require determination of target values for energy consumption in individual buildings. The RAKET programme developed a method for determining target values for consumption of heating energy, electricity and tap water in buildings that vary in age, type and amenity standard. The method includes Etana software, which facilitates drafting of energy consumption in a standard year. It has been tested in apartment blocks and service buildings and a commercial version is marketed as a practical tool to property management organizations by the Finnish Property Owners' Association.

The RAKET programme developed a method suitable in Finnish conditions for evaluation of the environmental impact of building energy use. It comprises a checklist for designers, methods for calculation of the specific emission values of the forms of energy used in buildings and a simplified calculation tool. The checklist is suitable for evaluation of the design stage. Evaluation of the annualized emission coefficients of the forms of energy used in buildings is made possible by the calculation methods for specific emission values. The calculations take account of the emissions produced in the fuel production and use chains and the problems entailed in co-generation of district heating and electricity, especially in the building sector.

3 Effectiveness of results

3.1 Industrial relevance

Low-energy buildings

The RAKET programme has verified with measurements that it is possible and economical to reduce consumption of heating energy in single-family dwellings by more than 50% (to some 120 kWh/m^2 annually). Various technical solutions for achievement of energy savings have been evaluated in test construction. On the basis of this experience, house suppliers have brought alternatives onto the market in which low energy consumption is a competitive advantage. The alternatives can be implemented with reliable technology and only a slight rise in building costs.

In the present projects, energy technology for single-family dwellings has reached the stage of commercial applications and this has been demonstrated in the test building. Commercial prefabricated house kits are a result. In contrast, the test-built apartment blocks have remained prototypes and have not had an effect on general building methods. Individual commercial products have been created, but no energy-economical type house. With regard to office buildings, only one test construction project exists.

Test building has offered companies an opportunity to develop and test energy-saving structures and products and to publish the results. Test construction has provided many details which can be developed in future design of energy-saving houses. Apart from equipment manufacturers, most prefabricated house suppliers have increased their capacity to offer energy-saving solutions to their customers.

The designs tested and proved functional in test construction and the energy-saving equipment and windows now on the market have made general use of the building method possible. The long-term goal is to develop methods and convert them into products that require little expertise for implemen-

tation. This objective has been sought for example by developing energy-saving house models together with suppliers of prefabricated houses and by preparing handbooks based on test building experience.

Structure and equipment systems

Research on window and glass structures has produced a high standard of information which is also of direct use to the industrial sector. The results of the new window and glass research has led to the launching of new products.

During the research, Fenestra Oy launched a window with improved heat insulation capacity. It is based on heat mirror technology. The new glass improves insulation by 50% compared with the products previously on the market. The research did not entail actual product development; analyses concerning the building methods and the technical aspects of the system were made instead. The total annual demand for the window technology in Finland is some 800,000 m^3; the realistic annual export potential is around 1,000,000 m^3.

The company project of the research programme developed an additional front window solution suitable for renovation purposes and there is now a commercial application (Lemminkäinen Oy). There are also commercial applications of additional insulation solutions for outside walls (Polar and Mäkelä Metals).

ABB Installation Oy's ThermoNet system was developed within the framework of several technology projects and programmes as the system covers not only air conditioning but also the entire energy supply chain. ThermoNet is ABB's building technology system. There are versions of the system for various applications, such as markets and swimming baths. A commercial application of ThermoNet technology is in the offing and the supply network for the system will be built within the framework of a separate ThermoNet technology programme. The RAKET research programme will develop more extensive systems based on ThermoNet technology and promote company networking. The cumulative turnover of the ThermoNet systems for approximately two years is FIM 200 million, of which turnover in Finland accounted for 90%. Products were exported to the Nordic countries and Russia.

Fruitful development work also created the MERKI low-temperature air-conditioning system based on Halton Oy's free cooling coupling. Room air-conditioning equipment is a commercial application of the research.

The model solutions for residential ventilation presented in the HEPAC 2000 research programme were realized in company projects conducted within the RAKET research programme. Vallox Oy and LVI-Parmair Oy, both suppliers of ventilation equipment, have taken responsibility for development of the systems.

The results of development work on new heat pumps, oil heating and fireplaces have been promising. New heat pump products for the SME sector, fireplaces and product development principles for oil heating have been produced. Their significance is increased by the fact that the manufacturing industry is relatively small in size and the potential for companies to invest in product development is limited. Technological support for the SME sector has been provided through the project, in accordance with Tekes policy.

Suomen Lämpöpumpputekniikka Oy will continue development of a ground heat pump. The work will take into account future requirements such as new refrigerants and logic control. The market potential for ground heat pumps in Finland at present is in the thousands, although sales amount to only 200-300 units annually. Domestic sales, however, are growing rapidly and the export potential runs into tens of thousands in the Nordic countries alone.

Few project proposals supporting R&D on renovation were included in the programme. No viable products or methods were developed in this area. The high price of the solutions compared with the energy savings achieved is a problem.

Operating technology and building automation

Research on diagnostics has produced concepts and prototypes which have been used in development of building automation systems. Area main-

tenance companies have modernized the remote control and other control systems used in property management; the principles of open building automation and intelligent operational interfaces have been applied (Atmostech Oy, Elektroniikkatyö Oy).

Lighting research has developed the key principles for the dimensioning, control and regulation of lighting. Company projects have developed products for need-based, energy-saving lighting systems (Helvar Oy and Oy Ensto Ab).

Helvar Oy has developed interface equipment for fluorescent lamps based on new technology; the savings effect is some 25%. In Finland, some 2.6 million conventional chokes for fluorescent lamps are used annually and some 100,000 electronic interface units. It has been estimated that 20% of the domestic market could convert to electronic interface equipment in ten years. Domestic sales would then amount to FIM 50 million. Helvar Oy exports 95% of its interface equipment to western Europe and the volume is increasing by some 15% annually.

3.2 Networking and researcher training

The RAKET research programme has conducted national research co-operation with Tekes research and development programmes in particular. Examples of partners are the building environmental technology (RYM), building automation technology (SAMBA), wood construction technology, district heating and renewable forms of energy and technology research (TERMO) programmes. Research communication has been handled in co-operation with MOTIVA.

Overall, the criteria used in domestic operations have been applied in the prioritization of international operations. International research co-operation has been conducted within the framework of the energy organization of the western industrial countries (IEA) and the European Union.

Participation by the research programme in IEA research co-operation has not had separate funding. The Executive Committee of the research project has chosen the projects. The national objective of IEA research co-operation is to create added value in domestic research on energy use in buildings through technology transfer and researcher networking. The research programme has participated in the Energy Conservation in Buildings and Community Systems project and in the Solar Heating and Cooling project.

The programme also encompasses some of the EU JOULE research projects. Some of the new research and demonstration projects of the JOULE/THERMIE programme concern core areas of the RAKET programme.

Thanks to the extensive content of the RAKET research programme and national and international networking, the opportunities for research or training have been good. One dissertation and one licentiate thesis have been completed. Approximately ten MScs and diplomas in engineering and technician's diplomas have been completed within the programme.

4 Main results of the interim assessment

The RAKET programme has started from the goals set by the Ministry of Trade and Industry, and thus its goals differ somewhat from those of Tekes, the host organization. The central goal of the TEKES technology programmes is to make companies more competitive by developing new products and by adding value to existing ones, thereby promoting exports and creating new jobs.

The assessment suggests that individual domestic low-energy test building be abandoned in the future. Resources will be channelled into commercialization of results by supporting test building. TEKES will see that the products developed in the RAKET programme are taken into consideration in test building for other technology programmes.

A new priority on the building level will be testing of the low-energy building concepts in international research projects, for example for the German market and for promotion of product exports.

The volume of renovation in relation to new building will increase. Most of the energy consumed in heating will be used in the existing building stock. The building potential and concepts for implementation have been studied adequately. Now functional solutions for new building and renovation are needed.

Priority on structural research will be as follows: Commercial applications of research findings on heat insulation structures will be developed. This will produce energy-saving buildings and competitive solutions and generate business. Heat insulation solutions suitable for renovation will be developed. They are also significant in building exports. Applied research will be channelled towards structures based on new window and glass technology and applications thereof. Future research on equipment systems will be directed more strongly into the development of electricity-saving technology and building technical system entities. Also, means for cutting peak loads and their impact on the energy chain is an important research entity.

Energy saving solutions for renovation and energy renovation still have great potential; effective methods should be sought and developed. The programme will be actively channelled where the greatest potential lies and into projects where the goals are high.

Priorities with respect to equipment systems are next. Comprehensive building technical systems will be developed and products parts will be integrated with the comprehensive systems. Resources will be channelled into the development of electricity-saving technology and systems for natural and artificial lighting. The means to cut peak loads and the effects on the energy chain will also be determined. Energy savings and renovation solutions will be developed. Apart from Finland, the need for renovation in nearby areas of the former Soviet Union will also be taken into account.

Companies and other users in the building automation sector consider a high standard of research in Finland essential. It is in the nature of research in this sector that not all results can be applied immediately. A base of knowledge and awareness is created with continuous high-quality research and much indirect benefit can arise on this basis. The programme should decide the extent to which beneficial results are desired and how much stress should be placed on more practical results. Development of intelligent product components should ensure that product components can be integrated and are recognized as essential parts of a controllable/adjustable system.

The priorities in research on building automation in the future are as follows. The direct potential for the application of technology already developed or to be developed will be determined. Tools and systems supporting the functions of real estate companies, such as remote monitoring and control and data transmission between energy authorities and real estate, will be developed. These will yield significant energy savings compared with the resources invested in them. Intelligent user interface equipment will also be developed.

Development of design methods is a long-term effort, and the effects become gradually visible. First and foremost, it is essential for both builders and architects to use the new methods and tools. There remains a need to create simple user-friendly applications, especially for the initial stage of design (for example life cycle calculations, simulation models and combining of databases with CAD systems) and for property management. It will be necessary to continue international co-operation, since Finnish expertise is above the European average. The RAKET programme will favour projects producing applicable results during its final years. Concrete, partially incomplete programme tools will get the results of development onto the designer's table quickly and feedback about their usefulness will be available.

Priorities will be as follows. Development of research findings into products and commercial applications will continue. Simple, user-friendly applications, especially for architects, are the goal. Design tools that support exports of building technology will also be developed. Development work linked with data management and data systems for the design process will be conducted primarily within the framework of other technology programmes.

5 Further planning based on the interim assessment

According to the interim assessment, the original goals of the RAKET research programme should be specified on the basis of TEKES' general goals. Energy saving in buildings and the development of energy-saving technologies remains the central goal of the research programme. The projects of the research programme will emphasize corporate interest in the technologies and products to be developed and the benefits obtained from results as well as their suitability for exports and renovation.

The new premises of the research programme are the following.

- Projects aiming at more efficient energy use in building complexes (for example the energy efficiency of entire blocks and regional energy supply systems) will be included in the research programme, in addition to building-level products and systems.
- Test building projects on the product and system level will be favoured instead of low-energy buildings.
- The emphasis in research on structural solutions will be on making products out of existing heat insulation methods and especially the development of new window and glazing-technology applications.
- Research on building-technical systems will emphasize development of comprehensive systems. Development will give equal weight to solutions that save electricity and fossil fuels and stress their integration with developed control and regulation solutions (intelligent product components).
- Development of intelligent product components and building automation systems will ensure that the product components developed are integrated with the existing systems.
- Research on energy efficient design technologies and data systems will emphasize development of products and commercial applications of design and maintenance programme tools.

6 Research organization and Executive Committee

VTT Building Technology has been responsible for management of the RAKET programme. The programme director was originally Reijo Kohonen and the coordinator Markku Virtanen, who eventually assumed leadership of the programme. Programme decisions were prepared in support groups and ratified by the Executive Committee, and a large number of experts in the sector have taken part. The substantial participation in the work of the management and support groups by companies and consultants within the sector has been significant.

The management of the research group comprises the following persons:

- Vesa Lehtomäki, chairman, Culminatum oy
- Reijo Hänninen, Insinööritoimisto Olof Grandlund Oy
- Reijo Kohonen, ABB Installaatiot Oy
- Aila Korpivaara, Ministry of the Environment
- Heikki Kotila, The Technology Development Centre of Finland TEKES
- Mauri Mattila, The Finnish Property Owners' Association
- Vesa Peltonen, Arkkitehtitoiminta Ky Kai Wartiainen
- Heikki Reijonen, Neste Advanced Power Systems
- Berndt Schalin, Helvar Oy
- Olli Vainio, Paroc Oy Ab
- Markku Virtanen, secretary, VTT Building Technology

Chapter 10
SIHTI 2 – Energy and environmental technology

Kari Larjava,
Technical Research Centre of Finland (VTT)
Rabbe Thun,
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1 Background and objectives

Prevention of global environmental problems requires long-term changes in the structure of industrial production, as well as research and new technology. These must all be carried out using commonly approved follow-up and control methods. The European Union aims to achieve harmonized legislation on the environment, which Finland, too, must comply with. We should therefore, acquire detailed information on the planned provisions, which may have far-reaching effects on different fields. One essential issue will be evaluation and comparison of the harmful environmental effects of energy production and consumption.

One basic problem in decision-making concerning the environment is to find ideal compromises. Unfortunately, progress without any negative side effects is rare in environmental matters. Because the effects are transferred from one medium or dimension to another, integrated control of emissions is necessary. Even this is not always enough, however, as aims for energy production and airborne emissions which are in themselves logical may conflict with other factors. The matter is further complicated by changes in values and a lack of basic data.

It appears that trends in environmental issues change in constant waves, and it sometimes seems necessary to react first to problems which are not always the most burning issues in reality. In such cases, it is relatively easy to increase our knowledge about basic facts, but the solutions may then have harmful indirect or even direct effects later on. In other words, it is all a question of optimization, which requires broad expertise, a good overall approach and reliable methods for evaluating impact.

With the growing importance of environmental issues, it has become necessary to allocate our limited financial and intellectual resources to appropriate actions and to those research areas which will be most essential in the future. Forecasting, and the related life-cycle analyses and model and cost calculations, have proved effective tools, for example in comparing in advance the efficiency of different ways of restricting emissions in complex situations.

The SIHTI 2 research programme comprises an extensive study of the harmful effects of different forms of energy production, ways of restricting them and the costs incurred by industry and society. Reliable databases on energy production, fuels and boilers used, and emissions from different forms of energy production are the basic requisite for all evaluation of the harmful effects of energy production. Creation of such databases has, indeed, been one of the most essential objectives of the SIHTI programme. Other very important goals are development of methods and tools required in decision-making concerning the environment, and tests on their feasibility and reliability.

Measurement of emissions constitutes a special problem field which frequently poses new challenges. Tighter regulations concerning airborne emissions, and advances in new combustion and treatment technology have created a need to measure the behaviour of particles in different processes. Hence, the first goal of particle emission research within SIHTI 2 is to create a real-time method of measuring size distributions which can be applied to flue gases. The program also focuses on detecting new gaseous components which may be difficult to measure and on designing and building equipment for continuous measurement.

In addition to energy production and related environmental issues, SIHTI 2 examines environmental questions concerning the forest industry. Objectives common to both industries are the reduction of harmful emissions, recycling of raw material, and reduction and utilization of wastes.

2 Major results

2.1 Tools for strategic environmental decision-making

Restrictions on emissions and the regulatory effects of taxes

Environmental protection has become one of the greatest forces for change in the energy industry, with reduction of flue gases as a major objective. This has resulted in several international agreements on emission reductions, which in turn have led to national programmes to reduce emissions. For energy production in particular, the implementation of such programmes invariably requires major investments in either emission-reducing equipment or new technical solutions for power plants. It is therefore very important for concrete aims, decisions on new investments and other strategic decisions to be based on an examination of forecasts for the cost-efficiency of alternative long-term measures to reduce emissions and related regulatory instruments.

While preventing acidification of the environment is one vital issue, reducing greenhouse-gas emissions is another environmental issue of global importance. Trends in carbon dioxide emissions, in particular, largely derive from the solutions adopted in energy production and consumption. At present, complete elimination of carbon dioxide emissions is neither technically nor economically feasible, but they can be reduced by achieving more efficient energy consumption and changing the structure of the energy system.

As emissions can be reduced using cost-effective treatment equipment, regulation through standards and permits is extremely efficient. Some countries impose special taxes to reduce greenhouse-gas emissions, but so far this has not led to an international system of taxation. To prevent distortion of competition and the resulting harmful effects on the environment, today's deregulation of energy markets calls for harmonization of various environmental standards and taxes.

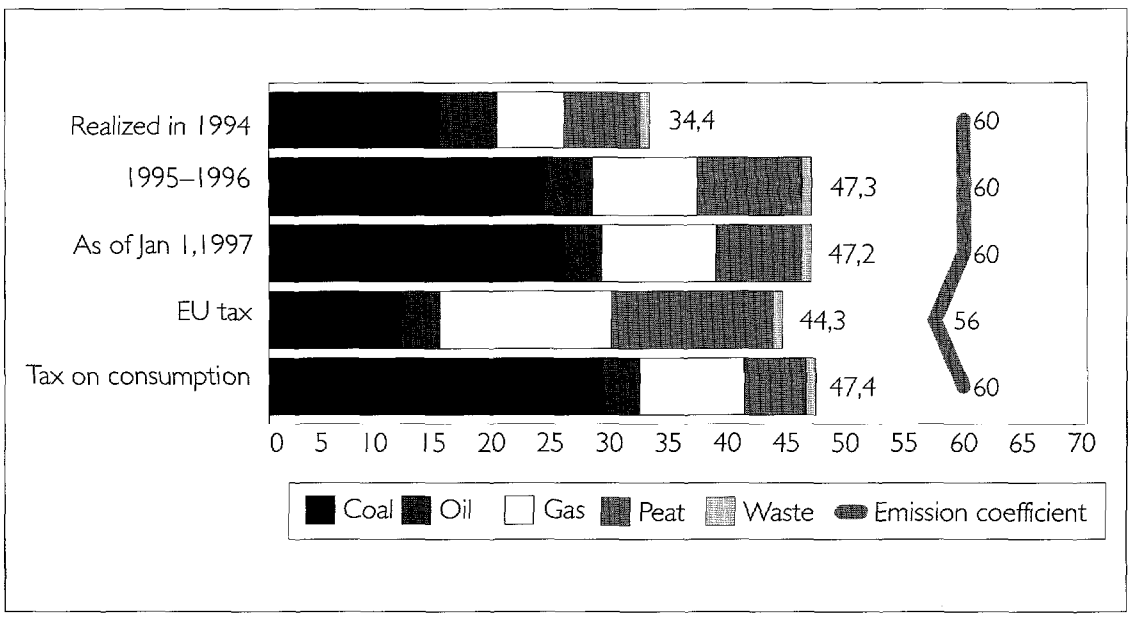

Figure 1. Carbon dioxide emissions and specific emission coeffiecients in 1994; the same in 2010, calculated according to the different taxation proposals.

