
Rapport SGC 052

**NORDIC GAS TECHNOLOGY
R&D WORKSHOP
APRIL 20, 1994**

Editor
Jörgen Thunell
Swedish Center of Gas Technology

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Preface

The Swedish Center of Gas Technology (Svenskt Gastekniskt Center, SGC) arranged April 20, 1994 a workshop with presentations of gas research and development activities within the Nordic countries and within Germany. The workshop was a follow up of similar workshops being arranged by the former Nordic Gas Technology Center (NGC).

After completion of the workshop Neste Gas declared that they were willing to arrange a similar workshop in 1995. The date was proposed to be April 25, 1995 in Espoo, Finland with a possibility to make a study trip the following day. Neste Gas will announce the workshop early next year.

SGC wants to thank all the speakers for their presentations and also for their written contributions which made it possible to publish these "proceedings" from the workshop.

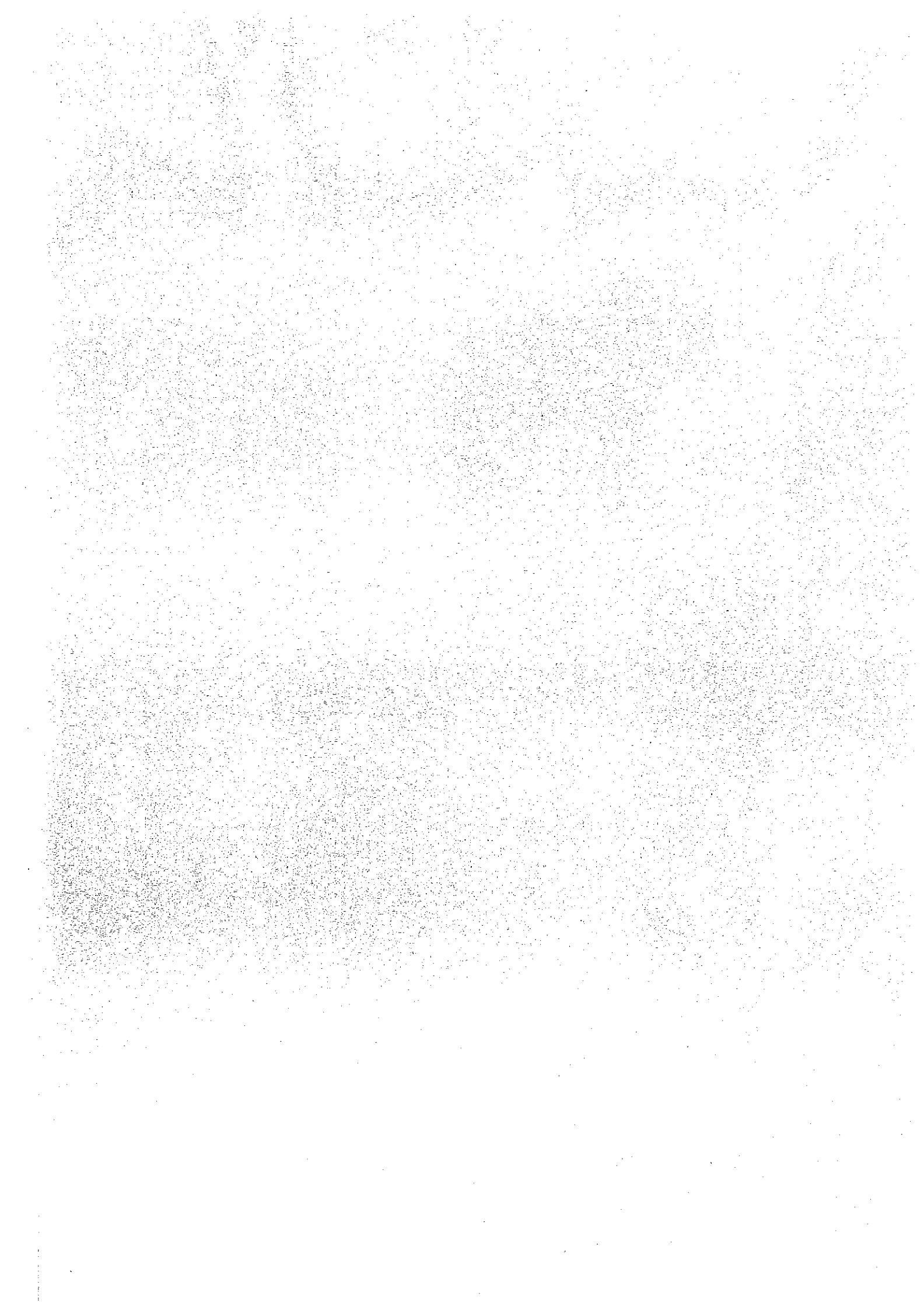
Malmö in June 1994

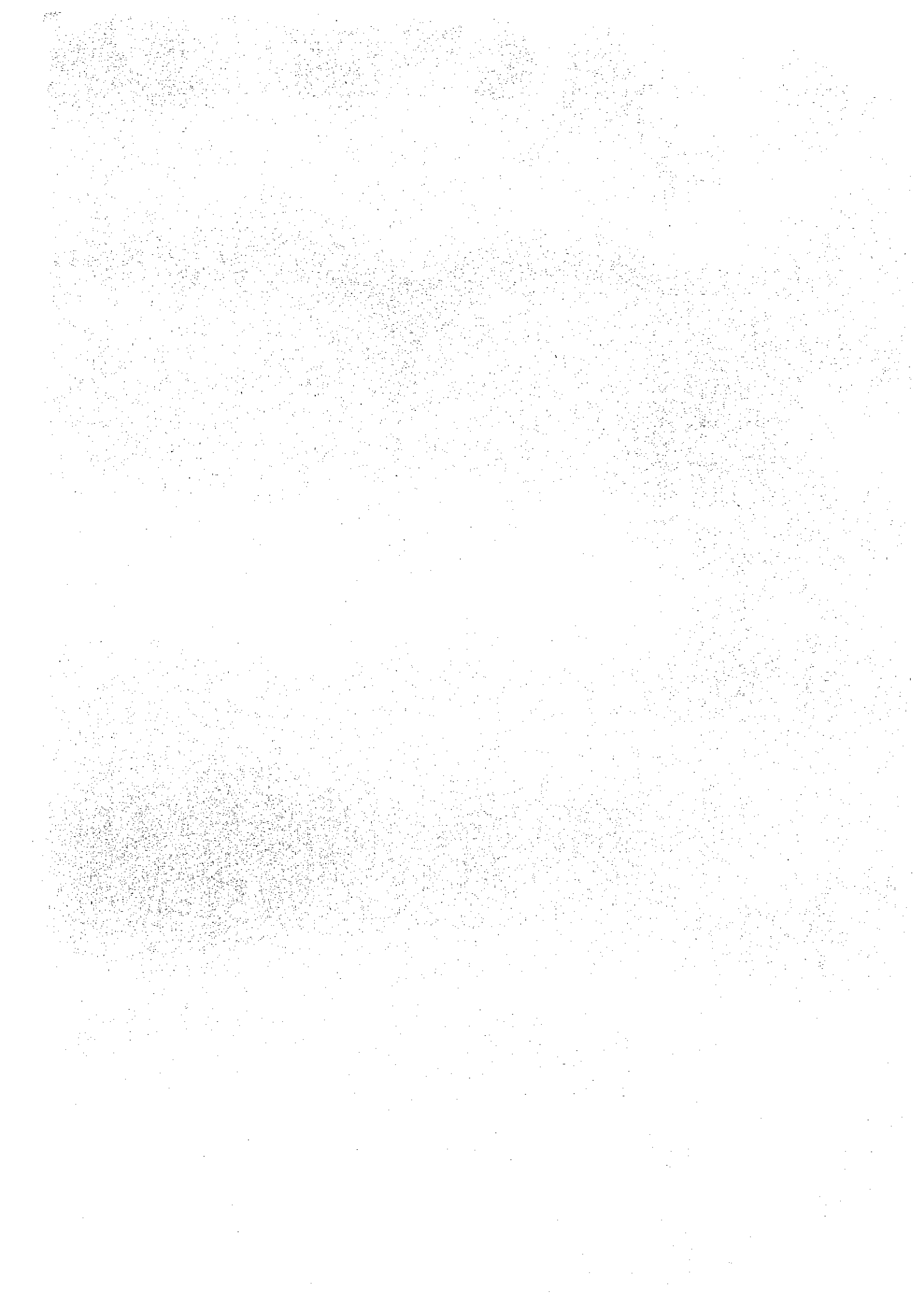
Jörgen Thunell



Content

Introduction	Jörgen Thunell Svenskt Gastekniskt Center AB
Technical Developments in the German Gas Industry. State of the Art and Outlook	Ernst Singelmann and Jan Thomsen, Ruhrgas AG
NGC Activities During 1993	Ingemar Gunnarsson, Energi-Analys AB
Danish Gas Technology Centre a/s 1993-1994	Peter I Hinstrup Dansk Gastekniskt Center a/s
Gas Technology R&D within Finland	Pekka Särkkä Neste Oy Natural Gas
Gas Technology R&D within Norway	Asle Lygre The Research Council of Norway
Gas Technology R&D within Sweden	Per-Arne Persson Svenskt Gastekniskt Center AB
Hydrogen - a Gas Fuel for the Future Energy System?	Ola Gröndalen Sydkraft Konsult AB
Concluding Remarks	Jörgen Thunell





Introduction

Jörgen Thunell

Svenskt Gastekniskt Center AB



INTRODUCTION

by Jörgen Thunell

Good Morning. I would like to wish all of you very welcome to this Nordic Workshop about research, development and demonstration within the natural gas technology sector. These workshops were initiated by the Nordic Gas Technology Center and they arranged five such workshops before the Center was closed down in December 1993. At the last NGC workshop we at SGC promised to arrange the next one in 1994 and as a consequence of that we are here together today.

As far as I can understand the Nordic gas industry is going on as usual since the workshop in 1993. Denmark has still some gas left and is exporting as well as consuming gas within the country. Norway is contracting more and more gas but still not distributing gas in a commercial meaning within the country. Finland is only a gas consumer but has now a closer cooperation with the gas supplier. Sweden has about the same gas network as last year and a gas line between Norway and Finland through Sweden is still at a very preliminary discussion stage. A new end user application in Sweden is natural gas vehicles. About 40 natural gas buses are now operating and a project involving 50 gas driven trucks is on the way.

As I mentioned earlier and as you all know the NGC-cooperation terminated last year. A question linked to this is: Is there no natural base for Nordic cooperation or, if there is a base, was the cooperation not organized in the right way? I don't have the answers, but I should like to give you some comments to it.

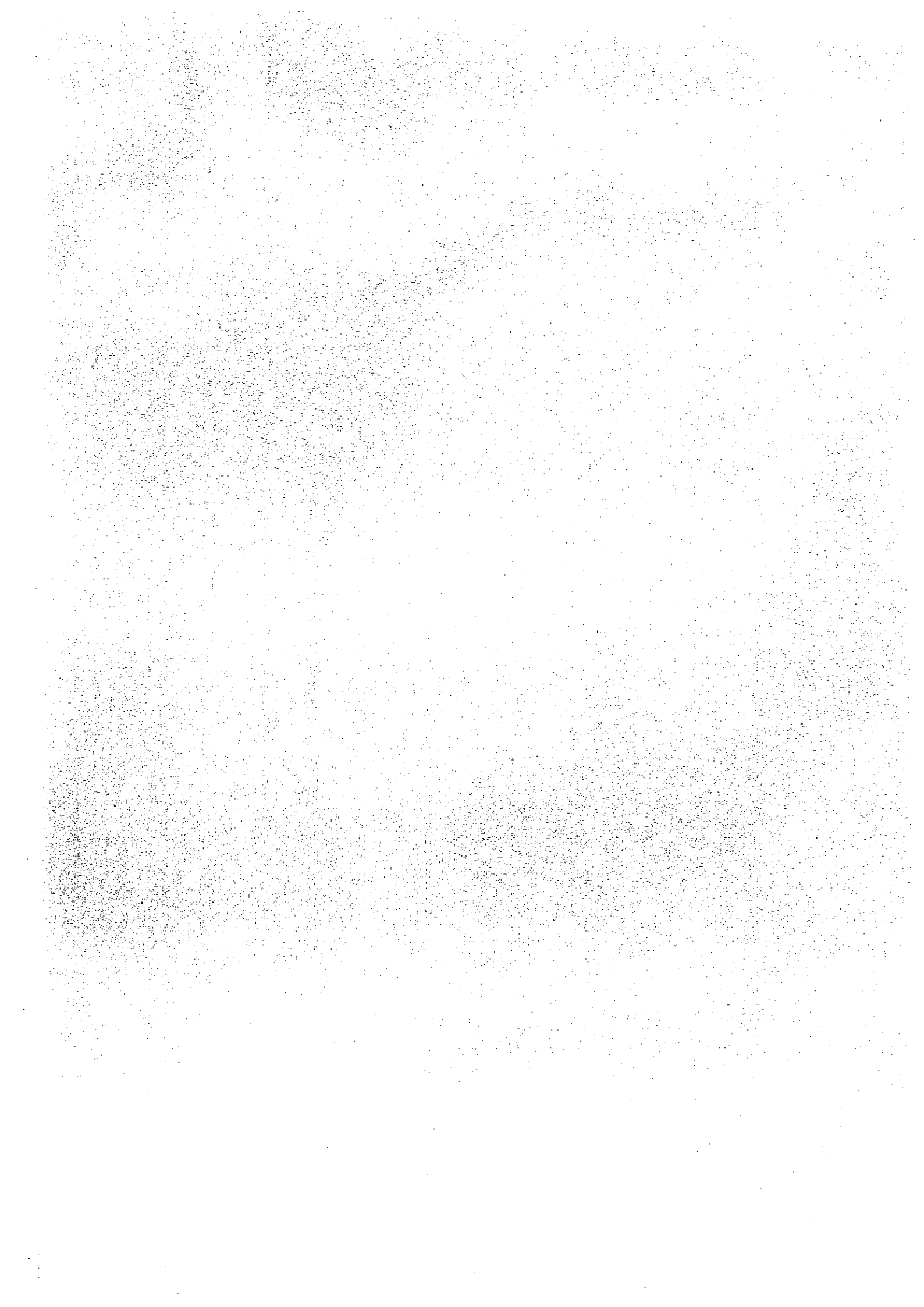
There are differences in the "natural gas profile" between the Nordic countries. Norway, for instance, has not much gas utilization of the kind that was emphasised by NGC. Denmark has that kind of utilization but due to Denmark's membership in the European Community (Union) the country is perhaps more oriented to the south than to the north when it comes to R&D cooperation. Finnish gas goes mainly to "heavy customers" such as power plants and paper mills while the gas in Sweden is supplied to many kinds of end users. This could be one of the reasons for the absence of a natural "suction" for common Nordic R&D projects.