Using both real and fictional examples, a study by Energia-Ekono examined the regulatory effect of environmental taxes and new tariff systems on the operation and profitability of power plants. The study focused on how taxation affected the profitability of building new plants, the choice of fuel and the utilization of co-generation potential. The study included an evaluation of the relationship between emission treatment costs and harmful effects. The effects of three different taxation models on emissions and distribution of fuel consumption were calculated using data from a database on boilers.

The results showed that a shift of emphasis from production (as in the present taxation system) to consumption would reduce the regulatory effect of taxation and make natural gas and peat less competitive than coal or oil. Under the present taxation system, condensing power from peat is the most expensive of the power generation forms examined and natural-gas-based co-generation the cheapest. Even if taxation is doubled, this order is maintained, but it weakens the profitability of coal-fired plants; a raise in taxes would improve the competitiveness of co-generation power in relation to condensing power production. The effects of environmental taxes on the scale and technology of power plants vary in different cases. The effect of changes in taxation on the profitability of an increase in the power-to-heat-ratio depends on how alternative energy sources are taxed. The amounts of emissions of particles, No_x or CO_2, varied little in different taxation models. It appears that the only effect taxation could bring about is a decrease in sulphur dioxide emissions.

Life-cycle analyses and emission databases

Consumer demands for cleaner products are reflected in the increased use of life-cycle analyses and eco-labels, which have become an important competitive factor, especially in the forest industry. This is already apparent in companies' need for information on the environmental effects of the energy they buy to manufacture their products. The SIHTI 2 programme demonstrates the importance of collecting data from life-cycle analyses of Finnish energy production in a common database which can be used for a whole range of analyses and research projects.

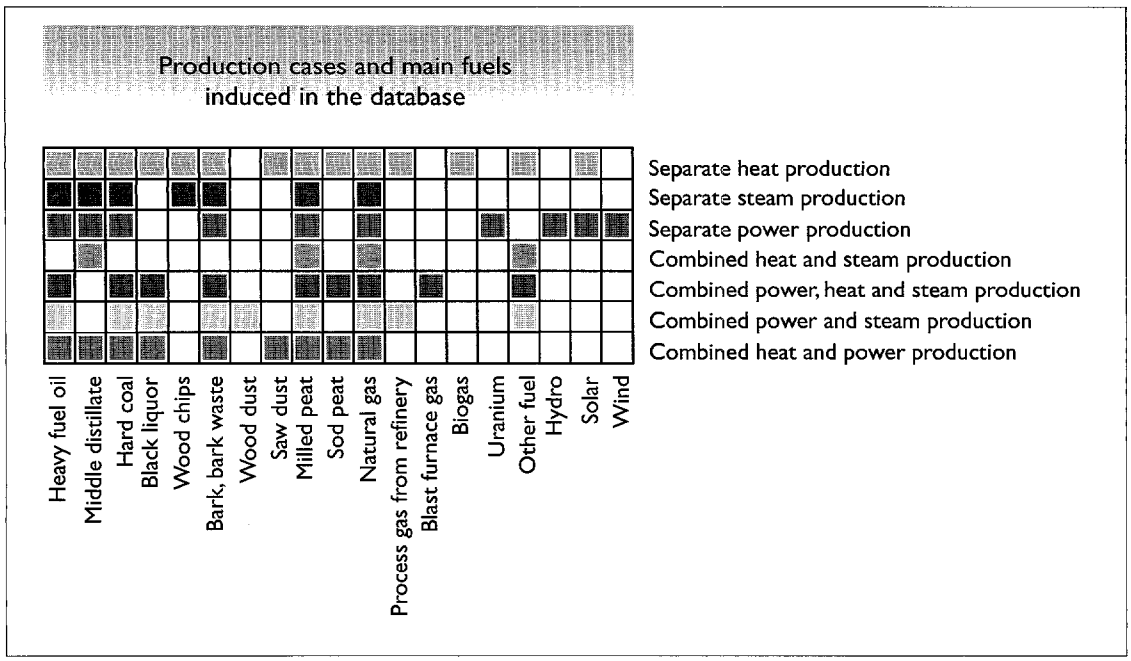

Figure 2. Power plants and main fuels covered by the SEEP survey.

The LCA database (SEEP), compiled by VTT Energy and LCA Engineering, covers the major part of Finnish energy production and contains data on various fuel chains, power-plant processes, (treatment) unit processes and emissions. Data have been collected on more than 900 boilers.

The information in the SEEP database is illustrated in figure 2. The database contains models of all existing or technically and economically feasible combinations of production methods and main fuels that emerged in the SEEP survey. Each square at the bottom of the distribution in figure 2 equals one of the 115 possible unit processes in the database.

A study carried out by the Meteorological Institute has compiled data on sulphur and nitrogen emissions from different sectors of industry. The aim of the study is to produce information on the concentration and deposition of air impurities, to examine their harmful effects on the condition of pine forests in the province of Satakunta which are likely to be first affected first by acidification. The study calculates the migration, transformation and deposition of the emissions to the nearest 11 kilometres. The calculations have been verified by readings from measurements.

The Helsinki Metropolitan Area Cooperation Council, in cooperation with the Meteorological Institute, has produced a more detailed account of nitrogen oxide emissions and calculations of nitrate deposition, with emissions grouped by source, and distinguishing between concentrations and depositions from long-range migrations. The results of the study can be used in assessing the need for emission reduction and its effect in the Helsinki metropolitan area.

Examination of forecasts

VTT Energy has examined how emission restrictions should be targeted in and around Finland in order to achieve the most cost-effective reduction of acidifying depositions, and has developed a linear optimization model for achieving optimal cost-effectiveness. The source data used in the model consist of the cost functions of reducing emissions of sulphur dioxide, nitrogen oxides and ammonia by source area, and migration coefficients for the deposition from sources of emissions. To simulate trends in Finnish energy production and industry, VTT Energy used an international computer model. A study by Energia-Ekono assessed the cost-efficiency of emission restrictions in the Helsinki and Tampere areas.

The present and future competitiveness of the properties of Finnish electricity was another topic in the SIHTI 2 programme. Imatran Voima Oy (IVO) has compared the present and predicted environmental aspects of electricity production in the EU countries and also in Norway, which is part of the free Nordic electricity market. IVO's project focused on emissions of sulphur, nitrogen oxides and carbon dioxide, which are essential criteria for environmental permits and a key topic in international debate on restricting emissions.

According to the forecasts, the mean level of specific emissions of SO_2 and No_x in the EU will decline in the future. Finnish energy production has a competitive edge in large-scale cogeneration of electricity and heat, structurally diverse energy production and major investments in air-pollution control. Compared with the other countries studied, Finnish electricity will be cleaner than average in the near future as well.

Environmental impact assessment

Because environmental impact assessment involves a great deal of uncertainty in the case of emissions, several projects under SIHTI 2 have focused on assessing the external environmental effects of energy production and the costs incurred by society. These projects involved various methods and calculation models and focused on the harmful effects of emissions on human health, nature and materials. The most serious national effects are possible damage to forests, crop failures in agriculture and acidification of water. The worst global impact is the greenhouse effect. Effects on biodiversity were not examined. The projects covered nearly all fuels, power plant systems and technology which may be used in Finnish energy production.

Energia-Ekono studied the local environmental impact and external costs of energy production based on coal, natural gas, oil or peat. More detailed assessments of external costs were made in the Helsinki metropolitan area and Tampere, for exam-

ple. A survey of people's willingness to pay for better air quality was made in Tampere.

IVO has assessed the external costs of nuclear, hydro, solar and wind power and use of biofuel, and their commensurability. Participating in a wider EU project, VTT Energy has applied a German model for the assessment of different fuel chains. Fine-particle emissions, their composition and their effects on human health have been studied by the University of Kuopio, the Meteorological Institute and IVO.

The eco-profile of oil products was evaluated in a research project by Neste Oy, where a team of 16 experts focused on the use of natural resources and emissions to the environment, and ranked action to decrease the environmental load from the point of view of sustainable development. Meanwhile, Jaakko Pöyry Consulting Oy has developed eco-efficiency indicators for forest-industry products, assessing, for example, the eco-efficiency of newsprint using new image-based GLCA analyses.

A study by the Thule Institute of the University of Oulu compared the profitability of wood combustion and alternative domestic fuels, in the public sector, in communities and regionally. The examples used in the calculations were a conventional 60/120 MW thermal power plant on the coast and another inland, and a 5 MW district heating station in a rural community. Indirect effects were calculated from input-output analyses.

A study by VTT assessed the local environmental impact of a bio-fuelled 50/50 MW IGCC plant planned for the Enso paper mill in Summa. The Forest Research Institute participated in the project by examining how the collection of forest harvesting residues (wood chips) for the plant would affect the nutrient level and biodiversity of the forest.

Solid waste from the biofuelled IGCC plant will be very different from that from conventional power plants. Most of the waste will be hot filter dust. Because of the high content of carbon and impurities from the dust generated in fluidized bed combustion of biofuel, carbon and other impurities must be recycled in the process or handled at a separate plant. Using clean wood fuel is likely to result in an end product which can be recycled to the forest and also used for soil improvement. Another way of minimizing the environmental effects of a biofuelled IGCC plant is to recycle the ash within the process.

A joint project by VTT Communities and Infrastructure and the National Public Health Institute examined the significance of northern water reservoirs in the production of greenhouse gases. Finnish interest in the effect of reservoirs on climate has basically grown out of the plans for a hydroenergy barrage at Vuotos. According to the calculations, overall emissions from Finnish reservoirs used for hydroenergy are approximately 1 per cent of total annual emissions from fossil fuels and peat used in energy production. VTT Energy has estimated greenhouse-gas emissions from alternative waste-treatment systems, and assessed ways in which these emissions could be reduced.

The great differences in the results of assessing environmental impact and external costs are partly due to differences in the methods used, researchers' assumptions, and the restrictions and goals set for the research subjects. The results are difficult to interpret because of the great variety in the amount of information on different effects, for example. Further projects under the SIHTI 2 programme will therefore include the development of methods for evaluating environmental impacts which can be applied to ensure more reliable assessment and commensuration of the external costs incurred from alternative energy-production methods.

2.2 Flue gas emissions from power plants

Measurement of emissions

Within the SIHTI 2 programme, VTT and Energia-Ekono have made numerous measurements of emissions from different types of power plants, e.g. IVO's peat power plants in Rauhanlahti and Seinäjoki, the Enso-Gutzeit Oy bark-fuelled boiler in Kaukopää, Meri-Pori's coal-fired power plant and Mäntän Energia Oy's power plant. The equipment used for the emission measurements included both commercially available instruments and tailor-made instruments designed under the programme. For example, continuous measurement of NH_3 and Hcl emissions, in particular, has been carried out

using the portable FTIR analyser manufactured by TEMET Instruments. The purpose of these measurements was to test the accuracy and reliability of measuring instruments and to check the effectiveness of flue gas scrubbers. The readings from the Meri-Pori coal-fired plant showed that the efficiency of the desulphurization plant was over 90 per cent, NO_x emissions from the flue gas stack were less than 100 ppm, and the post-catalyst ammonia content less than the detecting range of the FTIR analyser.

The largest amounts of emissions in normal power plant operation are fairly well known, but calculating total annual emissions would also call for data on emissions in abnormal situations, such as plant start-ups or shutdowns, chimney sweeping, disruptions in the flue gas scrubbers, and data on changes in combustion parameters and in fuel quality. Using standard methods to determine the volume of emissions in abnormal situations would require continuous measurements.

The SIHTI 2 programme includes several R&D projects on new methods and equipment for continuous measurement of particles, heavy metals and flue gases in particular. A project by Imatran Voima and VTT is examining in detail the waste streams of substances at a power plant equipped with desulphurization and de-NOx technology (Figure 3) and the behaviour of environmentally harmful components in these waste streams. The aim of the project is to create a standard sampling and analyzing system. Measurements at this plant showed that chromium and nickel end up in the bottom ash in much larger amounts than in the fly ash (filter dust), while other metals behaved in quite the opposite way. The amount of heavy metals in gypsum was usually less than one tenth of that in the waste sludge from the waste water treatment plant. Although about 20 times more gypsum is produced than waste sludges, it contains the same amount of heavy metals.

The programme has also included the development of a new electric low-pressure impactor (ELPI) for continuous measurement of fine particles. Operation of the equipment, which will be commercially available, is based on a unique design, which combines the structure of a basic impactor and electronic detection of particles. The reliability of the results obtained with this new equipment has been verified using reference measurements with a mechanical cone vibrator.

Another project under the SIHTI 2 programme produced new photoacoustic analyzing equipment for detecting sulphur and nitrogen compounds in flue gases at levels as low as 3-6 ppm. The results indicate that the flue gas analyser is technically feasible. The properties of photoacoustic measuring equipment, which will also be commercialized,

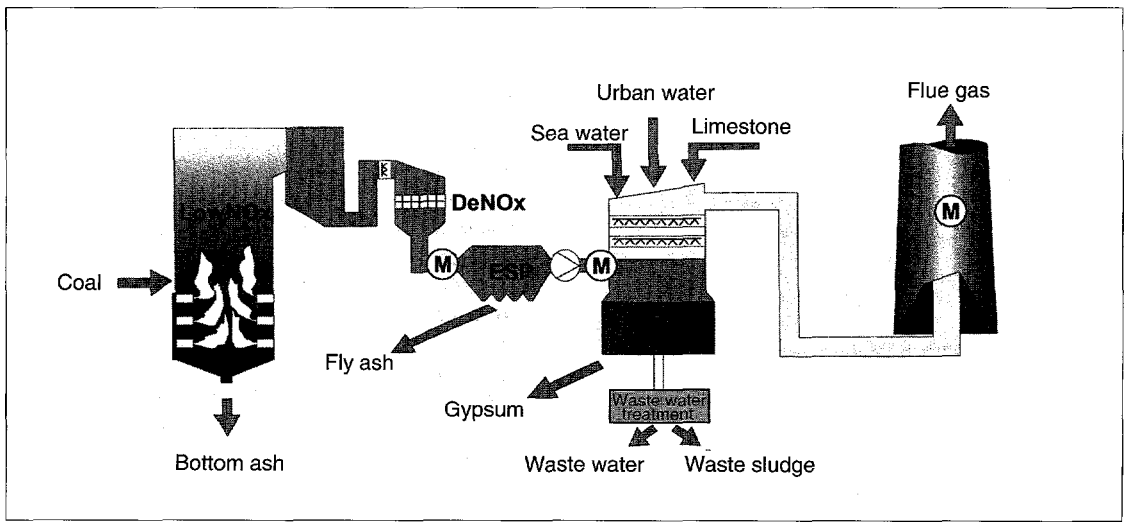

Figure 3. Material flows into and out of a power plant equipped with desulphurization equipment. (M = site of flue gas sampling)

are best represented in an *in situ* probe and in conditions where the temperature and particle load are very high.

In the case of CO, N_2O, NH_3 and other flue-gas components which are difficult to measure, measurement directly from the flue will be possible with a new spectrometric system based on an infra-red range voltage-controlled Fabry-Perot filter. Because of the technical design, the component measured will have excellent selectivity and stability. Operating costs will also be low and there will be no need to pretreat the samples.

Treatment of flue gases

At power plants, flue gases are usually separated from solid substances with an electric precipitator. Today's precipitators have very high resolution, with an emission level normally below 10 mg/m^3. However, a large amount of fine particles slip through the penetration windows of precipitators. In the SIHTI 2 programme, factors affecting the size of the penetration window were measured at modern pulverized-coal-fired plants and the results were verified using a laboratory-size combustion and precipitator unit.

The ideal sizing of electrostatic precipitators for the tight emission restrictions of the future calls for better knowledge of the effect of ash properties and the precipitator's operating parameters on its resolution. A joint research project between VTT and ABB examined the correlation between the resolution and the size of fly-ash particles down to 0.015 microns. The size distributions related to the amount and mass of ash particles, and the appearance and composition of the particles were determined using new aerosol technology measurement methods and modern analysis techniques. The carbons and fly-ash particles collected by the different electrode plates of the precipitator were analysed using the CCSEM method, to determine the transformation of carbon minerals and their selective penetration. The penetration was found to correlate strongly with both the size and the composition of the particles.

Tampere University of Technology has developed a simulation model for examining the mass and heat transfer of a filler scrubber and optimizing the scrubber's operation. The factors affecting mass transfer which were examined were the composition and temperature of the flue gas and the liquid/gas ratio of the scrubber and the parameters of the filler particles. The flue gas components were sulphur dioxide, hydrogen sulphide, hydrogen fluoride, carbon dioxide and methyl mercaptan. The study also included calculations on the simultaneous scrubbing of several components. Comparisons of different calculations showed the effects of the reaction rate coefficient, thermodynamic equilibrium constants, the diffusion coefficient and the stoichiometric coefficient of the reaction on liquid mass transfer.

Within the SIHTI 2 programme, Kvaerner Pulping Oy (Tampella Power Oy), together with several industrial plants, has developed the theory and technology for a new, electrically enhanced flue gas scrubber. Results from plant-scale tests show that the new scrubber reduces dust emissions up to 70-90 per cent more effectively than conventional scrubbers. The new scrubber has been successfully tested at a diesel power plant in Germany supplied by Wärtsilä Diesel, for example.

The main aim of a project by Carbona Oy (Enviropower Oy) has been to demonstrate on a pilot scale regenerative desulphurization of gasification gas and, at the same time, a method for recovery of elementary sulphur at a high temperature and pressure. The method removes sulphur very effectively from flue gases generated in the IGCC process, eliminates the need for a non-reusable desulphurization sorbent or further processing, and turns the sulphur end product into a very compact, commercially viable form. The researchers are developing a dynamic model for regenerative desulphurization which could be used in future for simulating the process and for planning adjustments.