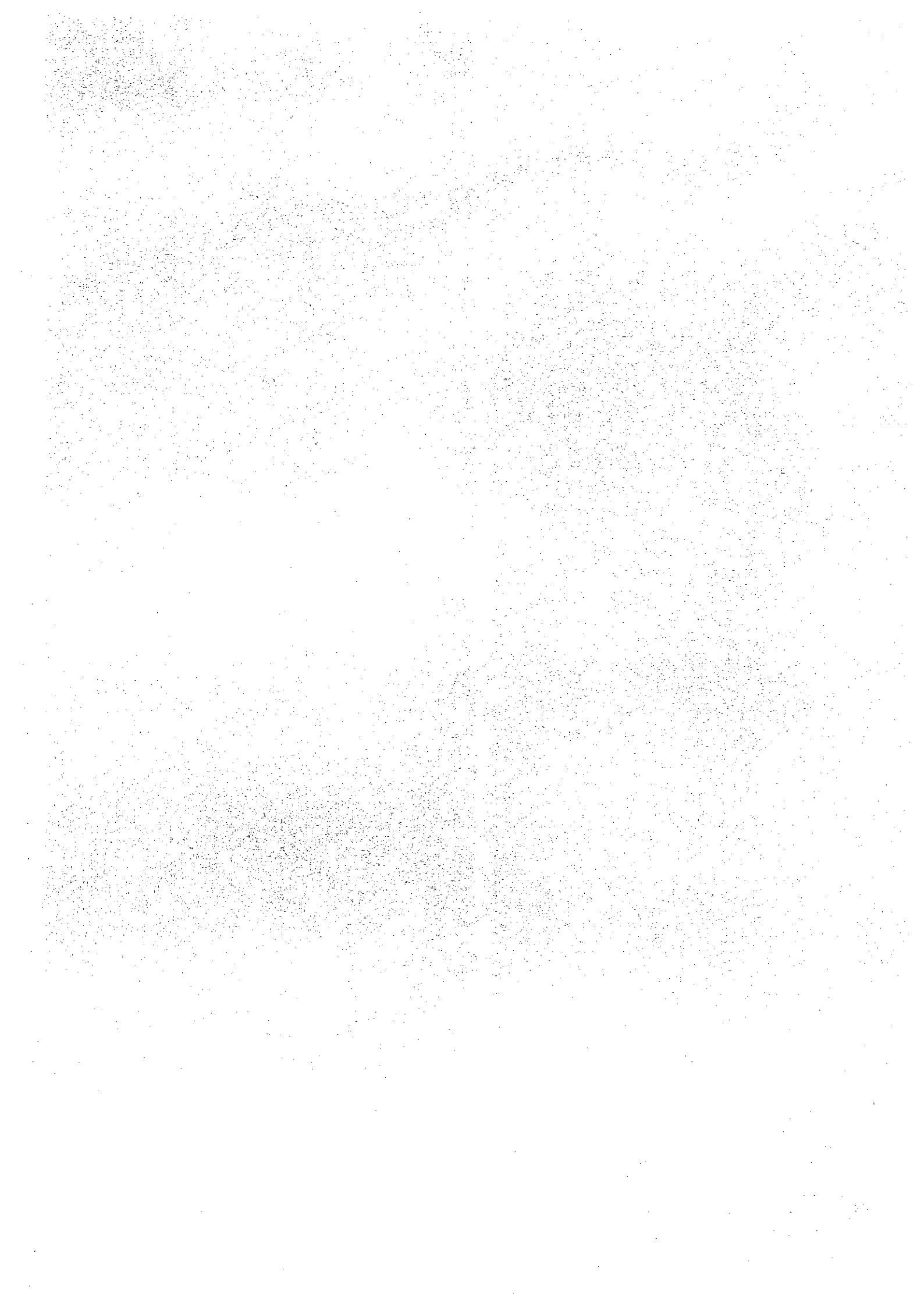
Therefore, it is my opinion that we for the time being should not try to replace NGC by some new organisation for Nordic gas R&D cooperation. I think that we should keep in contact with each other and, like for instance here today, present ongoing projects and plans for new projects. If then two or more countries are planning for the same kind of projects, let us then discuss if we could coordinate our efforts to realize these projects. I am sure that such a form for cooperation easily could be handled by the existing organisations like SGC in Sweden and DGC in Denmark and by existing companies like Statoil in Norway and Neste in Finland.

Now, let me turn back to the event of this day . One of the reasons for having English as the common language today is that we have a guest speaker from Germany, dr Jan Thomsen from Ruhrgas, and we think it is of value for the international exchange of information that dr Thomsen could follow all our presentations here today. Another reason is that if a workshop is in English, the documentation will automatically also be in English and we will use this documentation for international exchange of information also. Finally it is so that it sometimes could be difficult for Nordic participants to understand each other's languages. We have for instance noticed that Swedes living north of Malmö sometimes have difficulties in understanding Danish.

However, if somebody likes to put a question or to take part in the discussion in his or her own language, please feel free to do so!

I now give the floor to dr Jan Thomsen.





**Technical Developments in the German Gas Industry
- State of the Art and Outlook -**

by

**Dr. Ernst Singelmann
Dr. Jan Thomsen
Ruhrgas AG, Essen**

**Nordic Gas Technology R&D Workshop
Malmö, 20 April 1994**

**Technical Developments in the German Gas Industry
- State of the Art and Outlook -**

- 1. Introduction**
- 2. Reserves/Resources and Their Availability to Western Europe**
- 3. Gas Transmission and Distribution**
- 4. Gas Utilisation**
- 5. Environmental Trends and Perspectives**
- 6. Conclusion**

Technical Developments in the German Gas Industry - State of the Art and Outlook -

1. Introduction

In recent years, the international energy scene has changed considerably. In the past, natural gas played only a subordinate role, merely being obtained as by-product of oil production and even being flared (this still occurs in some countries). Today, natural gas is a highly important economic factor for many countries.