The Foster Wheeler Energy Ltd (A. Ahlstrom Corporation) project has successfully tested the use of a catalyst in reducing nitrous oxides generated in coal combustion. The project also showed that alkali consumption in desulphurization could be reduced by recycling the waste from the process. These solutions, and certain new combustion methods, will together contribute to optimizing the operation of fluidized bed boilers to meet different standards related to emissions. Foster Wheeler has also examined ways to reduce sulphur dioxide emissions from pyrometallurgic processes, ana-

lysed the economic aspects of alternative methods in a few case studies, and studied the reduction of dioxin emissions from fluidized bed combustion of the waste.

Within the SIHTI 2 programme, VTT, in cooperation with Sisu Diesel, has studied ways to reduce exhaust fumes from lean-burn engines running on natural gas, and has developed a closed-loop control system to optimize engine operation. The experiments were made on a 6-cylinder Valmet 634 G engine, which produces approx. 90 kW of power in energy production and has a maximum power of 160-170 kW. The NO_x content was clearly the parameter most readily controlled, but the conventional measuring instrument used in the tests proved too slow; also, the lambda sensor measuring the oxygen content was found inadequate for a leanblend. The closed-loop system for mixture control will be further developed, allowing any voltage signal to be used as a control signal. So far, the system has been tested on an engine dynamometer, but the test run of the final version will take place at a power plant.

The goal of a Wärtsilä Diesel project was to find an effective and economical desulphurization method for diesel power plants using residual oil. Experiments are being made at commercial plants supplied by Wärtsilä Diesel in India, Germany and Great Britain.

2.3 Reducing the environmental load from the forest industry

In 1994, Duoplan Oy completed their demonstration programme on technology for environmental protection in the forest industry, including a schedule and budget. This programme aims to

- promote the development and implementation of low-emission technology in the pulp and paper industry;
- minimize the risks for users of the technology;
- improve the competitiveness of the Finnish forest and mechanical engineering industries;
- evaluate the effects of application of the technologies on emissions from, and the energy consumption of, the Finnish pulp and paper industry.

Surveys and interviews conducted at industrial plants and research institutes resulted in twenty demonstration project proposals on varying scales: four plant-scale and five smaller-scale project proposals on pulp bleaching; three full-scale and five smaller-scale project proposals for mechanical pulp and paper making; and three proposals concerning recycled fibre. The total cost of all the projects, if implemented, was estimated at FIM 300 million.

Closed water cycles

Duoplan's project was followed by the construction of a closed-cycle water system evaporation plant at Enso's Kotka paper mill in 1995. The results of implementing the new, environmentally friendly technology have been very promising.

The production of mechanical and chemical pulp generates an abundance of high-temperature waste heat. Most of the energy used in production is spent on heating the water, and this is then - almost completely wasted in the hot water fractions. Application of a new multi-phase vacuum evaporation technology, allows the waste heat to be recovered from process waters, eliminating the use of live steam.

To reduce capital costs, Ahlstrom Machinery has developed a new multistage evaporator called ZEDIVAP™. The new heat-exchanger surface material and construction can eliminate those salts and small-molecule substances which are difficult to separate using other techniques. The water processed with the multistage evaporator is even cleaner than chemically treated raw water. The new diaphragm-type evaporation technique reduces water consumption by over 50 per cent.

Enrichment of dissolved substances which impair the production and quality of paper can be prevented by adding a small amount of clean water. Evaporation removes the harmful substances, and putrefaction of the concentrated waste-water sludge in an anaerobic reactor produces gas which can be burnt in the power plant boiler.

In parallel with the above demonstration project, the SIHTI 2 programme supports the development of evaporation technology, and is trying to find new

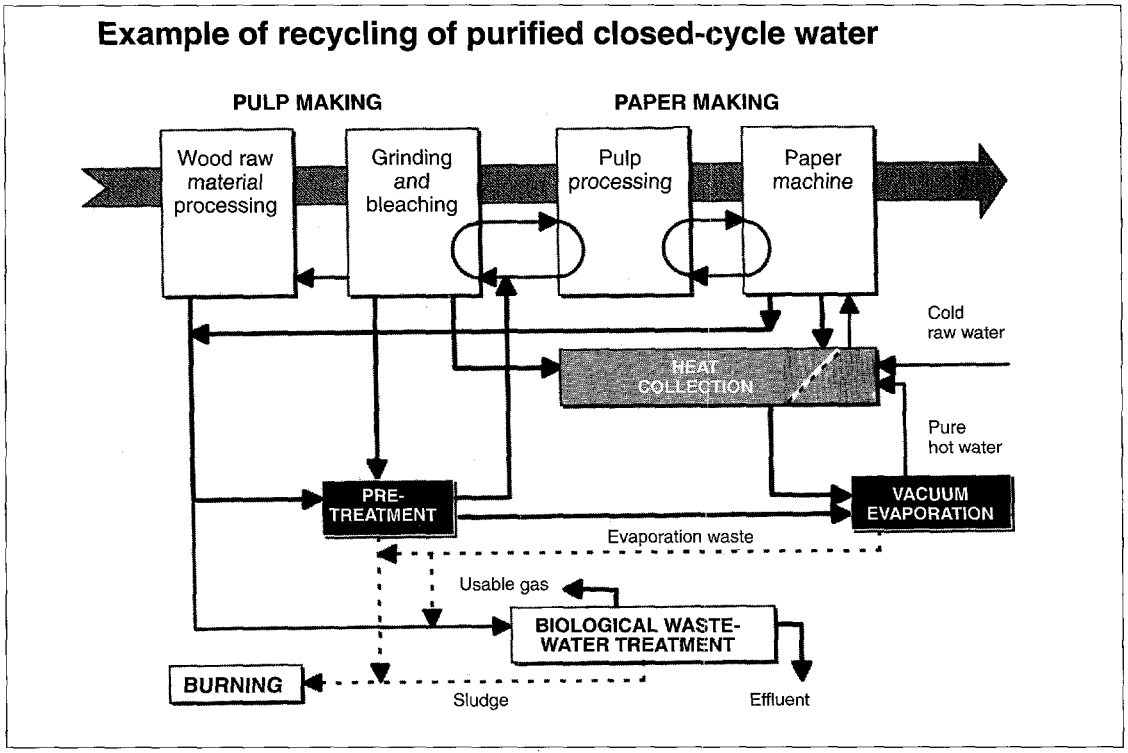

Figure 4. Treatment of recycled process water at a thermomechanical pulp mill using waste heat and vacuum evaporation.

applications for it in both the forest industry and other process industries. A study by Åbo Akademi measured substance contents at different stages of evaporation and examined various alternative connections in closed water cycles using mass and energy-balance calculations. VTT Energy analysed e compositions of condensates from the evaporation of waste-water fractions and evaluated recycling options for concentrates on the basis of the chemical indicators. The results of this study have already been used in planning projects concerning new evaporation plants and closed water cycle systems.

De-NOx at soda recovery plants

Another important demonstration project concerning the forest industry is the experiment on de-NOx at a soda recovery plant at Enocell Oy's pulp mill in Uimaharju. This method, developed by Kvaerner Pulping (Tampella Power) and used for the flue gas scrubber of a soda recovery plant, can reduce the average emission content of a soda recovery plant to approximately 20 g NO_2/MJ, which is about a quarter of the normal level. In the first stage of the process, nitric oxide is oxidized with ozone or chlorine dioxide into nitrogen dioxide, which is then reduced to nitrogen with carbon dioxide from the treatment of malodorous gases, or with sulphite cooking liquor. The method can be used for both new scrubbers and old, and is made even more effective by adding more purification stages.

Recycling of solid waste

A joint project between VTT and several companies examined the use of ash and other waste fractions from the forest industry for fertilization. The new integrated process scheme includes studies on separating water from green liquor dregs and burning the dregs in the bark boiler, fractioning and extraction of ash, and filtration and agglomeration of ash and biological sludge. More efficient recovery of the energy in the waste, savings in dumping costs and the reusability of ash fertilizers make the new process concept an economically significant alternative to the present practice of dumping most of the waste at landfill sites.

2.4 Recycling wastes from power plants and communities

Desulphurization products and ash

A joint project between several energy companies has charted experiences of the operation of major desulphurization plants and examined factors affecting desulphurization costs in different conditions and for different types of coal. One of the things indicated by the results was that the presence of chlorine, either in the coal or in the process water, can greatly affect the operation and costs of a desulphurization plant. According to experiences, the chlorine content in desulphurization waste correlates directly with the moisture and treatability of the waste. Experiments carried out under the project showed that the optimum range of the chlorine content of the end product is 1-3 per cent; a chlorine content of over 5 per cent clearly hampered the process. If the chlorine content in coal is very low, the desulphurization process can be made more effective by adding chlorine.

Research into reuse of by-products from power plants has earlier focused mainly on technical functionality rather than on environmental aspects. A joint project by Lohja Rudus Oy and VTT studied the development of desulphurization products into materials suitable for construction engineering, which could be an environmentally sound replacement for stone aggregates in certain earthworks.

For the test of environmentally acceptable properties, nearly 100 test pieces were manufactured from fly ash and desulphurization products mixed as indicated by earlier experience, using various types of binding agents. The solubility of sulphate, chloride, chromium and molybdenum in the test pieces was examined using diffusion solubility tests originally developed for stabilized materials.

The solubility results showed that masses prepared from a mixture of fly ash and a semi-dry desuphurization product can be used for embankments or road beds, for example. To apply the results in practice, a test field was built in Suomenoja, Espoo, and a test road in Vuosaari, Helsinki, both made from mixtures selected on the basis of the solubility tests. The technical properties and environmental aspects of the test sites have since been examined using tests of bearing strength and solubility, for example, with encouraging results.

In addition, new applications have also been found for residual products from power plants, such as use as binding agents containing fly ash (filter dust), desulphurization products and cement for strengthening the surface of old gravel roads and for mass stabilization at sites with a lot of clay. The surface of gravel roads can be strengthened by mixing fly-ash based, self-hardening binding agent in a 20-cm thick layer. Although containing much less cement, the mixture has the same strength as soil cement. The mass stabilization technique for soft clay sites has been successfully demonstrated in tests at the Ring Road III (road) construction site.

Community waste

Recycling the energy content of municipal waste is another target in the SIHTI 2 programme. Half of the municipal waste ending up at landfill sites consists of various combustible materials, such as paper, cardboard, plastic and mixed products. Although some of these can be recycled by making the present recovery systems more efficient, most of the waste cannot be reused. Separation of combustible wastes from non-combustible can considerably reduce the amount of material now taken to landfills.

A study by Soil & Water Ltd examined possible methods, costs and environmental effects of producing very clean combustible material by sorting materials by origin, turning them into fuel, and burning them at an existing boiler plant. The tests on collecting and sorting the wastes were carried out in Jyväskylä. To eliminate harmful components, such as PVC plastic(s), metals, glass and other undesired wastes, participating households were given detailed instructions on how to sort their wastes. The collection showed that, typically, 7 per cent of the waste sorted at homes was biological. This did not as such impede burning of the wastes, but would often generate unpleasant odours and begin biological decay processes during storage.

The material collected was crushed with a hammer crusher and a cutting rotor machine. Plastic films and textiles were found difficult to crush, whereas metal objects were efficiently separated with a

magnetic separator. The burning was done using the fluidized bed combustion boiler at Rauhanlahti peat power plant. For the combustion tests, 5-7 per cent waste was added to the peat, which roughly corresponds to the amount which could be expected from homes, workplaces and construction sites in and around Jyväskylä. The actual burning of the material collected was an easy stage in the process, whereas handling and feeding in the material turned out to be more complicated. The largest changes in emissions occurred in the case of HCl, which was 33 milligrammes per cubic metre, while burning peat with no waste content gave a reading of 12 milligrammes per cubic metre. No other significant rises in emissions were detected.

2.5 Effluents from peat production and the afteruse of released production sites

The *Aqua Peat II* project led by Vapo Oy has developed new methods of water treatment for the control of water pollution at peat production sites, studied the effects of peat production on the local environment, and developed methods for detecting and measuring these effects.

Some of the water treatment methods are effective, though applicable to special sites only, while others can be easily implemented at various production sites. The weather, having a decisive effect on the environmental load, creates problems with water treatment. Other difficult factors are winter and the effect of the thaw season. Use of some methods is also difficult at sites where there is no permanent staff to monitor their efficiency.

Chemical treatment is an effective way of reducing humus and colour in the water from peat production sites, in some cases by nearly 90 per cent. This method requires a separate treatment plant and can be used at exceptionally demanding sites where watercourses below the production area must be conserved.

In addition to the treatment results, the study focused on the chemicals used, the optimal doses of these chemicals, development of equipment, storage of data, and the automatic control and monitoring system. Because chemical treatment involves high investment costs, the method can be commonly used only at production sites of over 200 hectares.

Soil absorption is a treatment method which makes use of the soil's natural retention of nutrients. Water from the peat production site is led using a pump and perforated pipes or sprinklers to a forest area. The state of the forest, the growth of plants and trees, the level and quality of the groundwater, the undergrowth, and the results of the treatment have all been monitored, and the entire method, including the automatic controls and the remote alarm system, has been developed further. This approach removes soluble nutrients and solid matter effectively - by up to 80-90 per cent - from drainage waters from the peat production area, and can be used in seasons when the soil is not frozen.

During the follow-up period, a joint Vapo Oy and Forest Research Institute project found that the right kind of water distribution technique will keep the plants in the absorption field effective. Results showed that according to the growth of plants and trees the birches and also conifers grew faster. Stronger undergrowth will also remove soluble nutrients. However, this method can only be used in areas with a specific type of soil.

The evaporation pond method largely resembles the absorption method above, but here the pond is surrounded by embankments on a site with only a thin layer of peat, and water is removed both by direct evaporation from the water surface and by absorption into the ground. The efficiency of this method depends on the pond area and the amount of drainage water pumped into it. At first the purification efficiency is good. However, there are indications of lower efficiency after 4-5 years. The pond attracts waterfowl and has now become the nesting and feeding place for many species.

Flow regulation has been studied by Vapo Oy in cooperation with the Lund University, Department of water Resources Engineering, Sweden. The method, which aims at reducing environmental load, is based on cutting flow peaks by damming up water in the drainage network of the peat production area. Solid-matter particles then settle in the production area itself, thus reducing the solid-matter load by up to 80-90 per cent. In addition to developing the method and carrying out field in-

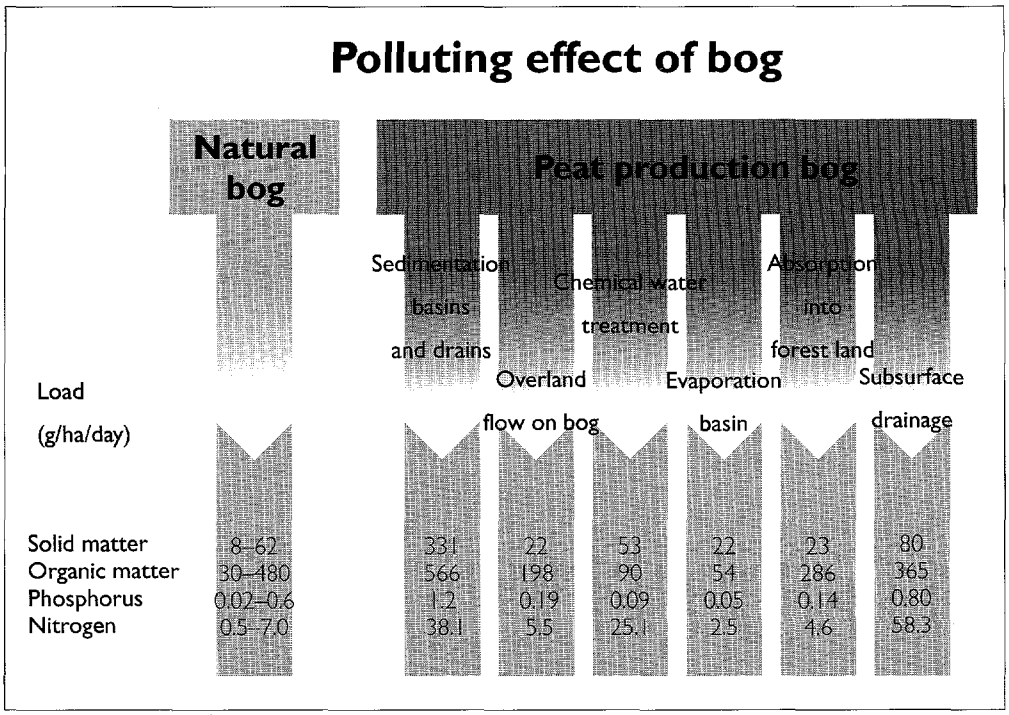

Figure 5. Water pollution loads of a peat-production bog and a bog in a natural state.

vestigations, new bed pipe barriers and a new run-over field have been developed to protect the recipients during the flooding season. A doctoral thesis will be published in connection with the project.

Flow measurement has been developed for more effective evaluation of run-off water from peat production sites and the resulting load. Using conventional V-shaped overflow weirs has not always brought reliable results, because the gradients of the production areas are often too low to be measured. The Helsinki University of Technology and Vapo Oy project has focused on producing continuous automatic measurement data and creating a new type of measuring equipment for difficult conditions. The research has also produced successful Venturi pipes which have little effect on damming, and has improved the potential for and reliability of flow measurement.

A joint project of Vapo Oy and the Institute for Environmental Research of the University of Jyväskylä has examined the *long-term effects of peat production*. The area, which had been drained and closely observed in the mid-1980s, was now monitored to detect long-term changes in the watercourses below it, and to devise measurement methods. One of these can be used to time sedimentation, and hence the settling time of solid matter.

A three-year project to find new ways of using cut-away peat production areas was carried out jointly by Vapo Oy, the Forest Research Institute, the Agricultural Research Centre, the Hunters' Central Organization, and the universities of Oulu and Jyväskylä. The most common new use is afforestation. Bog floors can prove as good substrates as pine forests. Whether the area is suitable for silviculture is dictated by the thickness of the remaining peat layer and the soil beneath the peat. Because the roots of the trees must reach the mineral soil at an early stage, the peat layer should ideally be 20 centimetres thick. A thicker layer requires startup fertilization or tillage. A bog floor with rough and water-permeable soil may be too meagre for trees, in which case some other use should be found for the area.

Bog floors are ideal for pasture, grain or special cultivation. Because they do not contain any residues of pollutants, pesticides or fertilizers, the

products grown can be considered clean. In Hirvineva, Liminka, 30 hectares of *Phalaris aducinarea* was sowed on the bog floor for use as bioenergy with peat and wood or for pulp or paper making. Experiments with various oil plants and medicinal and aromatic plants have also yielded good results, and cultivation of many well-known and important aromatic plants was particularly successful.