In Germany, the gas industry has to cope with a 3-way pull:

- the procurement situation, i.e. making gas available and supplying it;
- the market and customer demand, i.e. technological and service requirements;
- the legal framework in the shape of legislation and environmental regulations.

This gives rise to challenges for the gas industry that can be summed up as follows:

- environmental protection,
- reduction of costs,
- greenhouse effect,
- deregulation and third-party access,
- rival energies,
- new technology,
- diversification of resources,
- security of supply,
- CO₂ tax, energy taxes, etc.

New situations and circumstances call for adjustment to the changed environment. This should not consist in merely reacting but in identifying possible situations and scenarios well in advance.

How can these changes and challenges be handled? The aim of this paper is to show the role played by R&D in the instruments employed by the German gas industry in the past, present and future.

As the path of gas from the source to the final consumer covers much ground not only geographically but also technologically, it is not possible to deal with all areas. Instead, this paper will be confined to the following, placing special emphasis on the criteria of cost-effectiveness and environmental protection:

- supply situation (reserves, resources, availability)
- gas transmission and distribution (pipeline transmission, rehabilitation techniques, soil surveying)
- gas utilisation:
 - residential use
 - industrial domain
 - power generation
 - transport sector

2. Reserves/Resources and Their Availability to Western Europe

Today gas accounts for about a quarter of primary energy consumption worldwide, and almost a quarter of that amount is moved across national borders by pipelines and LNG tankers. This mobility is largely due to the successful endeavours of technicians and R&D staff. Thanks to the technological progress made in exploration, production and transmission, we are now able to discover more sources than ever before with a high degree of probability, to obtain gas cost-effectively from ever greater depths and to transport ever larger quantities over greater distances. Without the advances made in transmission technology, it would not be possible to transport Siberian gas over 6,000 km.

Proven recoverable reserves now total some 142 trillion m³ which means - assuming constant consumption - a static lifetime roughly up to the year 2060 (Fig. 1). Additional resources amount to roughly 191 trillion m³. In sum, these are the conventional natural gas resources, which have a lifetime of about 160 years. Overall resources are far larger if one includes sources that can be developed by unconventional means. Of the world's regions displaying the geological prerequisites for gas discoveries, only a part has been examined by exploratory wells. It can therefore be assumed that in future, too, the static lifetime of natural gas reserves will increase faster than consumption. In both the onshore and offshore sectors, new fields are likely to be discovered on a large scale. Some examples of technological developments that give cause for such optimism are cited below.

The use of geophysical methods, notably the seismic reflection technique, in conjunction with graphic computer-aided analysis programs has in recent years considerably increased the success rate of exploratory drilling. In the past, only one in every 10 or 15 wells drilled struck gas, but today this is achieved by one in every three or five wells. The technology of drilling and well treatment is also making remarkable advances. The main aim is to raise the gas recovery rate; this can be achieved by either the familiar fracturing technique or by means of side-tracked wells (Fig. 2).

While a 45° deviation from the vertical has long been the state of the art, deviation amounting to horizontal drilling in the reservoir is now possible. This allows the gas recovery rate to be increased many times over. Experts predict that by the year 2000 one half of all reservoir drilling will take the form of horizontal wells.

Offshore gas and oil production is also constantly gaining importance. Over half of the world's sedimentary rocks that may contain hydrocarbons are located below seas or oceans. Production platforms are being placed in increasingly deep water (Fig. 3).

Gas production in the Troll field with a water depth of about 400 m will start in late 1995. In the Gulf of Mexico, platforms have been installed in even deeper water. For example, Conoco has set up a so-called tension-leg platform in water having a depth of some 600 m; this floating platform is secured to the seabed by hawsers. This technology opens up completely new prospects for offshore gas production.

Returning to the huge potential of unconventional gas reserves mentioned earlier on (Fig. 4), these include, among others,

- gas from tight sand formations as well as aquifers and reservoirs at great depth, whose exploitation has partly been tested but which is still uneconomical;
- gas hydrates, which are solid snow-like combinations of gas and water that are stable under high pressure, even at temperatures of 20 °C. Huge reservoirs are located in Siberia and Alaska and though the potential is enormous, amounting to many hundred thousand billion cubic metres of gas, suitable production techniques are not yet available;
- last but not least, gas from coal seams which formed during the coalification process and adsorbed in the microstructure. Familiar as mine drainage gas, it is now internationally referred to as coalbed methane (CBM). Depending on the coal seam, a tonne of coal may contain between 5 and 30 m³ of CBM, over 90 % of which is methane. The technique of CBM recovery, including drilling, fracturing and water removal, has been refined during the last 10 years especially in the United States. There, no less than 9 billion m³ of CBM were produced in 1991, which is equivalent to about 60 % of Germany's overall indigenous gas production.

Together with other partners, Ruhrgas is endeavouring to develop such a reservoir in an area north-east of the Ruhr region. If the reservoir lives up to expectations, an annual production rate of 2 - 3 billion m³ is feasible.

For this purpose, wells are drilled into the coal seams. With a special fracturing technique, gas escapes from the seam and reaches the ground surface via risers for collection, processing and feeding into the normal distribution grid.

Leaving the subject of gas reserves and resources, a few aspects of gas transmission and distribution as the main link to the gas consumer will now be discussed.

3. Gas Transmission and Distribution

Although western Europe is closer than the two other consumption centres, namely the United States and Japan, to the regions from which additional gas could be obtained, a large distance nonetheless generally lies between the source and the consumer (Fig. 5).

But in this case, too, technical advances have laid the basis for transporting gas safely, reliably and economically over large distances to the consumption centres.

With the technology available in 1965, a gas transmission system from western Siberia to central Europe would have been highly uneconomical. Fuel gas consumption and transmission capacity in those days would have ruled out such a project.

The economical production and laying of large-diameter high-pressure pipelines over large distances did not become possible until about 1970, when thermo-mechanically treated high-strength steels began to be used. This allowed significant increases in transmission capacity and a substantial decrease in specific fuel gas consumption at compressor stations (Fig. 6). Since then a greatly improved steel, known as X80, has been developed which allows an up to 15 % higher pressure for the same wall thickness or a corresponding reduction in wall thickness and weight if the pressure remains the same. Ruhrgas is the first company in the world to use this steel on a 270 km pipeline section between North Rhine-Westphalia and Hesse.

Gas distribution to the final consumer, which occurs at relatively low pressures, is a very cost-intensive link in the gas transmission chain. Most R&D efforts are therefore aimed at reducing costs in this respect.