After peat production the area can also be converted into a lake, though this requires careful planning. In Rastunsuo, Rautalampi, the cut-away peat production site was turned into a 15-hectare lake. The related problems, techniques and water quality were investigated jointly with the University of Technology. A bog floor can also be repaludified. In Aitoneva, Kihniö, a part of the bog floor was turned into shallow pools and observed in order to study the growth rate and opportunities for plants. The results were compared with those obtained in areas which had been released naturally from peat production in the 1950s.

The SIHTI 2 programme has also yielded instructions for the prevention of water pollution in peat production. The instructions contain data on the planning, implementation, use and effects of different water treatments, sedimentation basins, overland flow fields, evaporation and absorption fields, chemical water treatment and flow regulation. The results also contain data related to pumping stations and open and subsurface drains. Special attention is drawn to the importance of soil analyses and careful planning to prevent sudden soil-related problems at the implementation stage.

3 Effects of the results and findings

3.1 Relevance to industry

Finnish industry has received considerable international recognition for both its energy production and its concern for the environment. This is due partly to the natural lack of fossil fuels and our wish to protect the unique, unspoiled Finnish countryside and partly to the often pioneering cooperation of process users and equipment manufacturers in the forest industry in particular, in developing low-emission production technologies and equipment. To maintain this leading position, however, we must be able to react swiftly and effectively to signals from our environment and continuously invest in research and development with an open-minded approach to tighter emission standards and to the potential offered by environmentally sound (cleaner) technology.

The SIHTI 2 programme attempts to meet these challenges by launching both multidisciplinary research projects on interaction between industry and the environment, and innovative projects aimed at developing and applying new technology. Development of energy conservation, technology and cleaner products in industry has a good starting-point in today's databases, which contain valuable data on nearly all Finnish boilers, emissions from power plants in different operating situations, the functionality and efficiency of flue-gas scrubber techniques, the reliability of measuring equipment and analysis methods, and the environmental effects of emissions. A variety of large databases also serve the authorities and companies when far-reaching strategic decisions concerning the environment are about to be made.

The creation of the valuable database on emissions is partly the result of the development of new equipment for continuous measurement of flue gas volumes and analysis of particle content. The data on emissions can be utilized by the authorities, boiler users, and manufacturers of boilers and related equipment. Measurements of operation, in particular, produce the kind of data that manufacturers can use in planning improvements, designing new generations of equipment and defining guaranteed ratings. All this will give Finnish industry an important competitive edge.

A good demonstration of industry's commitment to the SIHTI 2 programme is the fact that it involves nearly every major Finnish company on both the domestic and the export market, not only as grant-receivers but also as providers of funding.

3.2 Level of technology

Projects under SIHTI 2 which deal with particulate emissions and the development of related separa-

tion mechanisms are excellent examples of projects which have resulted in the commercial release of innovative new treatment equipment. For example, ABB has devised an effective new electrostatic precipitator, and Kvaerner Pulping has designed a flue gas scrubber for diesel power plants.

For researchers at universities and scientific institutes, measurement techniques offer interesting opportunities to design high-tech instruments and put them onto the market. For Finland, success in this type of activity, which is usually basic research by nature, can create opportunities for rapidly growing businesses and new jobs. Nevertheless, competition in the international market is extremely tough, and this calls for either a clear marketing plan from the developer of a new technology, or an outside user from the very first stage.

One of the four SIHTI 2 research projects on developing new measuring technology has already yielded a marketable product; another is currently at the interesting stage of being released by a small measuring service company jointly with Imatran Voima Oy (IVO). If these projects prove commercially successful, they may well lead to various spinoff projects on new applications.

An important aspect of the SIHTI 2 programme is support for research and development projects within major companies, such as Wärtsilä Diesel's project on the heavy fuel oil and residual oil use in diesel engines, and the development of desulphurization equipment - two very important fields in both today's market and tomorrow's. To secure the leading position of Finnish manufacturers, we must guarantee a serious input in R&D.

Other examples of a potentially growing market area are new separation techniques for closed water cycle systems in the process industry. The SIHTI 2 programme has responded by supporting Ahlstrom Machinery, for example, in its work on the new ZEDIVAP multiphase evaporation equipment.

One field of study which is very important from the Finnish point of view and is also supported by the SIHTI 2 programme is the design of new low-emission power plant concepts using biomass or peat. Although other energy research programmes focus on improving boiler technology, SIHTI 2 has focused on environmental issues which are critical for implementation of the new technology.

The SIHTI 2 programme also includes a number of confidential product development projects which have been launched by individual companies primarily to improve their own competitiveness. Many of these are connected with wet or catalytic flue gas scrubbing. Although all the projects benefit their industrial partners, they might be even more useful if research groups worked in closer cooperation.

3.3 Environmentally sound activity

National and international measures aimed at protecting the environment, saving energy and halting the greenhouse effect, for example, provide an excellent opportunity for consolidating the standing of Finnish technological know-how and improving the competitiveness of the Finnish export industry. In inventing cleaner processes and products, we must, however, remember that their competitiveness depends not only on buyer appreciation but also on the opinions of end users of the products - paper, for example. Consumers and other interest groups must therefore be convinced that operations and products are environmentally sound in a credible, factual manner. To support this aim, SIHTI 2 has assessed the environmental effects and life-cycle costs of various products, processes and systems by designing appropriate tools and methods, and finding key indicators and standard forms for environmental reports.

This research has resulted in new data and methods which can be utilized in both strategic decision-making and the development of new processes and product ranges. Because of the great variety and multidisciplinary nature of its projects, SIHTI 2 has been a pioneering research programme in Finland.

A good example is the new life-cycle study on the competitiveness of forest industry products carried out by Jaakko Pöyry Consulting. The study involved close cooperation with the industry and has yielded both extensive information on the present situation and useful forecasts on development trends in the industry, processes and products.

Another example is a study by Carbona Ltd (Enviropower Ltd) and VTT on the competitiveness of

a biomass-fuelled IGCC plant at a paper mill and its impacts on the local environment. In addition to new power plant technology and the environmental issues directly connected to it, the study focused on the environmental impacts and costs of the entire system, from acquisition of the biofuel to final disposal of the wastes.

The SIHTI 2 programme includes several other examples of similar extensive studies on environmental impact, dealing with an entire fuel chain or power plant system. For the purposes of interpretation, it is vital for the environment to be evaluated using reliable, unambiguous results.

Recycling projects related to secondary emissions from power plants and the forest industry have also been prominent in the programme. Finnish combustion technology and flue gas scrubbers are highly advanced, even by international standards, but utilization of solid wastes and reduction of environmental pollution from the wastes has been of much less interest.

Closed water cycle systems in the process industry constitute a new and challenging area of research, which aims not only at reducing water consumption and environmental pollution from waste water, but also at recovering valuable raw materials or chemicals contained in the effluents. The problems concern low dry-matter content, the corrosive properties of waste waters and their behaviour in the concentration process (in evaporation, for example). Answers to these questions are being sought in the SIHTI 2 programme in cooperation with equipment manufacturers and potential users.

In order to utilize the energy content of community wastes, political decision-makers need support from technical and economic background information that is extensive and reliable. However, there can be no standard, universally applicable integrated solutions to the problem of safe and economical treatment and/or final disposal of household and industrial wastes; the solutions must be tailor-made for each situation. This is why the field is included in the SIHTI 2 programme, with experiments on collecting and sorting household wastes, burning paper and packaging waste, anaerobic digestion of biodegradable wastes, and research on related environmental issues. International trends in this field of study have been followed, for example, through active participation in the work started by the IEA.

Because peat and biofuels are especially significant for Finland's self-sufficiency in energy, we must find solutions to the environmental problems involved in the use of peat, and especially reduce the watercourse pollution caused by peat production areas and later use of peatlands in a way which is consistent with the principles of sustainable development. These problems have been studied in several projects under SIHTI 2, resulting in practical instructions and methods which have helped improve the image of peat-based energy production.

Increasing the use of wood as a fuel is another aim of SIHTI 2. This has been studied by examining the district heating plant of a rural community, for example, and a major peat power plant where sulphur emissions can be cut by using wood as a co-fuel.

3.4 Networking

The SIHTI 2 programme actively promotes cooperation between research institutes, universities and businesses by organizing follow-up meetings and expert seminars. Cooperation is also one of the main criteria in assessing individual projects and granting funds. Funding decisions include an obligation to report on the results of projects at annual seminars. During 1993-1995, the number of participants in these annual seminars increased from 115 to 180, indicating a growing interest in the research done under the SIHTI 2 programme. By networking different research teams, groupings of first-class experts can be formed; some of these are focusing on elimination of particle emissions from flue gases, for example, or specializing in evaluating the external costs of environmental impact.

3.5 International cooperation

The programme promotes international cooperation in the form of expert meetings, seminars, workgroups and special assignments. As part of the COMETT training programme supported by the EU, and as a joint project with the Finnish Asso-

ciation of Graduate Engineers (TEK), a seminar on energy issues in life-cycle assessment was held in 1993, with a large number of foreign experts as lecturers and workshop leaders. The 1993 annual seminar included a series of lectures on scrubbing techniques, and a seminar in 1994 dealt with expectations, experiences and problems related to the environmental impact assessment, with the focus on bioenergy. In 1995, a small-scale series of seminars on assessing environmental impact was arranged with the SILMU programme of the Academy of Finland; also, the 10th World Clean Air Congress and the European Aerosol Conference were held in Finland and supported by SIHTI 2.

In the autumn of 1994, the SIHTI 2 programme participated in a technology export campaign to China, which was supported by the Finnish Foreign Trade Association, charting potential targets for export of energy and environmental technology in the province of Guangdong and greater Guangzhou(Canton). In 1995, SIHTI was actively involved, along with several companies, in the 'Arctic Shock' technology export campaign aimed at the international media.

Instead of seeking direct cooperation with foreign research programmes, SIHTI 2 prefers to cooperate on a project level where specifically Finnish aspects of research and development are taken into account. However, SIHTI 2 has also participated in research launched by the International Energy Association (IEA) concerning greenhouse gas emissions from biomass and reuse of the energy in community wastes. The coordinator of the SIHTI 2 programme has been involved in preparing the IPCC's second report on greenhouse gases and in the work of the Environmental Profile Product Working Group established under the ECE.

3.6 Postgraduate education

The SIHTI 2 programme actively encourages and supports researchers' postgraduate studies. In 1993-1995, three doctoral theses were written with funding from the programme.

4 Major results in interim assessment

The multidimensional SIHTI 2 programme is divided into six research areas:

- strategies for reducing environmental emissions
- environmentally sound technology in the forest industry
- flue gas emissions and scrubber technology
- measuring technology for environmental emissions
- utilization of secondary waste streams from industrial processes
- environmental issues related to peat production

These areas have involved various studies, creation of databases, development of theoretical models of processes and equipment, experiments in measuring emissions, technical and financial calculations and examinations of systems, and development of processes and methods, ranging from laboratory scale demonstrations to full-scale on-site demonstrations.

Development of power station and purification technology is an essential part of the technology programme, and this is expected to yield significant results which will serve both domestic industry and producers of technology and equipment for export. Tailor-made desulphurization techniques to meet the challenges of modern diesel technology, for example, could help boost exports.

Using common databases will help both the authorities and companies find cost-efficient solutions. The projects on the development of life-cycle analyses will allow specifically Finnish aspects to be taken into account in the EU, thus influencing, at least indirectly, the formulation of legislation and practices reflected in international trade.

So far, the programme has focused on the forest industry and paid less attention to other industries, but we need information on how the opportunities created by know-how in this field can be applied in other important Finnish industries with development potential. Another possibility is to modify the technology developed for major companies - flue gas scrubber techniques and evaporation technology, for example - for use by small and medium-sized companies.

Because projects on measurement technology related to emissions have been rather few, it may be wise to consider combining all the measurement projects in the energy programmes into one research programme.

Because of a shortage of international data, it is important to examine the environmental effects of the entire domestic energy production and consumption chain. To make peat and waste more acceptable as energy forms, we need further research on their use for energy generation. In addition, we should also carry out research on reducing emissions from small-scale burning of wood.

If a corporate project is funded out of a single energy research programme, it may not be sufficiently large-scale to meet the company's needs. Funding should therefore be allocated to projects creating know-how which will benefit several companies. The programme should continue to focus on only a small number of research fields in the future. Joint research projects between universities, research institutes and companies must also be given priority. According to external evaluators, projects on basic research and risk evaluation should be well represented in the programme.

5 Plans for further research

Considering that Finnish per capita energy consumption is among the highest in the world, it is self-evident that energy technology plays a very important role in the economy. This is due to both the climate and our energy-intensive industry, based on renewable natural resources. In addition, a surprisingly large proportion of exports in the metal industry is related to the energy business. Major companies involved here include Wärtsilä Diesel, Foster Wheeler, Kvaerner, Outokumpu, ABB and Ahlstrom. Investments related to environmental protection are the fastest-growing grouping in energy production, and Finnish industry needs government support for both product development and applied technical research and development if it is to keep up with the international competition.

On the other hand, environmental issues concerning energy production are becoming more and more urgent, and the time for transboundary supervision of emissions may not be far away. We are already bound by international agreements and recommendations on emission reductions, and there is also scientific proof that global warming is caused by human activity. In the light of these facts, making the right choices can be extremely difficult, requiring the kind of long-range multidimensional research carried out under the SIHTI 2 programme.

In the near future, the most important research fields related to energy production will be more effective elimination of sulphur and nitrogen oxides, and particle emissions, and utilization of solid wastes. This will entail not only the development of new equipment and techniques but modifications at existing plants to avoid heavy new investments whenever possible.

Although the problems and issues related to energy consumption may not be as clearly defined, developing technologies that will save raw materials and the environment as well as energy can be deemed extremely important for the forest industry in particular. The work done on closed chemical and water cycle systems in pulp processing is a good example of innovative research that must continue.

A third important area is the development of emission measurement in a way ensuring that the results can be reliably traced and meet national and international requirements. It must also be possible to use the data on emissions as a basis for new regulations on reducing emissions and for the development of treatment equipment.

Development of tools and methods for assessing environmental impacts and valuation of the environment will remain an essential issue. In particular, methods for life-cycle analyses and their application to various energy production systems or energy-intensive products should be developed further. Because of the forthcoming international standards for environmental (eco-)labelling, this field of research is of great current interest. Although the field clearly extends far beyond energy research, it can very well be included in the SIHTI 2 programme.

Although research on secondary emissions from power stations has many links with the Tekes technology programme on environmental geology,

which serves the construction-material industry, the evaluators do not recommend that these projects be combined, as the construction material industry and the energy business do not share the same interests.

Research on recycling other solid industrial and community wastes and recovering their energy content should also be supported, concentrating on waste materials and system solutions which are important from a Finnish point of view.

Solutions to environmental problems caused by peat production will affect the future of the peat industry and have a significant effect on Finnish self-sufficiency in energy, the economy and employment figures. Reducing watercourse pollution from peat production and finding ways for sustainable development of production areas is a task of great importance.

6 Organization and management of the programme

The steering group of the SIHTI 2 research programme represents a wide range of both decision-makers dealing with energy and environmental policy and industrial producers and users of energy. The steering group is chaired by Dr Heikki Niininen of Imatran Voima Oy. The programme is supervised by Ms Raija Pikku-Pyhältö of Tekes, and was until 1995 coordinated by Mr Kari Saviharju of VTT Energy.

Members of the SIHTI 2 steering group 1993-1995

- Heikki Niininen, Imatran Voima Oy (Chairman)
- Bertil Roslin, Alko Inc.
- Andres Ahnger, Wärtsilä Diesel Oy
- Marja Erola, Ministry of Trade and Industry
- Alec Estlander, Jaakko Pöyry Group
- Antero Hietaluoma, ABB Environmental Systems Oy
- Juha Pohjala, ABB Environmental Systems Oy
- Matti Hiltunen, A. Ahlstrom Corporation, now Foster Wheeler Energy Ltd
- Erkki Kiiskilä, A. Ahlstrom Corporation, now Ahlstrom Machinery Ltd
- Terho Jaatinen, Eco Technology JVV Oy, (Outokumpu Ecoenergy)
- Kauko Janka, Tampella Power Oy (until 1994)
- Ari Tamminen, Tampella Power Oy, now Kvaerner Pulping Oy
- Pertti Laine, Finnish Forest Industries Federation
- Pirkko Molkentin-Matilainen, Finnish Forest Industries Federation
- Raija Pikku-Pyhältö, TEKES
- Simo Salanne, Kemira Oy
- Sirpa Salo-Asikainen, Ministry of the Environment
- Pirkko Selin, Vapo Oy
- Heikki Uusi-Honko, TEKES
- Tapio Öhman, Helsingin Energia
- Kari Saviharju, VTT Energy (Secretary)

Because of the extensiveness of the programme, SIHTI 2 consulted the following experts for assessment and supervision of the various projects:

- Professor Allan Johansson, VTT Chemical Technology (strategic and clean technology issues)
- Professor Johan Gullichsen, Helsinki University of Technology (forest industry)
- Docent Juhani Ruuskanen, University of Kuopio (measurement technology)

The supervising groups in charge of organizing cooperation between researchers, publishing information on the research and monitoring the progress of projects were chaired by the following experts:

1. Strategic and clean technology issues: Allan Johansson
2. Technology for power plants and purification equipment: Kari Saviharju
3. Measurement technology: Juhani Ruuskanen
4. Forest industry (water treatment, recycling of ashes), secondary emissions from power plants, reuse of energy in wastes, and peat production: Pertti Vakkilainen.

Chapter 11
SULA 2 – Energy in steel and metal production

Håkan Hakulin
Association of Finnish Steel and Metal Producers

1 Background and objectives

SULA 2 is the energy research programme of the steel and metal producing industry. The participants are the steel and metal producing companies Outokumpu, Rautaruukki, Imatra Steel and Fundia Wire. The combined gross value of their production in 1995 was FIM 31.5 billion with exports accounting for FIM 13 billion. The sector employed 15,650 people in Finland in 1995. The fact that the steel and metal producing industry is not located in Finland's major cities increases its significance as a regional economic factor and source of employment.

In 1995, the steel and metal producing industry used a total of 3,995 GWh of electricity, or 11% of the total electricity used by Finnish industry, while the energy content of fuels and reductants was 60,000 TJ, 17% of the Finnish industry total. The share of energy costs in the production costs of various metals varies from 25% to 50%.

The general objectives of the SULA 2 programme are:

- Lowest possible specific energy consumption;
- Harmful emissions in air and water must not exceed internationally agreed standards;
- Best possible utilization of raw materials;
- Best possible utilization of by-products and waste heat;
- Reducing the amount of process waste and utilizing this waste, economic aspects permitting;
- Developing stronger materials, improving measurement accuracy and developing dimensioning so that the volume of products scrapped in further refinement would be minimised.

The objectives proposed by the energy research working group of the Ministry of Trade and Industry are the goals for the programme:

- The world's lowest specific consumption of energy in existing processes;
- Leadership in reducing the energy consumption of certain unit operations;
- New energy-saving processes.

The research will help achieve the following objectives:

- Improve the competitiveness of steel and metal producing companies and increase technology exports;
- Maintain and improve the level of expertise in research in the field at universities and research institutes;
- Help the steel and metal producing industry contribute to observation by Finland of international agreements on CO_2, sulphur and NO_x emissions.

Only research projects that are specifically related to steel and metal producing technology are approved for the programme. Projects involving steel and metal producing energy production are referred to the LIEKKI 2 programme (combustion and gasification), while projects involving emission reductions and waste treatment are referred to the SIHTI 2 programme (energy and environmental technology). Projects involving the product properties of metals have mainly been referred to other Tekes programmes even if their objective is to reduce energy consumption.

The priorities of the SULA 2 programme are in process development. Worthwhile areas of concentration in energy research by Finland include the following:

- Iron and steel production
- Zinc production
- The production of ferrochromium and stainless steel

- The pyrometallurgical production of copper and nickel
- Rolling and heat treatment of steel.

2 Results in major research areas

2.1 Iron making in blast furnaces

Blast-furnace production of pig iron is the overwhelmingly greatest consumer of energy in the steel and metal producing industry. The primary energy consumption is about 43 PJ per annum, accounting for 80% of the total energy content of fuels and reductants used by the entire steel and metal producing industry.

Although the specific energy consumption of blast furnaces in Finland is among the lowest in the world, there is still potential for further reduction of energy consumption and costs. Also, the blast furnace process is difficult to control, so one object of research is how to improve control over the process. Producing iron in a blast furnace usually involves producing coke and iron ore sinter.

Eleven projects have focused on developing blast furnace, coking plant and sintering processes. Participants have included Rautaruukki Oy, Fundia Wire Oy Ab and units from the University of Oulu, Helsinki University of Technology (HUT), Åbo Akademi University, Tampere University of Technology and VTT the Technical Research Centre of Finland.

Increased oil injection, blast furnace charging control and blast furnace computer control are three of the research objectives. The studies have also involved the blast furnace projects of Jernkontoret, the conversion of Koverhar to 100% pellet charging, and improved energy economy at the Raahe Steel coking plant.

Increasing oil injection

Coke is being replaced by oil injected through the tuyeres of the Raahe and Koverhar blast furnaces.

At the Raahe Steel Works, the equipment modifications needed for increasing oil injection were made in connection with renovation in 1995 and 1996. The aim is to replace a further 100,000 tonnes of coke per annum with heavy residual oil from the Neste refinery. Heavy residual oil has a high sulphur content, so it is not a desirable component of fuel oil. However, it is an affordable fuel and reducing agent for blast furnace use. In blast furnace processes, the sulphur can be bound completely to the slag.

At the Koverhar blast furnace, the equipment modifications needed for increasing oil injection were made in connection with renovation in summer 1995. The aim is to replace a further 25,000 tonnes of coke per annum with oil.

Replacing coke with oil has several benefits, including considerable cost savings due to the price difference between coke and heavy residual oil. The hydrogen in the oil accelerates the reduction reaction, raising production capacity. Also, the production capacity of the coking plant at the Raahe Steel Works will be enough to satisfy the need for coke in Finnish blast furnaces even after the iron output of the Raahe and Koverhar steel plants is increased.

As the amount of oil used is increased, the point is reached at which the oil cannot be completely burned in front of the tuyeres. If this is the case, some of the pyrolysis gas will escape into the blast furnace shaft and create soot deposits as it decomposes. Factors affecting oil combustion have been studied in the programme.

The University of Oulu (Process Metallurgy) has studied the thermodynamic requirements of combustion. The contribution of various gas components has been examined using thermodynamic databanks, with the temperature and the ratio of oil to air in the tuyere as variables. The effects of hydrocarbons, hydrogen and sulphur have been examined separately. This study is a literature study. Lab tests have also been performed on hydrocarbon with a high-temperature reduction under load test.

At the moment it seems that hydrogen has a positive effect and that sulphur can have a detrimental effect on both reduction and the high-temperature

properties of the ore. Lab tests show that as hydrocarbons decompose, the carbon generated may carbonize the reduced iron, which in turn leads to the softening of the ore and premature melting.

The Combustion Chemistry Research Group at Åbo Akademi University has studied the kinetics of combustion reactions in the race way, first nitrous oxide and acetylene formation and then soot formation. The results indicate that thorough mixing of the oil with the hot blast prevents soot formation. The reaction kinetics study is finished, and the companies are satisfied with the results.

The Energy and Process Engineering Laboratory of Tampere University of Technology has studied oil combustion through simulation. In modelling oil combustion in the race way, three phases have to be considered: the gas, the coke and the oil droplets.

In the first stage of the study, oil combustion phenomena were modelled. The most trouble was caused by calculation of the coke swirling in the raceway. In the current second stage, the behaviour of coke and the phenomena related to combustion are considered. The third stage is intended for modelling tuyere and oil injection details with a more detailed model.

The Energy Engineering and Environmental Protection Laboratory of HUT has studied droplet formation in oil injection with a scale model. Droplet size has proved to be the main factor affecting combustion speed.

The only way to examine droplet formation in oil injection is by testing. Factors affecting droplet size cannot be studied under production conditions. It was therefore decided to build a scale model to test injection with suitable blends of liquid and air at room temperature. The dimensions of the model, the speed of the liquid and the water and the properties of the liquid must be selected so that the factors influencing oil droplet size in the blast furnace can be estimated with dimension analysis.

The work was begun in 1994. The results show that the average droplet size grows in proportion to the oil speed and surface tension and decreases in proportion to the hot blast speed and the inner diameter of the injection lance. Droplet size does not seem to depend on the viscosity of the liquid.

The University of Oulu (Process Metallurgy) is analyzing the results of the individual tasks presented above and constructing a comprehensive model of phenomena in the race way. This model is intended to demonstrate the gas flow field, pressure and temperature distribution, gas composition and coke movements. The results are used for example in examining soot formation and determining measures to prevent soot formation.

Work is in progress on a doctoral dissertation in Raahe as part of the Rautaruukki research programme on the reduction of iron ore and its behaviour under conditions that presumably exist in the company's blast furnaces when large quantities of sulphurous oil are injected. A tuyere with two lances was installed in one of the two blast furnaces before the renovation. This tuyere was fitted with a video camera so that the oil combustion could be observed.

Blast furnace charging management

Gas distribution in the blast furnace shaft is controlled through charging. Efficient blast furnace gas reduction potential and low coke consumption require even gas distribution. The gas distribution also affects formation of wall deposits and the steady movement of the charge in the shaft.

The gas distribution can be affected with the charging sequence, movable throat armour and the technical design of the charging device.

The Heat Engineering Laboratory at Åbo Akademi University has developed an AI application for guiding charging. These models, based on estimation theory, neural networks and polynomial applications, have been installed for testing in the automation system of the Koverhar blast furnace.

In practice, it has been observed that the models do reflect changes in distribution, although converting the blast furnace from sinter to pellets has proved problematic, and the signal from the measurement probe has proved unreliable. Application of the models developed for the Raahe blast furnaces is being discussed with Rautaruukki. Blast

furnace wall temperature data will be integrated into the models at a later date.

Rautaruukki Oy and the University of Oulu (Process Metallurgy) have examined blast furnace charging models. These models were necessary tools for the changes carried out in connection with the renovation of the Raahe blast furnaces. The shaft diameter of blast furnace no. 1 was enlarged in 1995, and no. 2 was fitted with a bell-less charging device in 1996.

The Rautaruukki research centre 1:10 scale model was rebuilt, with many technical improvements introduced. Tests were run on both the old and the new model.

On the basis of the scale model tests on blast furnace charging, the charge material distribution in the shaft was examined using different charging methods and material proportions; the differences in charge distribution between the present and the future enlarged blast furnace were also studied. The results have been used in the design of the rebuilt blast furnace no. 1 and the configuration of the charging program, and a mathematical charging model was created.

An automatic charging model was created for the bell-less blast furnace, designed for a blast furnace with two feeding hoppers and charged with sinter/pellets and coke.

Marketing for the mathematical models was started this year. The first delivery will take place by the end of 1996. The added value contributed by the models to the system, which consists of a dozen mathematical models, is about FIM 300,000. Rautaruukki delivers two to three systems annually.

Computer control of blast furnaces

Blast furnace computer control was studied in the SULA programme in cooperation with Jernkontoret. A rules-based control system has been implemented in Koverhar and an expert system has been acquired for the Raahe blast furnace, as the SULA programme final report stated. These control systems are being further developed. The control systems now incorporate the charging models developed by Åbo Akademi University and Rautaruukki Engineering, described above.

The Koverhar rules-based charging model has been developed in cooperation with Fundia Wire Oy Ab and the Heat Engineering Laboratory of Åbo Akademi University. The interactive control system operates in real time, and the process computer is linked to a relational database. The control system has a graphic display based on mathematical models, simulation software and a knowledge database that provide the user with exact information on the state of the process, any problems, and any measures needed. The control system has made process monitoring and control very clear, making it easy to optimize use of energy and raw materials.

The programme is studying the applicability of neural networks and fuzzy models to blast furnace control. The research combines an expert system with mathematical models developed for the upper part of a blast furnace, neural network models and existing measurements. The models use data from the upper part of the blast furnace to predict gas and temperature profiles in the upper part of the blast furnace and the form and location of the cohesive zone. The objective of these models is to enhance charging control. Models are also being developed to interpret the state of the high-temperature area in the blast furnace and inform the operating engineer of changes in the process.

The system predicts and warns of irregularities in material descending and proposes control measures. Modelling is in progress for both the Raahe and the Koverhar blast furnaces. Integrating neural network applications with the existing expert system is expected to introduce new features to the system and open new potential for developing process control.

The research in the project is being conducted jointly by the Control Engineering Laboratory of the University of Oulu and the Heat Engineering Laboratory of Åbo Akademi University. Rautaruukki Oy and Fundia Wire Oy Ab are also participating.

Blast furnace projects in the Jernkontoret joint research

The materials manufacturing technology laboratory at HUT tested the effect of gas composition and additives (Ca, Mg) on iron oxide reduction. When the amount of oil injected is increased, the

amount of hydrogen and sulphur also increases, so it is important to examine what effect these have. The tests have established the effect of hydrogen and additives on the reduction rate.

The process metallurgy laboratory of Luleå University of Technology and the Process Metallurgy and Control Engineering Laboratories of the University of Oulu have jointly studied dust formation. Dust formation in the LD converter is being studied in Luleå, while Oulu is studying dust formation in the sintering process. The aim is to reduce the amount of return fines and emissions and to utilize emissions.

Much new knowledge has been gained in the research, but it has proved difficult to convert this knowledge into practical improvements in the process. Return fines and emission levels can possibly be reduced by changing operation parameters. Coke dust from the coking plant can be used as fuel in the sintering plant.

An oxygen meter for sintering gases has also been developed for use in controlling. An ECSC project, with Rautaruukki as coordinator, was launched to improve the usability of the oxygen meter. Joint Nordic research will continue in Luleå once the Jernkontoret project is concluded.

Koverhar converts to 100% pellet charging

In summer 1995, the Koverhar blast furnace was converted to use pellets instead of sinter in the blast furnace charge. This was because the sintering plant was closed down for environmental reasons. This closure reduced the CO_2, SO_2, NO_x and dust emissions from the plant considerably. The annual consumption of electricity and fuel also decreased: coke breeze by 33,900 tonnes, light fuel oil by 1,360 tonnes and electricity by 13,600 Mwh.

Pellets behave differently from sinter in blast furnace charging. Converting from sinter to pellets has caused serious problems abroad. The main problem is charging control. However, some conversions have gone rather smoothly. To make the change with as few problems as possible, it was decided to test the arrangement on a charging model that has yielded good results in research on sinter charging. In addition to model testing, it was considered necessary to carry out tests at production scale to determine any potential problems in pellet handling and use.

Pellet behaviour was first studied with a blast furnace scale model. The charging system of the old model was converted to correspond to the new charging system installed in summer 1994. Tests were carried out on the new charging system during summer and autumn 1994. The results of the scale model test could be transposed to production scale.

Production scale tests with a 100% pellet charge were scheduled for September 1994, but due to the poor condition of the lining of the blast furnace, the tests were carried out with only 15% to 30% of pellets. The results were encouraging; it was possible to control the charging and the quality of the iron was good. Thanks to the preliminary work, conversion to pellet charging after the blast furnace renovation went smoothly. The charging was well under control and new production records have already been set.

Improving the energy management of the Raahe Steel coking plant

Energy consumption in coke oven batteries has been reduced and a model suitable for coke oven battery heating control has been developed in a project managed by Rautaruukki Oy. So far, a 16% fuel saving has been achieved, corresponding to about 615 TJ per annum. The coke production capacity has increased by 7.6%.

The coke oven battery heating control model is excellent for the coke oven battery automation system marketed by Rautaruukki Engineering. Three export deals concerning the control model have been concluded. A new temperature measurement device with other potential applications has been developed in the projects.

Sub-contractors in the project include the University of Oulu, Tampere University of Technology and VTT Jyväskylä. Development of the control model is being continued in cooperation with the Control Engineering Laboratory of the University of Oulu.

Producing steel in an LD converter

This study has focused on improving converter control.

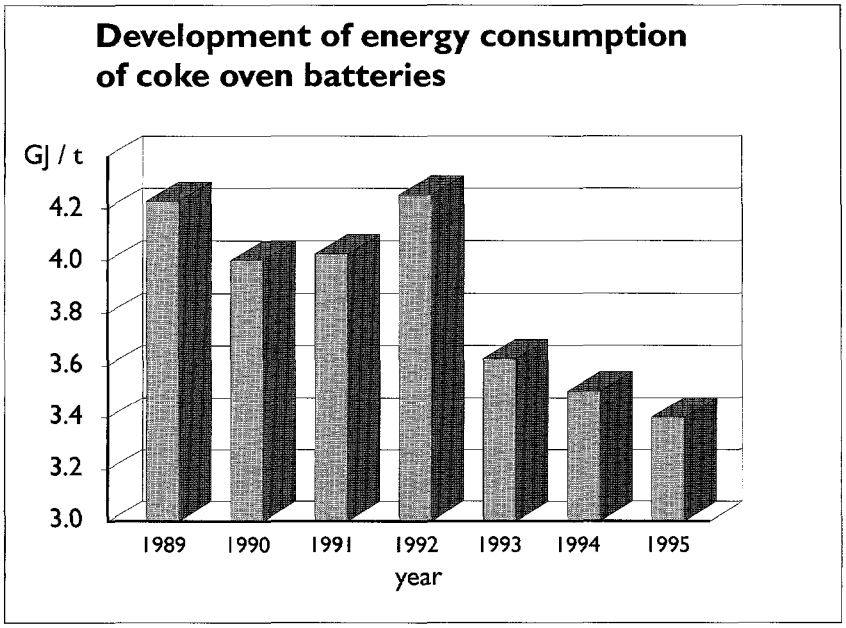

Figure 1. Energy consumption at the Raahe Steel Oy coking plant.

Rautaruukki Oy and the metallurgy laboratory of HUT have participated in the 'Konverterstyrning project' managed by Jernkontoret. In this programme, HUT has developed a programme called CONSIM-2, while the Royal Institute of Technology has worked on its own model and MEFOS has worked on the MEFCON programme.

The calculation program developed (CONSIM-2) simulates the chemical and thermic evolution of the process: it calculates changes in the amount, composition and temperature of the molten iron and slag as blowing progresses. The oxygen conversion process is simulated by introducing the basic values from the real process and connecting the parameters from the kinetic subprogram into the actual blowing program and the physical properties of the reactor. Various working versions of the program exist; in the most recent one, the surface blowing parameters — oxygen blowing speed, lance height and lance geometry — direct the process, i.e. oxidization of the impurities and iron and the formation of slag.

CONSIM-2 is written in QuickBasic. Although CONSIM-2 is still too slow for converter control, its scientific standard is high and it can be used in process research.

MEFCON has been tested by Rautaruukki since February 1996. It calculates the carbon balance in blowing and predicts the carbon content of steel when blowing stops. The off gas analyzer used in carbon balance calculations has worked well, but the calculation itself has had problems. After the test period, the applicability of MEFCON to dynamic controlling of the Raahe converters will be assessed.

In the new Rautaruukki project on direct pouring from the converter, tests with drop probes were begun in late 1995. The experience gained shows that the use of probes significantly reduces the number of heats that have to be corrected due to temperature.

Slag in steel production

This project consists of five master's theses for Process Metallurgy at the University of Oulu. The experimental part of these theses was carried out as a production test at the Raahe Steel plant. The study focused on the use of calcium aluminate slag in the ladle, slag handling in the converter, the effect of desulphurization slag on the cleanness of steel, and the effect of inclusions on steel quality and castability.

The project has increased the theoretical and practical knowledge of slags. The changes to slag practices made as a result of the research have so far reduced production costs by FIM 7 to 8 million per annum and improved steel quality. The results have also been applied at the Koverhar steel plant. Some are applicable to the Imatra Steel Works.

Handling of the arc furnace and its exhaust gases

The objective of the project on the new arc furnace of Imatra Steel was to improve competitiveness in steel melting and energy economy and to minimize emissions.

The project has produced optimum solutions for the production process. Steel scrap is preheated with furnace off gases. The material flow between the furnace and the secondary metallurgical treatment was designed to be straightforward and quick, thereby reducing heat loss. Imatra Steel made a significant contribution to the design of the preheating. The furnace gases are purified with a bag filter. The work has been supported by a literature survey conducted at the Laboratory of Metallurgy of HUT.