About 130,000 km of the 200,000 km gas distribution pipelines in Germany are made of steel. About half of them were laid at a time when there was no long-lasting corrosion protection by polyethylene coatings. These pipelines are now reaching an age where they will have to be rehabilitated in the medium term.

There are a number of high-quality techniques for distribution mains renewal involving PE pipes inserted into the existing lines. The swagelining technique was originally developed for grey cast iron pipes but is increasingly being used for steel pipelines in Germany.

Under the refurbishment programme, all existing service pipes must be connected to the new internal PE pipe.

Connecting new service lines to distribution mains after rehabilitation is more difficult as this involves removing the top half of the old pipe at the tie-in point and care must be taken not to cause mechanical or thermal damage to the PE pipe inside. For this work, "diga rohrtechnik gmbh", a subsidiary of Ruhrgas, has developed a machine based on a simple principle: along the circumference line of the piece of pipe to be removed (top half of a pipe section) a groove is cut into the pipe wall, reducing the thickness to about 0.5 mm. The cut-out can then be removed. For this purpose, use is made of a hydraulic removal device, whose claws fit exactly into the longitudinal grooves.

Free passage through the pipe to be rehabilitated is indispensable so that the new PE pipe can be introduced into the old pipeline without damage, can be installed without folds and attain maximum service life. Unfortunately, pipelines to be rehabilitated are not always free of internal projections. Quite often weld beads protrude inwards or connecting pieces welded in earlier decades are in the way. Moreover, some steel pipes were subjected to excessive mechanical strain during laying that they have dents. These inner protrusions impede the introduction of the new PE pipe and have to be removed. A very expensive solution is to unearth the pipe at the points where obstacles are detected by internal inspection. Together with digma, Ruhrgas developed a low-cost alternative in the form of two machines for treating the pipeline interior without excavation.

One of the machines is able to grind off internal protrusions, while the other can repair dents. Both can travel up to 100 m into the pipeline; their location and operation are observed and controlled with the aid of a monitor.

Another method of reducing the high costs connected with gas distribution is to improve ground-probing for construction work on underground pipes. Ground-probing radar technology makes it possible to locate underground objects, such as stones and metallic or non-metallic pipelines. It is until now the only method for locating polyethylene pipes. Although ground-probing radar technology is not new and is handled by a number of companies world-wide, a breakthrough has not been achieved yet because its efficiency depends greatly on the type of soil and because the results can only be interpreted by experts: radargrams show clear anomalies, but precise evaluation is not easy.

Improving the efficiency of this technology offers considerable potential and is therefore the point of departure for our R&D efforts. The reduction of equipment costs and expenditure on evaluation of results is an objective that will be pursued later.

Some developments illustrating the contribution that can be made by R&D in the field of gas utilisation will now be described.

4. Gas Utilisation

Thanks to its excellent physical properties, natural gas has a very positive image among large sections of the population, but it must be able to compete on the market with other energies. Key factors are long-term availability, cost-effectiveness and user-friendliness.

In some areas of application, stiff price competition exists with oil and coal, but these energies suffer from their adverse environmental impact. The electricity industry also tries to exploit this aspect, arguing that electricity does not cause any emissions. They omit to mention that, though not at the point of use, high emissions occur at power stations where the electricity is generated. Nonetheless, electricity is becoming the main rival in many fields.

This calls for an effective R&D strategy enabling the gas industry to maintain its existing positions and penetrate new sectors by means of the following:

- reduction of pollutant emissions through advanced burner technology;
- development of appliances and equipment with high efficiency, thus not only lowering operating costs but also reducing carbon dioxide emissions;
- reduction of costs, while simultaneously achieving high flexibility, availability and user-friendliness.

These objectives basically apply to all areas of gas utilisation, but they may carry different weight in the industrial, residential or commercial sector.

What has to be done? Below are some examples showing how to respond to changes and challenges in the gas industry with the aid of R&D activities. The examples chosen are:

- a) future use of natural gas in well-insulated buildings,
- b) natural gas for high-temperature processes,
- c) natural gas for power generation,
- d) natural gas in the transport sector.

a) **Future use of natural gas in well-insulated buildings**

Despite moderate energy prices in Germany, the Thermal Insulation Regulation is being amended to attain - according to the Building Ministry - about 30 % heating energy conservation compared with the current 1982 regulation. A new aspect of the amended regulation, which is likely to come into force in 1995, is the determination of a maximum allowable heating requirement per square metre of living space as a function of the surface/volume ratio of the building.

Fig. 7 compares the specific heating requirements of existing buildings with the values anticipated for 1995. Heating requirements are likely to decrease by more than 50 %. With specific heat demand between 54 kWh/m² a year (large blocks of flats) and 100 kWh/m² a year (detached houses), such buildings can rightly be described as low-energy buildings.

To round off the picture, the graph also shows specific heat demand for extremely low-energy buildings, which is below 40 kWh/m² a year. For such buildings, however, the heating costs saved are out of proportion to the extremely high additional spending on thermal insulation.

What implications does this development have for the use of gas in new buildings?

For various types of building we have - on the basis of the new Thermal Insulation Regulation - estimated the annual gas consumption for space heating and hot water production. In 1995, a new detached house (140 m², 4 persons) will need only about 2,100 m³ of gas, including 1,600 m³ for space heating. The estimated 500 m³ for hot water production is about a quarter of overall gas consumption.

In the second example of a small terraced house with some 100 m² living area (4 persons), gas consumption will merely amount to 1,300 m³ a year (space heating 850 m³, hot water 450 m³). As gas consumption for hot water production will drop only slightly due to almost unchanged consumption patterns, the share of gas for hot water production will rise to about 30 %.

(Merely in passing it should be mentioned that a future apartment for a single person in a large block of flats, whose total gas consumption will amount to some 350 m³ a year (space heating 250 m³, hot water 100 m³), will no longer allow cost-effective individual gas supply.)

An analysis of the anticipated heat demand for space heating yields some interesting insights:

On the coldest day, the detached house (140 m²) will only need 8 kW for space heating, and the small terraced house (100 m²) merely 5 kW. The single-person apartment (40 m²) as an extreme example will require only 2 kW. This corresponds to the capacity of an electric fan heater which is available in Germany nowadays at a price of DM 50.

What conclusions have to be drawn? Several predictions can be ventured:

- The share of individual gas-fired heating systems in flats built after 1995 will decrease significantly and be replaced by central heating serving numerous flats.
- The cost-effectiveness of individual service connections to terraced houses, too, will in future become increasingly doubtful for both the gas utility and the consumer.
- Hot water production will only be economical if combined with hot water storage tanks and space heating.

- Group heating will gain importance in housing estates.
- The power-generating industry will step up its efforts to penetrate the heating market.

Gas suppliers and gas appliance manufacturers must meet these new challenges. In so doing, they can consistently use the opportunities arising from decreasing heating capacity requirements. What are those opportunities?