The decision to launch the project was made in autumn 1994, and the new melting shop was started up in August 1996. The arc furnace commissioned is an AC furnace with a charge weight of 75 tonnes and a transformer rating of 50 MVA + 20%. The estimated electricity consumption of the new arc furnace will be 440 kWh per tonne, or about 50 kWh per tonne less than the present, once the operating practice has been established. To develop this, a new Tekes-assisted project entitled 'Arc furnace energy optimization' has been launched.

New iron and steel production processes

The major industrialized countries have been developing several new iron and steel production methods based on smelting reduction technology. Coal is used instead of coke, and some methods focus on smelting the iron ore concentrate without pre-treatment, i.e. sintering, or pelleting. It is important for Finnish steel producers to know whether a serious rival to the conventional blast furnace and converter process is emerging in the near future, so some research, at a reasonable cost, has been dedicated to smelting reduction.

The work has been carried out at the Laboratory of Metallurgy of HUT from 1989 onwards. The research has yielded the following:

- a test method based on X-ray image system and temperature measurements to observe the behaviour and reactions of iron oxide pellets at high temperatures
- a thermodynamic material-energy balance model to examine the smelting reduction process and to optimize parameters
- reports on the state of new smelting reduction processes in production or in development.

The future availability of steel scrap for the steel industry is uncertain. Steel scrap is an important source of raw material for the steel plants of Imatra Steel and Outokumpu Polarit. Steel scrap is also important in keeping the production costs down at the Rautaruukki Raahe Steel Works and the Fundia Koverhar steel plant. The development of steel production methods and trends in the international scrap metal market show that the supply of steel scrap in relation to consumption is declining. It would therefore be economically sound to take up alternative raw materials.

The Laboratory of Metallurgy of HUT has surveyed the options of replacing steel scrap with alternative raw materials in the Finnish steel industry; a master's thesis on iron carbide production has also been written. The objective was to establish the properties of potential alternative raw materials and their effect on the steel production process and product properties. The production and availability of materials replacing steel scrap was estimated with a scope of five to fifteen years.

Iron carbide is considered an interesting potential replacement for steel scrap. In the master's thesis mentioned above, the thermodynamic requirements for the formation of iron carbide were examined and the formation of iron carbide and its mechanisms were studied in practice.

Strip casting

The purpose of strip casting is to cast a thin strip that after slight finishing in a rolling stand is suitable as is for cold rolling or other finishing. This

would practically eliminate the energy-intensive and expensive stage of hot rolling, bringing the casting and rolling energy consumption and production costs down to about a quarter of the conventional.

With the present thin sheet production of Rautaruukki Oy, 700,000 tonnes per annum, this would translate into total energy savings of 70 GWh of electricity or 60 million Nm^3 of coke gas per annum.

In the MEFOS strip casting project of 1990-1993, a pilot strip casting machine was constructed, the problems of strip casting were addressed and test castings were started. The strip casting machine constructed is a belt casting machine. The casting speed is 20-60 m per minute, the thickness of the strip cast is 5-10 mm, the strip width is 450 (900) mm, and the charge is 4-6 tonnes.

Further test castings were made in the strip casting project in 1994-1996, ensuring that the method selected lends itself to further development. The main development points at the testing stage were the feeding of molten steel onto the belt, heat transfer from the cast strip, and the properties of the strip.

A simulation model of heat transfer and solidification in the strip casting method has been developed at HUT. The model enables calculations of how the composition of steel and the parameters of the casting process affect the temperature and solidification of the strip and the microstructure of the cast strip.

The project participants in 1994 were Rautaruukki Oy, Avesta Sheffield AB, Daido Steel, Jernkontoret, Mannesmann Demag Hüttentechnik, AB Sandvik Steel, SSAB Tunnplåt AB, Vattenfall and Vítkovice, and MEFOS, HUT and the Swedish Institute for Metals Research. Funding has been obtained from the Swedish NUTEK, the Finnish Ministry of Trade and Industry, the participating companies and Jernkontoret.

The European Coal and Steel Community has contributed to the funding since 1995, and the partners outside the EU have had to withdraw. They were replaced by Krupp and Preussag of Germany. Development of strip casting for stainless steel has been discontinued.

2.2 Ferrochromium and stainless steel production

The Laboratory of Metallurgy of HUT has carried out basic research on chromium containing slags and the reduction of chromite. Outokumpu Chrome has done work on the properties of the charge in ferrochromium furnaces. Outokumpu Polarit has conducted research and surveys that led to acquisition of a ferrochromium converter. A minor project in optimization of ladle treatment of stainless steel has also been carried out.

The Laboratory of Metallurgy of HUT has conducted reduction tests in solid state with pellets and lump ore. The tests with sintered pellets having varying degrees of oxidization showed that a higher oxidization degree makes the reduction reaction faster. A high-temperature reduction test series has been planned in cooperation with Outokumpu Chrome. The new high-temperature furnace of the Laboratory of Metallurgy enables testing at higher temperatures than before (c. 1750 °C); this means that slag compositions corresponding to those in process conditions can be used in smelting reduction tests. The tests, in which a chromite sample is immersed in molten slag in a graphite crucible, are being carried out with different slag compositions and at different temperatures. Smelting reduction tests are also being carried out in the presence of molten FeCr. The tests are in progress.

Models depicting gas reduction of carbon-free pellets and lump ore over a wide range of reduction degrees and taking into account the transient stages in which reaction control changes as reduction proceeds have been developed in a study entitled 'Kinetic reaction models of chromite reduction by CO'. The modelled calculations and test results correlate well. The parameters of the reaction models have been modified and the next step is to evolve expressions for the sintering effect and to integrate these into the models.

For thermodynamic reasons, the melting of ferrochromium is an energy-intensive process. Although the technology used by Outokumpu Chrome Oy is among the best in the world, the electricity consumption is about 3200 kWh per tonne of ferrochromium.

Due to improvements made in connection with the research, the operating time power has increased by 14 MW between 1992 and 1995. At the same time, ferrochromium production has increased by 25% and energy consumption has dropped by 80 kWh per tonne of ferrochromium. With an annual production of 235,000 tonnes, this means a saving of 18,800 MWh.

The utilization of the energy content of the molten FeCr in steel production was also examined in the research programme. It was found that a separate FeCr converter is the best for temporary storage of the molten metal and for utilizing its energy content. The operation practice, control system and process model of the converter were determined and created in the programme, and points related to lining deterioration and timing control were estimated.

The decision to construct the converter plant was made in summer 1994 and the first charge was processed in the new converter on November 29, 1995. By the end of July 1996, the converter had produced 73,300 tonnes of desiliconized and decarburized ferrochromium. Electricity consumption had decreased by about 80 kWh per tonne of steel produced, which is in line with the objectives set for the research project. Other cost savings were achieved in electrode consumption and improved chromium yield.

However, the major economic return on the converter investments will come from increased production capacity. It is estimated that the slab production capacity of the steel plant will increase from 440,000 tonnes to 540,000 tonnes.

In the project dealing with optimization of ladle treatment of stainless steel, a timing control model and a temperature control model between the AOD and the ladle station were completed. Preliminary results show that handling times at the ladle station have decreased by about 40 minutes per ladle, which indicates energy savings of about 1000 MWh per annum.

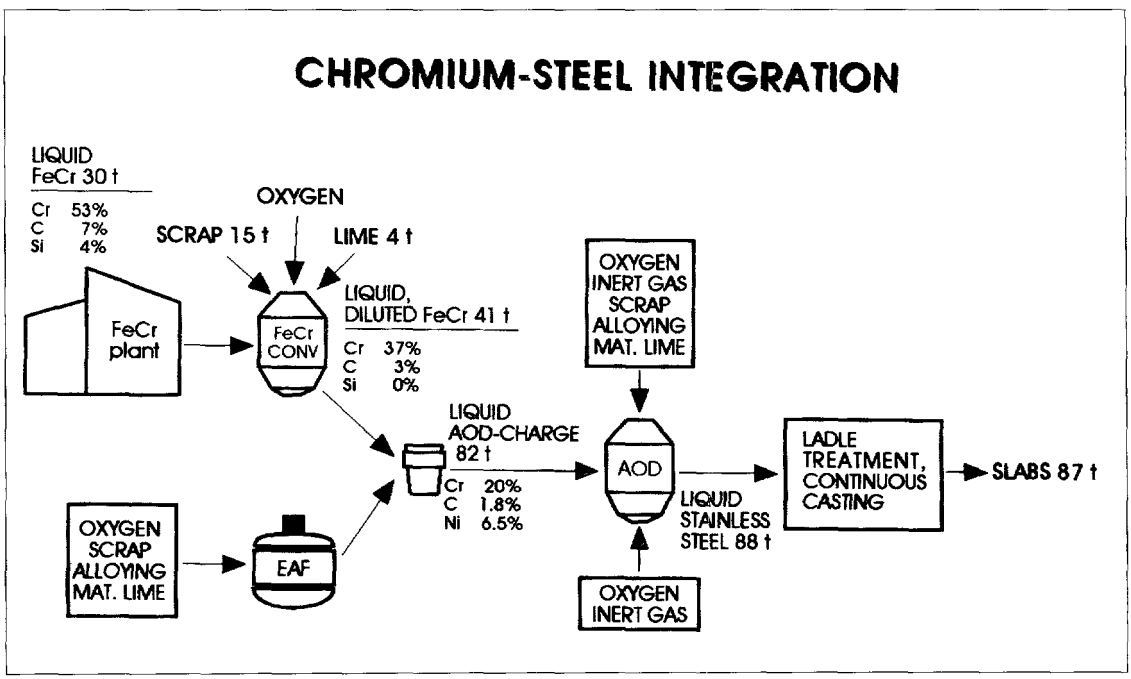

Figure 2. The chromium converter at the Tornio Stainless Steel Works.

2.3 Pyrometallurgical production of copper and nickel

The optimization of suspension smelting technology through computer simulation has been studied in the Outokumpu flash smelting technology project. The research was carried out at the Laboratory of Materials Processing of HUT. Experts from Outokumpu furnished the necessary process data.

The project was launched in 1992, and its objective was to improve energy use in suspension smelting technology by using computer simulation to seek optimum conditions for reaction phases in the process and more efficient operating parameters. By combining reaction kinetic and thermodynamic calculations on the combustion reactions with flow and heat transfer simulations, a variety of alternatives can be examined; improvements to process control and regulation and to energy recovery, loss minimization, combustion reaction optimization and enhancement of energy use can therefore be found quickly and at low cost. The design of smelting furnaces can also be improved.

The research concentrated on equipment and process technology objectives: modelling of flash smelting furnace flow and heat transfers, simulation of sulphide combustion reactions, development of concentrate burners, reducing the dimensions of the waste heat boiler and use of boiler shaft technology.

The flash smelter and its waste heat boiler have been simulated in two and three-dimensional laboratory models with commercial Computational-Fluid-Dynamics software used for the calculations.

The completed project resulted in a well-functioning model of waste heat boiler flow and heat transfer. The objectives related to the concentrate burner and the flash smelting furnace were largely achieved, but the reaction objectives were achieved only in part. The models are being developed further in a new project.

So far, the research results have been applicable to the expansion of the Harjavalta smelting plant of Outokumpu and to several projects managed by Outokumpu Engineering.

2.4 Zinc production

The most extensive project in the research programme involves the pyrometallurgical production of zinc. Thermodynamic calculations show that this is more advantageous in terms of energy consumption than the present roasting-leaching-electrowinning method.

In the concluded SULA programme, Outokumpu Research conducted test runs with three process alternatives. Two of these, reduction of zinc calcine in a flash smelting furnace and injection of zinc calcine into molten iron, have been described in the final report of the SULA programme. The third alternative, injection of zinc ore concentrate into molten copper, was nevertheless considered the most promising at the time when the programme concluded.

A test apparatus has been constructed at a pilot plant to test this method. The apparatus consists of a combined electric furnace and converter and a zinc splash condenser.

Two test runs were performed in 1993; these demonstrated that the apparatus had to be improved. In the test run after the improvements in September 1994, the results were more promising, but the combination of electric furnace and converter still did not work as expected. A three-week test run carried out in autumn 1995 proved that the link between the furnaces was not functional enough. The furnace construction needs further development.

The new method has a significant economic advantage in that the copper and lead in the concentrate, as well as trace elements such as silver, can be recovered. Tests performed so far have provided enough information for a reliable profitability calculation. This calculation was completed in spring 1996, but it has not been fully discussed yet.

Outokumpu Zinc has studied heat recovery in zinc production in Kokkola. It seems that the best solution is to heat the return acid with steam using Alfa-Laval heat exchangers.

2.5 Steel rolling and heat treatment

In steel rolling and heat treatment, research focused on steel slab and billet reheating furnaces. The objective was to reduce scale loss and to improve energy management (Raahe Steel, Imatra Steel, Fundia Dalsbruk and Fiskars Forging) and to increase heating capacity (Fundia Dalsbruk and Imatra Steel).

Rautaruukki Raahe Steel performed optimization of reheating furnace atmosphere. The objective of the study was to establish suitable measurement sensors and measurement points for furnace gases. In the related scale study, the effect of various conditions on scale removal during rolling was examined.

The test furnace achieved an annual energy saving of 17,500 GJ. The project has improved the surface quality of hot rolled products through reducing scale loss; an annual return of FIM 1 million was obtained.

The billet furnace at the Fundia Wire Dalsbruk rolling mill has featured in several SULA projects. In 1993, two energy management improvement projects were conducted. They resulted in an annual saving of 19 TJ in specific oil consumption and an annual saving of 10 MWh in the specific electricity consumption.

In 1994, a research project was begun at the Laboratory of Processing and Heat Treatment of Materials at HUT on energy savings in hot forming by reducing the amount of scrap and scale loss. The oxygen content of the atmosphere in slab reheating furnaces at the Raahe Steel Works, in the billet reheating furnaces of the Imatra Steel Works and the Taalintehdas rolling mill were measured at various locations and in different operating situations. Oxygen levels of a height previously unknown were observed. The situation is better under control in Raahe than in Imatra or Taalintehdas, however.

The best results so far have been achieved in the billet furnace of the Imatra Steel Works, with a 9.5% (19 TJ) reduction in energy consumption. Changes made in connection with the project account for about 10 TJ of this. A cautious estimate of the cost savings generated by the project is FIM 600,000 per annum.

3 Impact of results

The results of 29 projects are referred to in this intermediate report of the SULA 2 programme. The results of 18 of these projects have been directly applicable to production.

Four projects are for basic research in production process development. Three concern increasing the amount of oil used as fuel and reducing agent in blast furnaces.

Two projects have examined iron and steel production methods still in the development stage and new raw materials not yet used in Finland. The objective has been to create capacity for changing production processes and raw materials, should the competitive situation and raw material availability so demand in the future.

Two projects have focused on developing new processes. Rautaruukki has participated in a consortium working on strip casting. Outokumpu has run a project aiming at developing a new pyrometallurgical zinc production method. The company has not issued its final statement regarding the profitability calculation completed in spring.

3.1 Effect of the applications on specific energy consumption and economy

Considerable savings in production process energy consumption, estimable from production reports, have been achieved in several projects.

The following economically significant results can also be mentioned:

- The production capacity of the Raahe blast furnaces has increased by 7.5%. The blast furnace expert system accounts for a major portion of this.
- Coking plant production capacity has increased by 7.6%, and the lifecycle is longer.

Table 1. Energy savings achieved through the SULA 2 programme.

	Heat TJ/y	Electricity GWh/vy	Graphite electrodes ton/v
Blast furnace expert system, Raahe Steel Works	270		
Energy economy in a coking plant, temperature control of a coke battery, Raahe Steel Works	615		
Optimization of the electric resistance of a submerged arc furnace burden, Tornio ferrochromium smelting plant		18,8	
Utilization of the energy content of molten FeCr in the production of steel, Tornio Stainless Steel Works		30	300
Optimizing the ladle treatment of stainless steel, Tornio Stainless Steel Works		1	
Optimization of gas composition in slab reheating furnaces, Raahe Steel Works	17,5		
Billet reheating furnace energy management improvement, Taalintehdas rolling mill	19	0,1	
Energy savings in hot working by reducing the amount of steel scrap and scale loss, Imatra Steel rolling mill	10		
Total	930	**50**	**300**

The total energy savings are worth over FIM 30 million per annum.

- The new slag practice at the Raahe steel plant cuts costs by about FIM 7 to 8 million per annum.
- The economic benefit gained from the improvement in the surface quality of hot rolled products from the slab reheating test furnace at the Raahe Steel Works is about FIM 1 million per annum.
- Improving the yield of the billet furnace at the Imatra Steel Works has generated savings of about FIM 500,000 per annum.
- The capacity of the ferrochromium plant has increased by 25%; the SULA 2 project has made a major contribution to this.
- The capacity of the stainless steel melting shop of Outokumpu Polarit will increase from 440,000 tonnes per annum to 540,000 tonnes per annum.

Further electricity savings can be expected as a result of investments at the Imatra steel plant and the Tornio stainless steel melting shop once the operating methods are developed. The total annual savings are expected to be about FIM 11 million.

The necessary changes for increasing oil injection were made to the Raahe Steel Works blast furnaces in connection with the renovation in 1995 and 1996. The aim is to replace 100,000 tonnes of coke per annum with sulphurous heavy residual oil from the Neste refinery, in addition to the replacements already made. The necessary changes for increasing oil injection have also been done at the Koverhar blast furnace in connection with renovation in summer 1996. The aim is to replace 25,000 tonnes of coke per annum with oil.

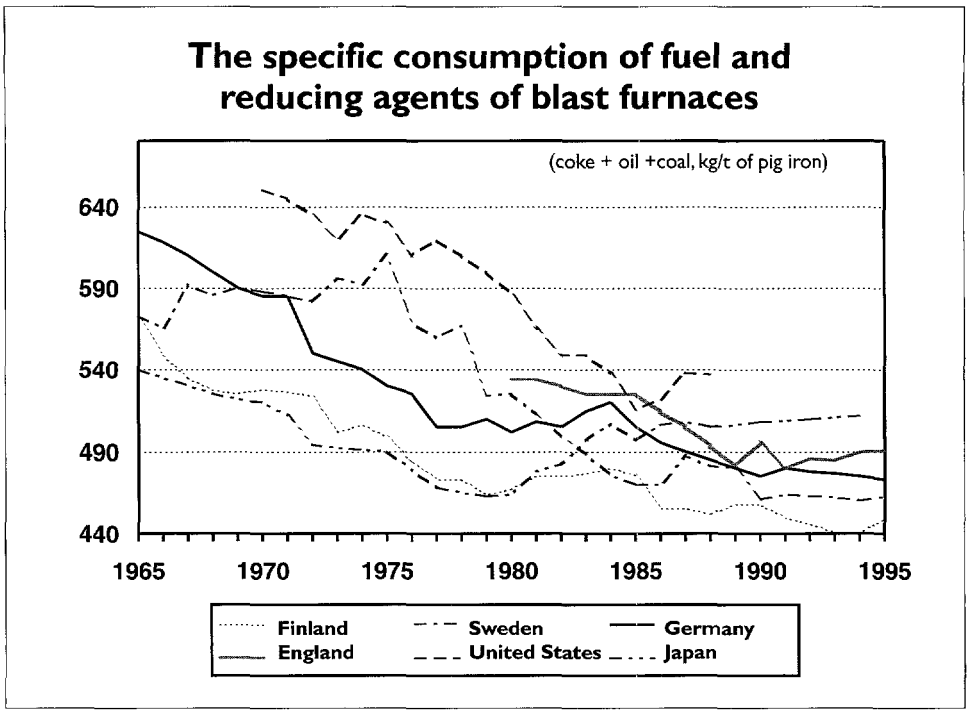

Figure 3. Improvement of blast furnace energy efficiency.

The economic benefits of replacing coke with oil are the following:

- A significant saving due to the difference in price between coke and heavy residual oil.
- The hydrogen in the oil speeds up the reduction reaction, raising the production capacity.
- The production capacity of the coking plant at the Raahe Steel Works is enough to satisfy the need for coke at all Finnish blast furnaces, even after iron production at the Raahe and Koverhar Steel Works is increased.

3.2 Minimizing environmental damage

Two projects have ended significant emissions.

The new arc furnace at the Imatra Steel Works is fitted with an exhaust gas cleaning plant that can recover the dust generated in melting. The amount of dust containing zinc is about 2500 tonnes per annum. Conversion to a 100% pellet charge at the Koverhar steel plant meant that the sintering of iron ore could be discontinued. This eliminated emissions from the sintering plant — 1100 tonnes of SO_2, 500 tonnes of NO_x and 800 tonnes of particles.

When coke is replaced with Neste heavy residual oil, the sulphur in the oil is bound in the slag, which can be used for a number of purposes. The annual increase in oil injected into blast furnaces contains about 3500 tonnes of sulphur.

3.3 Technology exports

The results of the research programme have been directly applicable in exports. Three export deals have been concluded for the blast furnace expert system, three in connection with coking plant energy management, and one for the blast furnace charge model.

The results have also been used in sales work by Outokumpu Engineering Contractors.

3.4 Networking

The steel and metal producing industry in Finland has cooperated in the field of research for quite some time and also worked with the Swedish steel industry in connection with research by Jernkontoret. The Tekes-assisted continuous casting development projects are a good example of successful networking.

A new cross-disciplinary network focusing on blast furnace oil injection has been created within the SULA 2 programme. This network combines expertise from the SULA 2 and LIEKKI 2 programmes. The participants are the University of Oulu (Process Metallurgy), the Laboratories of Materials Processing and Energy Technology of HUT, the Combustion Chemistry Research Group of Åbo Akademi University, the Energy and Process Engineering Laboratory of Tampere University of Technology, VTT Energy, and the implementers of the results, Rautaruukki and Fundia Wire. The network consists of a chain comprising basic research, pilot tests, production tests, and production application.

3.5 Training for researchers

The steel and metal producing industry has traditionally worked in close cooperation with the universities and departments that train engineers in the field. The Department of Materials Science and Rock Engineering of HUT, the University of Oulu (Process Metallurgy) and the Heat Engineering Laboratory of Åbo Akademi University are well represented in the SULA 2 programme. Other university and research laboratories have been involved in the Rautaruukki blast furnace research. Cooperation has produced good results.

A centre of competence in the blast furnace process has been created at the University of Oulu in the course of the programme, and HUT has founded a CFD technology application centre at the Laboratory of Materials Processing.

By summer 1996, the programme had generated three doctoral dissertations, five licentiate's theses and 40 master's theses. Four further doctoral dissertations and six licentiate's theses are in preparation.

4 Main results of intermediate assessment

The management group feels that the programme has been sufficiently versatile and meets the needs of the industry. In the programme, it has been possible to implement the research needs of the industry more extensively and with a tighter schedule than before. The programme has also served as a discussion forum for the steel and metal producing industry.

The management group feels that the locating of production process research in the SULA 2 programme is a better idea than placing the projects according to the methods used, such as flow dynamics or neural networks, in various Tekes programmes. The management group feels that knowledge of the relevant process is of crucial importance in project supervision.

5 Further planning on the basis of the intermediate assessment

In connection with the intermediate assessment, the management group decided that the programme should focus on improving general production efficiency. Important criteria for assessing project proposals include the following:

- low specific energy consumption
- reducing the environmental impact
- maximum utilization of raw materials
- maximum utilization of by-products and process heat
- improving competitiveness
- enabling technology exports.

In addition to research projects, life cycle analyses can be accepted for the programme if they are suitable in content.

Outokumpu might be interested in developing a process for local processing of ore.

The university research programme for the coming years is included in the research programme proposal of the management group in autumn 1995.

Accordingly, the University of Oulu has begun new projects concerning reactions in the blast furnace process and injections in the blast furnace. Åbo Akademi University has begun two new projects on blast furnace computer control. The ferrochromium production process research at the Laboratory of Metallurgy of HUT has moved to an interesting new phase with the availability of the high-temperature furnace to scientists. Research on the flash smelting process is being carried out at the Laboratory of Materials Processing at HUT.

The CFD modelling of slab and billet reheating furnaces is a new project, although it is connected to the objectives of the four slab and billet reheating furnace projects carried out and begun in the first half of the programme. A new project in converter control improvement research can probably be started at the Laboratory of Metallurgy of HUT.

6 Programme organization and management groups

The industry has guided research through the management group and expert groups. It is a better idea to have an expert group for each priority than to have a separate guidance group for each project.

The management group members in 1993-1995 were as follows:

- Tapio Tuominen, Vice President, Science and Technology, Outokumpu Oy, chairman 1993-1994
- Peter Sandvik, Vice President of Research, Raahe Steel, Rautaruukki Oy, chairman 1995 (member since 1993)
- Jussi Asteljoki, Vice President, Research and Development, Outokumpu Oy, 1995
- Seppo Haarala, Manager, Development and Quality, Imatra Steel Oy Ab
- Pertti Kostamo, Director, Development, Fundia Wire Oy Ab
- Sirpa Smolsky, Managing Director, Association of Finnish Steel and Metal Producers
- Mikko Ylhäisi, Project Manager, Tekes

The coordinating organization is the Association of Finnish Steel and Metal Producers, and the programme director is Håkan Hakulin.

The management group has appointed an expert group for each priority area that has at least one research project; members are selected from universities and companies participating in research, although outside experts can also be included. The management group has at least one representative in each expert group. It is recommended that the participating companies' development projects in each priority area also report to the expert group.

The expert group members at the end of 1995 were as follows:

Basic processes in iron and steel production

- Kyösti Heinänen, Rautaruukki Oy, Raahe, chairman
- Håkan Hakulin, SULA 2 programme
- Prof. Lauri Holappa, HUT, Laboratory of Metallurgy
- Prof. Jouko Härkki, University of Oulu, Process Metallurgy
- Prof. Reijo Karvinen, Tampere University of Technology, Heat Engineering Laboratory
- Pertti Kostamo, SULA 2 Executive Committee
- Timo Lintumaa, Outokumpu Steel Oy, Tornio
- Kalevi Raipala, Fundia Wire Oy Ab, Koverhar
- Henrik Saxen, Åbo Akademi University, Heat Engineering Laboratory
- Matti Seppänen, Rautaruukki Oy, Engineering
- Kari Terho, Imatra Steel Oy Ab, Imatra
- Mikko Ylhäisi, Tekes

Ferrochromium and refined steel production

- Prof. Lauri Holappa, HUT, Laboratory of Metallurgy, chairman
- Jussi Asteljoki, SULA 2 Executive Committee
- Håkan Hakulin, SULA 2 programme
- Prof. Jouko Härkki, University of Oulu, Process Metallurgy
- Helge Krogerus, Outokumpu Research Oy, Pori
- Timo Lintumaa, Outokumpu Steel Oy, Tornio
- Pekka Niemelä, Outokumpu Chrome Oy, Tornio
- Mikko Ylhäisi, Tekes

Pyrometallurgical production of copper and nickel using the Outokumpu flash smelting technology

- Pekka Taskinen, Outokumpu Research Oy, Pori, chairman
- Jussi Asteljoki, SULA 2 Executive Committee
- Håkan Hakulin, SULA 2 programme
- Prof. Mikko Hupa, LIEKKI 2 programme
- Ari Jokilaakso, HUT, Laboratory of Materials Processing
- Ilkka Kojo, Outokumpu Engineering Contractors Oy
- Prof. Kaj Lilius, HUT, Laboratory of Materials Processing
- Mikko Ylhäisi, Tekes

Steel rolling and heat treatment

- Pekka Mäntylä, Rautaruukki Oy, Raahe, chairman
- Seppo Haarala, Imatra Steel Oy Ab and SULA 2 Executive Committee
- Håkan Hakulin, SULA 2 programme
- Prof. Pentti Karjalainen, University of Oulu, Laboratory of Materials Processing
- Mikko Korteniemi, Outokumpu Polarit Oy, Tornio
- Henry Lönnberg, Fundia Wire Oy Ab, Taalintehdas
- Mikko Ylhäisi, Tekes

Chapter 12
TERMO – District heating

Tero Mäkelä
Finnish District Heating Association

1 Background and objectives

District heating is a large-scale business in Finland and its position is strong; it is the most common form of heating. Our major cities rely on it for 80-90% of their heating. District heating and related electricity generation are a basic element in Finland's energy supply. It is increasing its market share at a rate of approximately 2% per year.

The total length of district heating networks in Finland at the end of 1995 was 7400 kilometres. Most of these networks were built in 1975-1985. Annual capital outlays for this network have been around FIM 500 million. As these investments are of a long-term nature, with a typical life cycle of 15-50 years, today's systems will be in use well into the 21st century. Increasing demands are being placed on the efficiency of these investments. The district heating business in Finland amounts to some FIM 5 billion annually.

Some 15 kilometres undergo renovation every year, and this figure will rise to 18-23 kilometres by the year 2012. Most of the pipes are freely moving plastic casing pipes, which will be replaced by preinsulated bonded pipes.

In 1991 1.1 million apartments in Finland were served by district heating and their heating energy costs were FIM 1.7 billion, excluding hot water.

With respect to price, district heating will remain competitive with other forms of heating. The low level of variable costs, in particular, will guarantee district heating a stable market position in existing buildings and areas presently served by district heating. High capital costs make district heating less competitive in areas of single-family houses.

Some 15,000 PJ of district heating are generated annually throughout the world, while Finland's total annual energy consumption is approximately 1,300 PJ. Approximately 85% of the world's district heating is produced in Russia and other eastern European countries. Finland generates 0.6% of the world's district heating.

The level of investment in district heating is high, for example in eastern Europe and the Far East. Technical systems are being improved and becoming more uniform as standardization progresses. Business in the sector is international. The integration of Finland with Western Europe has opened up new potential for co-operation, for example in research and exports.

Unlike other programmes, TERMO has focused on a specific sector. Suppliers of district heating have developed their own operations through the programme. Funding for the programme has been provided on a fifty/fifty basis by energy companies and Tekes. Since participation by companies producing technology for district heating has been limited, few new products have emerged. Consequently, TERMO has sought primarily to determine the significance of district heating for overall energy policy, to make operations more economical and to assess the need for new technology. Both research institutes and companies have taken part in the programme.

2 Results in major research areas

Projects in the TERMO research programme fall into four areas:

- heat distribution
- measurement and data transmission
- financial aspects
- systems development

2.1 Heat distribution

A system for analyzing the condition of district heating networks

Leakage from district heating pipes can be detected at an early stage on the basis of ground surface temperature and flow sound. Prolonged leakage from district heating pipes can be detected at the latest when water penetrates to the surface of the ground, in an inspection chamber or in a basement. Injecting dye into district heating water has been primarily successful in the detection of leakage from customers' heat exchangers. In such cases, district heating water may become mixed with hot tap water.

In the autumn and spring, leakage can be detected when there is frost on the ground or in winter by observing the snow surface. This means is limited because it is random. Leaks between two inspection chambers may be found by digging up the ground between them, by listening with a microphone at ground level or by inserting a sound source and microphone from the inspection chambers into the pipes from two directions. The use of sound to detect leaks is hampered by background noise and pipes to customer buildings located between inspection chambers.

The temperature of the ground surface can be measured with a manual infrared thermometer. Measurements are taken when the ground is dry and free of snow. The method is sensitive to weather variations, although it has proved the most certain means of observing incipient heating leaks and damage to insulation in particular.

The research programme has developed a method for the analysis of a district heating network based on thermography, which is used in comprehensive maintenance. It entails continuous monitoring of the network and requires experience of the behaviour of different types of heating pipe construction and knowledge of soil properties.

The district heating analysis system developed in the research programme comprises a thermography imaging section, an analysis section and a data management section. The thermography section records all the necessary information on a video tape, which can subsequently be transferred to a database. The analysis section produces temperature profiles on the basis of the thermography and includes individual pictures. Temperature profiles can be compared on the basis of pictures of the same section of district heating network made at different times; conclusions can also be drawn concerning the changes that have occurred.

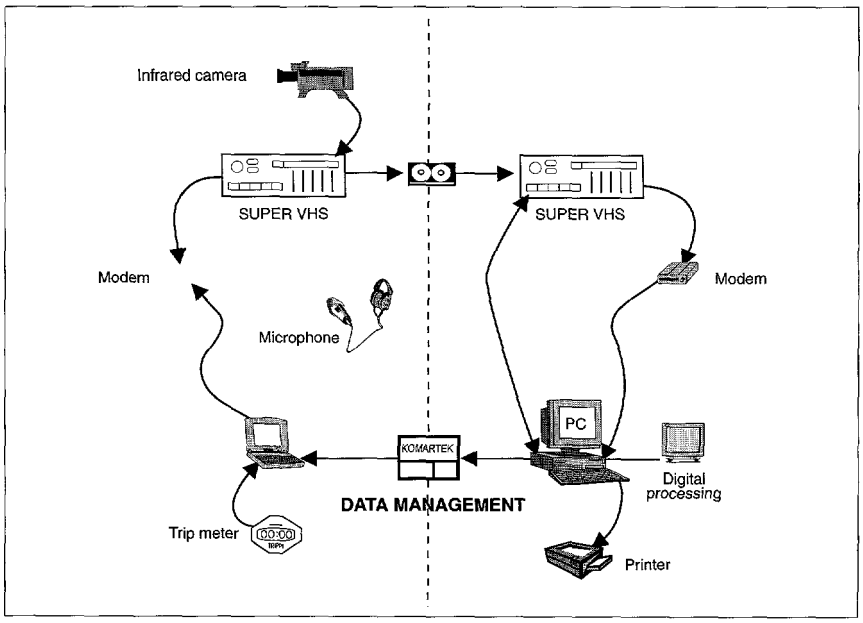

Figure 1. A district heating analysis system.

By means of data management, the basic data in the system is updated, the thermography is planned, data is downloaded from a video tape and samples are chosen for examination of the longitudinal temperature profiles.

The greatest limitation of the thermography method is the weather, for the ground must be dry and free of snow. The difference between the temperature of the pipe and the space area must be sufficiently large. The effects of disturbances are eliminated by drawing a longitudinal profile of the ground temperature distribution. In this way even small increases in temperature can be detected.

Savings in pumping energy

Approximately 200 GWh of electricity per year is consumed by district heating pumps in Finland. Selection of a suitable district heating pump and choosing the best adjustment method and location for it can yield savings in capital expenditure and energy.

The research programme compared two control methods, a frequency converter and a fluid clutch.

The basic efficiency of a frequency converter is better over the entire operating range than that of a fluid clutch. As an investment, the frequency converter is also more economical up to a motor size of 200 kW. For smaller sizes, frequency converter control is more economical in terms of overall costs.

For larger pumps, a fluid clutch is more economical in terms of the cost of acquisition, although its lower efficiency must be taken into account. Recovery of cooling heat from the fluid clutch and the value of the recovered heat are of considerable significance.

The specific investment costs of booster stations depend basically on the size of the main pumping station. If the pump size is increased from 25 kW to 340 kW, the costs of investment fall from a level of FIM 25,000/kW to some FIM 5,000/kW. It therefore seems reasonable to develop factory-made booster stations that would make acquisition more economical.

Thermal strain must be controlled

The steel pipe and insulation of a preinsulated district heating pipe tend to expand and contract with temperature fluctuations in the steel pipe. If thermal movements are prevented, tension arises between the pipe and the insulation. The extent of this tension depends on the temperature loads and the properties of the material.

The potential for damage to the insulation was studied in conjunction with cutting a cold layed pipe. If the pipe is cut while hot, in which case there is considerable compressive stress, the thermal strain tends to be released and the pipe increases in length. On the basis of available material parameters, the sheer stresses will not exceed the values permitted by the standards and the insulation will not be torn off the steel pipe.

In a cold layed pipe there is high compressive stress at the operating temperature; this stress exceeds the yield point. The research calculated the trench lengths for several pipe sizes that would prevent pipes from buckling when they are dug up while hot. The permitted length for a DN 100 pipe was 0.54 metres, for a DN 300 pipe 2 metres and for a DN 600 pipe 4 metres.

2.2 Measurement and data transmission

Forecasting district heating consumption

The research programme applied a new development in data processing called knowledge engineering for forecasting short-term district heating consumption. For example forecasts covering periods of up to 24 hours are needed to optimize generation of heat and electricity.

The research showed that the results of the forecast programme are good, compared with results based on conventional mathematical models and those provided by a regression analysis model based on time-series analysis. The results are excellent compared with the results from commercial models.