- There are no oil burners for heating capacity requirements below 10 kW.
- The specific cost of an oil tank rises with decreasing consumption; in other words, a 3,000 litre oil tank is hardly cheaper than a 5,000 litre tank.
- Space heating using electricity is not politically encouraged in Germany and runs counter to the efforts aimed at reducing CO₂ emissions.

These are three clear advantages for natural gas.

The opportunities can be fully exploited only if we succeed in consistently tapping all means of cost reduction. Present consumers and, even more so, our future customers will opt for gas only if the fixed costs of gas service connections and appliances are in a reasonable and economically viable proportion to the decreasing gas consumption.

Where can cost reductions be sought with the aid of R&D?

Possibilities of cost reduction exist in three fields:

1. Service connections and in-house installations:

Use can be made of new low-cost laying techniques (trenchless laying and simplified establishment of subsequent connections) and new installation methods.

2. Refinement of heat generators:

Systematic adaptation of heat generators to the lower heating capacity requirements results in novel concepts entailing reduced capital expenditure. Prototypes are currently being developed.

3. Simplified flue design:

The existing philosophy that a flue must withstand temperatures of more than 900 °C now appears outdated in view of modern gas appliances. The flue gas of a modern low-temperature boiler has a temperature of roughly 60 °C. There is no sound reason why flue gas removal still accounts for some 20 % of the overall cost of a gas heating system. Cost reduction opportunities are afforded by smaller pipe diameters and lower pollutant concentrations.

Solutions have been developed, for instance on the basis of plastic pipes, but their implementation is still difficult and protracted.

Apart from lowering fixed costs, there is a second set of measures for consolidating the position of gas in the residential sector: measures designed to open up new areas for gas.

A few examples are:

- increased connection of dishwashers and washing machines to the central hot water supply;
- air conditioning in large dwellings for the purpose of more comfortable living conditions;
- growing use of tumble dryers due to their greater convenience.

Sales of electric tumble dryers have surged at a breath-taking pace. Today, some six million homes in Germany have such dryers, and their expansion is undiminished. Gas tumble dryers for households are not available on the German market, but their commercialisation has started in Britain and wide-based field tests are already under way in the Netherlands. In Germany, a prototype is being developed by a noted appliance manufacturer, with Ruhrgas participating.

Summing up, it can be stated that the amended German Thermal Insulation Regulation will have a considerable impact on the use of gas in new buildings. Given the opportunities just outlined, gas will - with the aid of new technical concepts - surely remain the most attractive energy for home-owners.

Unfortunately, it is not possible here to deal with the numerous other R&D activities pertaining to the use of gas in the residential sector.

Developments in the industrial sector can likewise not be discussed in detail here. Merely the use of gas for high-temperature processes will therefore be treated.

b) Natural gas for high-temperature processes

In Germany, the use of fossil energies in the industrial sector has dropped by more than 20 % over the last 20 years, despite a 30 % rise in industrial output, whereas electricity consumption has gone up by roughly 50 %. These changes were caused, on the one hand, by rational energy use and the introduction of low-energy production techniques and, on the other, by automation and structural transformation of industrial production. This structural change is generally conducive to industries and products with a relatively low specific heating requirement. Despite this unfavourable setting, the use of gas in the industrial sector has increased. Considerable efforts are being made by the gas industry worldwide to develop gas-saving and environmentally friendly combustion equipment, with increasing importance attaching to integration into automated production cycles. Furthermore, more stringent environmental regulations have resulted in a preference for natural gas and also for electricity because these energies make it possible to dispense with costly waste gas treatment facilities. Against the background of this competition between gas and electricity, developments were promoted, such as radiant tubes, recuperative burners, vacuum furnaces and infrared radiant heaters for surface drying, which enable gas to penetrate market sectors that were hitherto electricity's preserves, for instance high-temperature processes.

Two examples from Ruhrgas's laboratories are described below.

Fig. 8 shows a low-NO_x high-velocity burner available in either metallic or fully ceramic design. The ceramic design permits air preheating temperatures up to 600 °C and is suitable for furnace temperatures up to 1,400 °C. Even under such heavy-duty conditions, the NO_x emissions are lower than 500 mg/m³ of flue gas.

Another important technical innovation in the high-temperature sector is the ceramic radiant tube. It is used for indirect heating and thus competes with electric heaters. As the products of combustion do not come into contact with the charge, this development is suitable for a whole number of processes, for example heat treatment in a controlled atmosphere as well as the melting of metals, e.g. zinc and aluminium. Compared with conventional heating, this allows the heat transfer to be improved, metal oxidation reduced, and spending on environmental protection measures reduced as the waste gas does not contain any pollutants from the process.

For the development of this concept we made use of numerical flow simulation in order to optimise various design parameters, such as the distance between the ceramic inner tube and the burner port. In this way, the right amount of waste gas is recirculated and the NO_x emissions are, despite high process temperatures, brought below the limit of 500 mg/m^3 stipulated by the Clean Air Code. For traditional process temperatures of about $1,000 \text{ }^\circ\text{C}$, the NO_x emission limit can easily be observed, but in the case of process temperatures of $1,250 \text{ }^\circ\text{C}$ we have not quite attained our development target, as the NO_x emissions are still roughly 750 mg/m^3 .

c) Natural gas for power generation

This is another market sector in which changes are emerging. In some western European countries, for instance Italy and Britain, a clear trend towards increasing use of gas is discernible. But this trend is not directly transferable to other countries in Europe, such as Germany. Unlike other countries in western Europe, Germany has a balanced mix of nuclear energy and electricity from hard coal or lignite to meet the base load. Increased use of gas for general power generation in Germany is restricted not only by political arguments but also by economic factors because gas used in the power-generation sector is liable to a tax that currently accounts for over 20 % of the gas import price. Gas is instead likely to gain a greater share in cogeneration, whether centralised or localised.

The advantages of localised, i.e. point-of-use, cogeneration are:

- large energy conservation potential,
- low total emissions and
- high plant efficiency.

The electrical efficiency of various cogeneration technologies is shown in Fig. 9a/9b.

Modern combined cycle power plants with ratings of up to 1,000 MW already have electrical efficiencies of up to 54 %. They are therefore predestined for pure electricity generation. At lower ratings, gas turbines and gas engines are suitable; their electrical efficiency has in recent years likewise been considerably increased.

Depending on the return temperature of the heating system in cogeneration plants, the overall efficiency (electrical and thermal) lies between 80 and 90 % in the case of engines and between 75 and 80 % in the case of gas turbines.

Due to these benefits, the market trend for cogeneration plants has been very positive. At present, over 130 gas turbines and more than 3,000 gas engines are in operation in Germany alone, with an overall capacity of 2,400 MW.