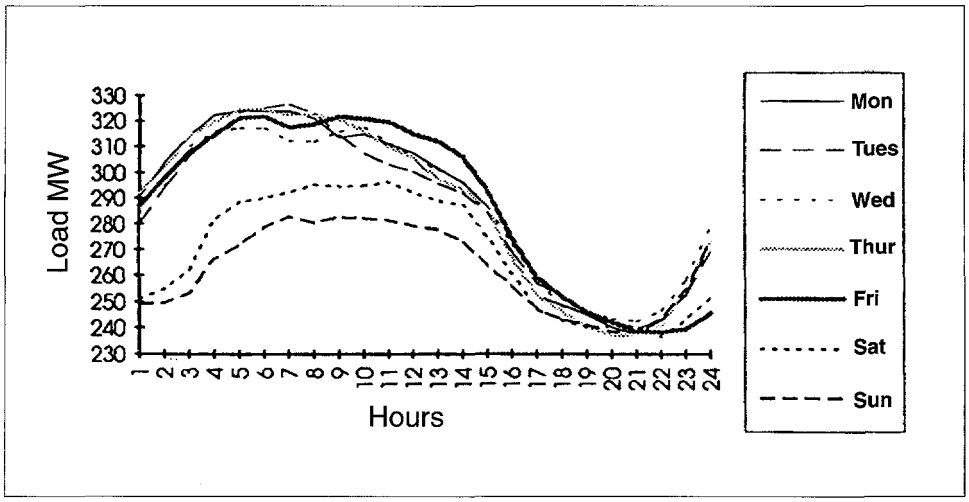

Figure 2. Type curves for the days of the week during the winter, assuming an outside temperature of 0°C.

The relative error in winter is 3.8% and in summer 5.0%.

Knowledge engineering relies on the use of rules based on experience and facts and on structures depicting consumption. District heating consumption is affected most by the outside temperature and by daily, weekly and monthly fluctuations. Also, the heat storage capacity of the district heating network and buildings and the lag between production and consumption exert their own effects.

The consumption rhythms in the method developed by the research programme are predicted by means of three reference days. Reference days are chosen on the basis of how well they represent the day of the week and the predicted outside temperature.

An increase of one degree in outside temperature reduces consumption in winter by 7.5-13 MW, in spring by 9.5-15.5 MW and in autumn by 11-16 MW in a district heating system with a connection load of 890 MW. A forecast of the outside temperature is obtained from the Finnish Meteorological Institute; the control staff can also amend the forecast on the basis of their own information.

Data on wind and cloudiness are applied in the forecast by means of the weighted values for the reference days. For weak and low quality explanatory variables, an adaptive and self-learning model based on error forecast has been developed. Solar radiation was taken into account in the choice of reference days.

Calibration of the flow meters

Flow meters are used to monitor and control significant flows of energy and material. Flow measurement in district heating determines the accuracy of the energy measurement almost entirely.

Eleven laboratories in Finland and two located elsewhere in Europe, where the flow meters were calibrated, took part in the comparison carried out during the research project. The measurement results were estimated on the basis of how much they deviated from the reference level. A deviation of less than 0.5% was considered a good result.

At three laboratories, the measurements results of the magnetic meter surpassed the limit mentioned above at all flow velocities. The deviation of one laboratory exceeded the limit at the highest volume flows. The results obtained with the turbine meter deviated from the reference level more than those obtained with the magnetic meter.

Heating cost allocation for individual apartments

The research programme determined how the heating energy costs of apartments could be allocated fairly in housing served by district heating. The

procedure is used on the Continent and Finnish building companies must include it in their export projects.

The most economical heat allocation equipment in terms of investment cost which operates on the evaporation principle does not function with sufficient accuracy in Finnish heating systems.

Accurate allocation of heating costs would require compensation for discrepancies caused by the location of apartments and consideration of heat transfers caused by the temperature differences between rooms. The expense of equipment of this kind is so great that its acquisition and use cannot be justified solely on the basis of the economies achieved through energy savings.

2.3 The economics of district heating

Determining the subscribed heating demand

Determining the subscribed heating demand of a building served by district heating with maximum fairness is of financial significance for both customers and suppliers of district heating.

The research programme developed a simple computer-based program to facilitate determination of a new customer's subscribed load and for checking the subscribed load against the heat energy consumption.

In practice, direct measurement of the subscribed load of a building is difficult, because the dimensioning outside temperature should be -26...-32°C. The subscribed demand can be checked by reading the building's invoicing meter, for example at intervals of two hours over a week during the heating season. The energy needed for hot tap water can be determined separately.

Pricing methods for district heating

Pricing is an essential factor for the profitability of a company in both the short and the long term. Low prices cause financial difficulties for the company in the short term, because the price does not cover the costs. High prices, however, may prevent new customers from joining the network and encourage existing customers to switch to another form of heating.

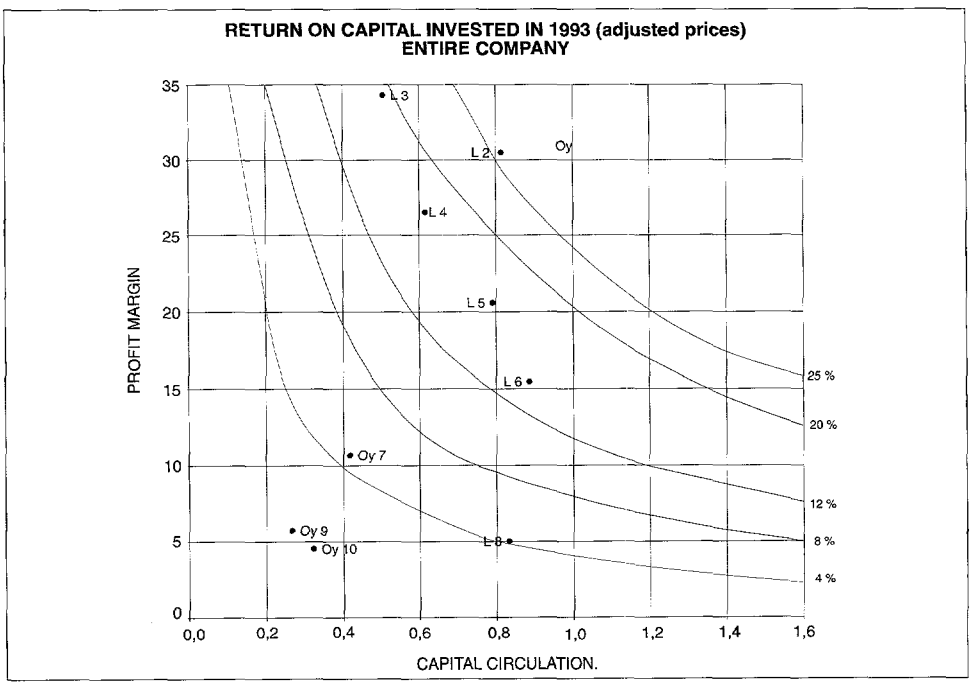

Figure 3. Return on capital invested and its component factors.

Determination of product-specific costs is the basis for a company's pricing decisions. In pricing, the operations of the company must represent a continuous process, so that the production resources needed to sustain operations can be acquired at the prices used in the calculations.

Many companies set prices either partially or entirely on the basis of costs. The most common cost-based pricing methods are cost pricing, contribution margin pricing and rate of return pricing.

Rate of return pricing is best suited to district heating. The method allocates all costs incurred to the product, including the return requirement on the capital tied up in the product. It is well suited for long-term pricing.

Success factors for energy companies

Corporate profitability can be measured with several different criteria, the most common of which are the gross margin percentage, operating margin percentage, profit percentage and ROI. In assessing profitability, different yardsticks can lead to different conclusions.

The price level significantly affects the return on capital invested. In a competitive market, companies have to price their products with respect to those of their competitors so that the ratio of price to quality is mutually competitive. The price level for a standard product is therefore rather even. On a competitive market, companies in general attempt to maximize their returns. In the energy business, some companies set low energy prices as their target, either instead of or alongside maximization of return.

Future prospects for district heating

Due to the high investment required by district heating, the pace of change and reform in the sector is slow. In most Finnish communities served by district heating, generation plants and networks already provide the extent economically profitable.

Further investment usually aims at optimization of production, securing heat distribution, improving the network controllability or replacement of existing facilities. These objectives obviously require less investment than did the building of the network in the 1970s and 1980s.

The specific heat consumption of buildings served by district heating has declined steadily since the oil crisis of 1973. This trend is expected to continue. The easiest savings have already been made and additional savings will require investment in conservation technology.

The research did not discover any factors that would threaten the position of district heating or the current low level of stable prices. There are no factors in the offing that would weaken the market for district heating. Flexible fuel choice is an obvious advantage of district heating.

New methods of energy generation such as gasification and fluidized bed combustion will replace conventional heating plants when they reach the end of their life cycles. New technologies will permit more environmentally sound use of low-grade fuels and the benefits of cogeneration will also be exploited. All new large-scale energy generation technologies allow cogeneration of heat and electricity.

The competitiveness of district heating, particularly in new building by small-scale customers, may decline. A solution to this problem must be sought by developing control and automation systems for heat exchange stations, and by using cheaper heat distribution technology.

2.4 System development

Changes in heat loads

New buildings and renovations of existing buildings may change the community district heating load.

The objective is to reduce the specific heat consumption of buildings by some 20% from the present level by 2005. Per capita living space will increase by approximately one-third by the year 2030. By 2040, the Finnish building stock will have increased by some 60% on the present figure. The present building stock will then have been completely replaced or renovated.

Modernization of the building stock and equipment technology may permit lowering of temperature levels in the district heating network, which would in turn reduce heat loss and increase the potential for back-pressure electricity generation.

In 2005, the heat consumption of renovated buildings will be 15% below today's level and in 2040 some 30% below that of a renovated building today.

Calculations showed that total district heating consumption will change only a little from 1994 to 2040. The specific consumption of energy and peak demand will decline, but growth in the building stock will require greater heating capacity.

The research examined optimization of generation capacity in an example company. In 1994, the optimum size of a base load power plant was 15/36 MW, but the cost difference between plants generating 4 MW more or less is very small. The optimum power plant size in 2040 would be 19/45 MW.

District cooling

Rising electricity prices and the ban on use of CFC compounds has put the designers of cooling equipment in a new situation. Alternatives must be found for the conventional refrigerants. No final alternatives have yet been found.

Absorption cooling is one such alternative. In the absorption process a mechanical compressor is replaced by a compressor running on thermal energy. Compression is based on the properties of the solution; steam is absorbed in a suitable liquid and the solution is pumped to a higher pressure. The work required is much less than that needed for the compression of steam.

The cooling process is based on a refrigerant and a solvent. Ammonia and water, which were widely used in the past, are not the best combination for an air-conditioning system. The biggest problem is due to the toxic nature of ammonia. Lithium bromide and water are used extensively. Water serves as the refrigerant and an aqueous solution of lithium bromide as the solvent. Problems are caused by significant underpressure and the powerful corrosive effect of the solution. Structures must be made of special alloy steel and be very tight.

The effects of temperatures on the properties of the absorption equipment are important for the use of district heating as a source of primary energy. Reducing the temperature of the outgoing water adequately poses problems. As the incoming temperature of the district heating water declines, the water flows increase and the heat ratio falls. The temperature of the outgoing district heating water must not fall below 65-70°C. In summer the incoming temperature is some 75-80°C, so the cooling effect can be only around ten degrees. The result is a large flow of water.

With respect to investment costs, the absorption equipment is more expensive than a compressor. With respect to operating costs, the absorption equipment is more economical only if the price of district heating is less than FIM 50-75/MWh. This research shows that today's absorption cooling equipment cannot compete with conventional compressor cooling at present energy prices.

3 Effectiveness of results

The district heating load forecasting system, the thermography method, and the cost-sharing method for cogeneration of heat and electricity are examples of the exportable products developed by the programme.

The projects in the research programme have been practical. Research topics have stemmed from the needs of district heating companies. In recent years, some of the research has been of a basic nature and some has aimed at the future.

Striking a balance between current questions and preparations for the future is a frequent problem in corporate-driven research programmes. The programme must also be directed towards balanced development of the entire district heating system.

The applicability of TERMO programme research has been good, and the results obtained have been put to work throughout district heating. The projects have made companies in the sector more competitive. District heating and cogeneration of heat and electricity have improved the quality of the Finnish environment, and this can be demonstrated by research.

4 Main results of the interim assessment

The research programme was organized so that the projects of most interest to companies were chosen for implementation. The programme brings research in the Finnish district heating sector together, and this facilitates coordination and use of resources.

Research has served the needs of companies in the sector in accordance with the interests of the funding companies. The role of industrial companies must be increased in the future and then operations can also be directed towards product development.

The main targets of the programme are correct. Advances in technology should be more important in the future, although overall development of district heating operations must be continued.

The coordination and cooperation in Finland are relatively effective. International cooperation requires increased emphasis. Problems related to language and financing hinder cooperation. Coordination becomes more difficult as internationalization increases.

Marketing and publicity in the programme have increased, but are still rather ineffective. Different target groups require different complementary approaches. Marketing can also encourage new users to join the programme.

5 Further planning based on the interim assessment

The funding procedure for the research programme guarantees that projects of interest to district heating companies are carried out. Research has been of an applied nature and has focused on solutions to practical problems. Some future-oriented projects were also included, and they have also included a practical view, basically technical and economic.

The priorities in the programme are on economy and sustainable development for district heating; they are based on analyses of research needs and on energy policy. The goals direct research towards solutions to key problems.

Research has focused on the interest of national heat suppliers. The district heating market in Finland, however, is too small for industry in the sector. During the final part of this programme or in the next programme there should be more stress on product development and export promotion. It must, however, be recalled, that the district heating system is an entity that also requires economic and administrative support systems. Establishment of a functioning entity on the export market is both the strength of Finnish companies and an opportunity for them.

The main objectives of the TERMO programme, economy and sustainable development, support the goals of national and also international energy technology. The goal of district heating remains the optimal use of energy; this has already been its greatest advantage. The system must be, however, subject to continuous development in order to become increasingly efficient and economical. The trend is the same throughout the world.

The role of product development and efforts to this end can be increased. In this respect, encouragement of industrial companies to participate is crucial.

International coordination has been achieved primarily by participating in the work of the IEA district heating programme and the energy research programme of the Nordic Council of Ministers. Fairly effective monitoring of international research has been possible thorough these channels.

Information on the programme has been more widely available than in the previous period (1988-1993). Results have been presented regularly at sessions arranged by the Finnish District Heating Association. A review of progress in the programme is compiled and published twice a year. A seminar for researchers is held annually. Information still does not reach all those interested.

Sessions arranged by the Finnish District Heating Association have proved an efficient means of disseminating information. Information reaches members of the organization through these sessions, but not all parties in the sector. Researchers obtain information mainly at the programme's annual seminars.

The principal advantages of district heating could be emphasized more in marketing the research. District heating is not perceived as a high technology product, which would be of general interest. Information reaches a narrow group, mainly in the energy sector.

Research institutes should seek closer co-operation with heat suppliers and industrial companies. Companies would also be the source of competent experts who could implement the projects or parts of them. Some companies could also include research among their operations. This would provide additional resources for research.

6 Research organization and Executive Committees

The TERMO programme has been coordinated by the Finnish District Heating Association. The nature of the programme and its goals are set and monitored by the Executive Committee. Research proposals come from the research organizations on the basis of master plans and requests for tenders from the Executive Committee.

The Executive Committee comprises the following individuals:

- Ilkka Pirvola, Helsinki Energy (chairman)
- Heimo Hiidenpalo, Helsinki Energy, (chairman)
- Professor Lasse Koskelainen, Helsinki University of Technology
- Heikki Kotila, Tekes
- Veli-Matti Mäkelä, Lappeenranta Energy
- Arto Nuorkivi, Energia-Ekono Oy
- Markku Salminen, Suomen Talokeskus Oy
- Kari Sipilä, VTT Energy

Each project has its own project group, including representatives from each source of funding. This method has developed a direct connection between researchers and research.

The projects to be implemented will be chosen in two stages; the first elimination will be made by the Finnish District Heating Association and the final one by the funding organizations in their funding decisions. TEKES funding will be sought for projects that obtain sufficient funding of their own.

The funding procedure screens the applications to find those of most interest to companies. The funding companies take an active part in implementing projects and supervising the work. This procedure provides the greatest potential for benefiting from the results. The arrangement provides an incentive to researchers to be in contact with funding/benefiting companies, because their support decides whether the projects are implemented.

Responsibility for corporate funding rests almost entirely with the companies supplying district heating. The role of industrial companies has been small. Consultancies that have provided significant financing for their own projects are an exception.

International Energy Agency (IEA) ENERGY TECHNOLOGY COLLABORATION	LIEKKI 2	BIOENER	NEMO 2	FFUSION	SIHTI 2	MOBILE	SULA 2	SUSTAIN	RAKET	EDISON	TERMO
Buildings and community systems			x						xx		x
Energy Storage											
High-temperature Superconductivity in Electric Power Sector			xx								
Energy Technology Data Exchange (ETDE)	x	x	x	x	x	x	x	x	x	x	x
Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET)	x	xx	xx				x		xx	x	x
Advanced Energy Efficient Technologies for the Pulp and Paper Industry	xx				x			x			
Process Integration Technologies											
District Heating and Cooling									x		xx
Alternative Motor Fuels Agreement						xx					
Co-operation on Technologies and Programmes for Demand-Side Management										xx	
Bioenergy	x	xx									
Hydropower Technologies and Programmes											
Solar Heating and Cooling			xx								
Photovoltaic Power Systems			xx								
Wind Turbine Systems			xx								
Coal Research Information	xx										
A Cooperative Program on Technologies Relating to Greenhouse Gases Derived from Fossil Fuel Use	xx										
Fluidized Bed Conversion of Fuels Applied to Clean Energy Production	xx										
Programme on Research, Development and Demonstration of Coal Combustion Sciences	xx										
NORDIC ENERGY RESEARCH											
Bioenergy processes - photosynthesis		x									
Fuel cells			xx								
Energy and society											
Solid fuel	xx				xx						
District heating											x
Petroleum technology											
Process integration											
EU ENERGY RESEARCH PROGRAMMES											
ALTENER		x									
JOULE	xx	xx	xx		xx	xx		x	xx		
THERMIE	xx	x						x	xx		
BRITE-EURAM											
FAIR	x	x									
FUSION 12				xx							
OTHER INTERNATIONAL COOPERATION											
Intergovernmental Panel of Climate Change					xx						
++ permanent project cooperation and/or funding from the programme											
+ cooperation through exchange of reports, etc.											

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