The wide acceptance of gas engine-driven cogeneration systems is due not only to the high overall efficiency and low emission levels but also to improved cost-effectiveness and operational reliability. As various types of natural gas are used in Germany, engines are usually dedicated. Within certain limits as regards gross calorific value and Wobbe index, gas utilities are, however, able to add LPG/air mixtures, which they do particularly at times of peak load. This changes the knock resistance of the fuel gas, which may in extreme situations even cause considerable engine damage.

To ensure optimum operational reliability of engines even at times of highly fluctuating gas composition, we have developed together with a research institute an electronic control unit that allows the ignition timing, engine load or air ratio to be adapted to the respective gas properties. As an indication of the gas properties we measure the thermal conductivity because an empirical link exists between the thermal conductivity and the methane number of individual hydrocarbons, e.g. methane, propane or butane. The methane number is similar to the octane number for petrol engines and describes the knock resistance of the fuel gas.

Very favourable experience has been gained so far with prototypes. The unit is now at the commercialisation stage.

Apart from conventional technologies, the development of fuel cells for cogeneration has been promoted in recent years with considerable funds. The electrical efficiency attainable is well above the efficiency of conventional technologies. A particular advantage of these fuel cells is, however, their excellent part-load behaviour. Moreover, they are marked by very low pollutant emissions.

Of the various types of fuel cell being developed, the phosphoric acid fuel cell has the longest history and is now available as a prototype for commercial use. To assist its commercialisation, Ruhrgas has acquired a 200 KW PAFC. The plant was commissioned in autumn 1992 and operated for about a year until it was recently - as the second step of a demonstration project - handed over to a municipal utility near Essen for operation under practical conditions. The main data and results of our demonstration project are as follows:

The power-generating capacity is 200 KW, and the thermal capacity 220 KW. The power-generating capacity can easily be adjusted between 0 and design load. The power-generating efficiency of the PAFC is 40 %, and its thermal efficiency 45 %. The results of the trial operation are satisfactory. Special mention should be made of the emissions and outstanding part-load behaviour. Compared with engine combustion, the NO_x emissions (3 mg/m^3) are virtually negligible. The same applies to the CO values (4 mg/m^3).

A project reaching far into the future and in which Ruhrgas and a German electricity supplier, RWE, are participating involves the development of the molten carbonate fuel cell. This MCFC project is being managed by MTU, an affiliate of the Daimler Benz Group, with the backing of the German Ministry of Research and Technology and the European Union.

In sum, the following can be stated on the use of natural gas in power generation:

- Utilisation of gas for power generation, whether centralised or localised, is gaining importance worldwide.
- Commercially available technologies, such as gas engines and gas turbines, are registering high annual growth rates.

- Fuel cells open up new avenues, with the prospect of high efficiencies and very low emissions. However, molten carbonate fuel cells and solid oxide fuel cells in particular involve a high development risk. Even PAFC technology, which is the most advanced at present, has still not reached a point where it is economically viable. Owing to the very small number produced, capital expenditure between DM 5,000 and 5,500 per kW_{eI} is much too high. Nonetheless, as an energy company, we consider it expedient to participate in this high-risk development, our objectives being energy conservation and pollutant reduction.

d) Natural gas in the transport sector

All the fields mentioned until now are traditional market sectors for the gas industry. This does not hold true of the transport sector, which is a new market for the German gas industry.

The desire for unlimited personal mobility has led not only in Germany to a steep increase in the number of vehicles. This desire of each individual is coming up against limits, as illustrated not only by the heavy traffic on our roads but above all by the high level of emissions caused by it. Especially pollution within cities leading to winter and summer smog is already largely attributable to the transport sector.

One way of reducing emissions further is to use alternative fuels. The oldest representatives in the energy sector are gases, including natural gas.

The first NGVs appeared on the scene in the 1930s. Today there are over 800,000 NGVs worldwide. Though this figure is relatively high, this is only 0.3 % of all motor vehicles in use worldwide. NGVs are mainly employed as fleet vehicles, e.g. delivery vans, as public transport buses or as taxis. The main advantages of using natural gas are:

- low-pollutant emissions
- quiet running
- absence of emission odours and
- high knock resistance.

Unfortunately, natural gas also has drawbacks, such as low energy density, which necessitates considerable storage space and increases the weight of the vehicle.

While pollutant emissions from stationary sources, namely households, power stations and industry, are decreasing, this is unfortunately not true of the transport sector. The acute ozone problem in conurbations calls for alternative engine concepts.

Fig. 10 shows that at present no other conventional engine system has an ozone-reducing potential comparable to that of gas engines. A reduction of more than 80 percentage points against conventional fuels is possible.

And what is being done in Germany?

Immediately after the war, the number of NGVs reached a peak, though not for environmental reasons but because of the shortage of other fuels.

In 1950, there were over 7,800 such vehicles in the Rhine-Ruhr region. However, they were soon driven out of the market because cheap crude oil became available for producing petrol. In the mid-1980s, a few vehicles were converted to gas operation with our support. They belonged to the Rottweil utility, which now possesses long-standing experience with NGVs. In 1990, we gained our first own experience with NGVs and a CNG refuelling station. This was immediately followed by preparations for a demonstration project involving a dedicated bus. In collaboration with Mainz and Wiesbaden utilities, Ruhrgas is carrying out a demonstration project with two CNG busses in the period from 1993 to 1996.

Fig. 11 shows emission limits for commercial vehicles that are being lowered in stages. Euro I is currently valid, Euro II is to apply as from 1996, and Euro III as from 1999. Our own operating experience indicates that dedicated NGVs are already able to stay well below the limits to be introduced in 1999.

The engine noise level is also over 50 % lower than that of a comparable diesel engine.

Ruhrgas, too, will soon operate its own NGV. This is a dedicated Chrysler van, i.e. a vehicle whose engine is optimised for gas operation in terms of efficiencies and pollutant emissions. This vehicle will shortly start operating once the German authorities have approved it.

Our aims are

- to gain experience with dedicated NGVs and their components for the purpose of fleet operation;
- to obtain data on emissions from practical operation;
- to make technical know-how available to our customers.

We believe that NGVs have market potential as fleet vehicles in Germany if

- economic problems are resolved, i.e. fiscal obstacles due to current petroleum taxation are removed, and
- technical developments are successfully carried out to increase fuel use efficiency, lower costs and reduce vehicle weight.

Despite the impressive results already achieved, there is still considerable scope for development.

In a study on future motor vehicle types, the Prognos Institute in Basle determined the market potential of NGVs in several countries, including Germany (Fig. 12). According to scenario A, over 150,000 NGVs could be in use by the year 2010. Scenario B "Economic Incentives and Appropriate Legislation" indicates that as many as 250,000 NGVs could be in operation in the year 2010. However, this is rather modest compared with the predictions for the United States, namely 4.5 million NGVs. (To avoid misunderstandings, it should be added that the chart merely shows US predictions converted to the German population figure, i.e. approx. 1.5 million vehicles.)

The coming years will show how fast developments in Germany proceed, but in this case, too, R&D efforts serve to pave the way.

5. Environmental Trends and Perspectives

As illustrated by the debate on the use of natural gas in the transport sector, environmental protection is surely the subject that has caused the greatest change in public perceptions during the last few decades.

In the middle of this century, environmental protection was still a largely unknown concept. In the 1960s, dust, soot and sulphur dioxide as pollutants with a direct impact were at the forefront of local thinking. Since then, there has been a trend away from pollutants to greenhouse gases, i.e. from direct effects to highly complex mechanisms, and a trend away from local to global thinking.

Let us now look at how the gas industry has tackled and solved environmental protection problems, taking nitrogen oxides as a simple example.

This was a large problem about 15 years ago. At that time, natural-draught burners caused NO_x emissions in the range of 200 to 250 mg/m^3 (Fig. 13). Thanks to substantial R&D efforts, it proved possible to lower the emissions dramatically in all areas of application. In the case of residential gas burners, burner inserts used for flame cooling - this know-how originated in the United States - allowed NO_x emissions to be decreased by 30 to 50 % in the mid-1980s.

A further milestone was the development of fully premixed fan-assisted burners, in which Ruhrgas also played a significant part. In 1990, the NO_x emissions of these burners lay between 40 and 80 mg/kWh . They are now widely in use, especially in condensing boilers. Last year, optimised fully premixed burners were presented, whose NO_x emissions are now merely 15 mg/kWh . Even more remarkable is the fact that natural-draught burners, which were considered to be out of the running 10 years ago because of NO_x emissions twice as high as those of fan-assisted burners, have made considerable technological headway. Today, their emissions lie between 20 and 50 mg/kWh , which means that these robust burners of simple design have a clear advantage over the best oil burners.

Without these NO_x reduction activities by R&D engineers and technicians, natural gas would today not occupy such a large share of the residential sector.

Fig. 14 shows a hemispherical fully premixed burner produced by the Viessmann company; it is a so-called matrix burner with extremely low NO_x emissions of only 15 mg/kWh .

Virtually non-polluting combustion of natural gas is now within reach. Catalytic and catalytically aided combustion processes are being developed. Prototypes already exist whose NO_x emissions are at the lower limit of the detection range of conventional measuring instruments. It will, however, take some years until these are ready for the market.

But this euphoric preview must not make us forget the risks of these highly sophisticated gas burners, namely

- their higher production costs,
- the more complex control systems needed,
- their increasing sensitivity to changes in gas properties and to faulty burner adjustment.

The prime objective of continuing R&D efforts must therefore be to avoid these drawbacks, while achieving an adequately low emission level.

6. Conclusion

Given the host of promising R&D efforts and the high product quality of natural gas, it will surely remain possible to ensure cost-effective gas supplies, even in a complex environment. Furthermore, the utilisation of natural gas is cleaner and more simple, requiring fewer installations and less auxiliary energy than the combustion of any other fossil fuel. A key element in responding to a new environment and meeting future challenges are R&D activities. They alone enable us to find responses to new questions and challenges.

In the 3-way pull exerted by reserves and resources, by markets and customers and by the legal framework, it appears possible to cope with the questions and problems arising.

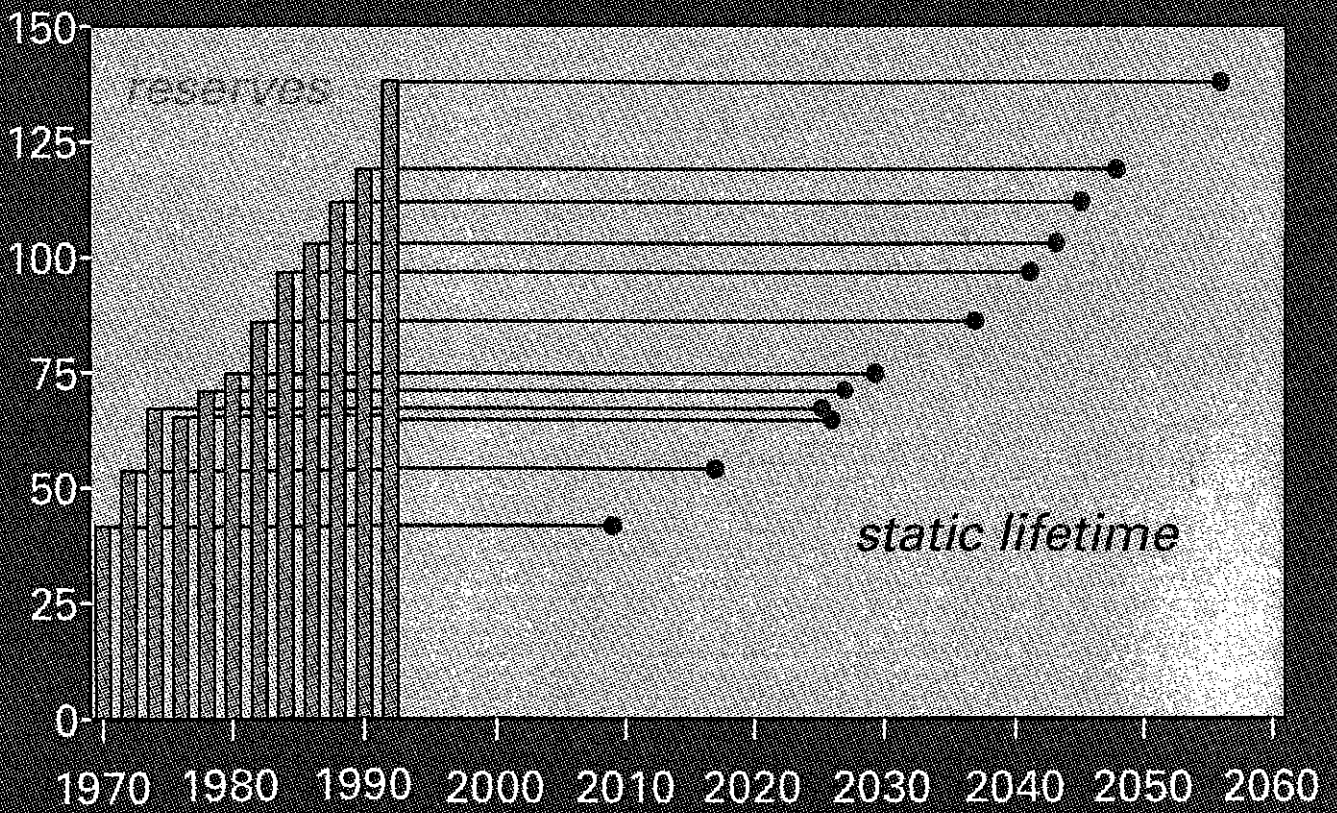
If we are all to succeed, it is essential for us to exchange information, to communicate with each other and to be on the same wavelength. It would be gratifying if this paper contributed in some measure to that goal.

Fig. 1

Development of Proved World Natural Gas Reserves and Static Lifetime



billion m³

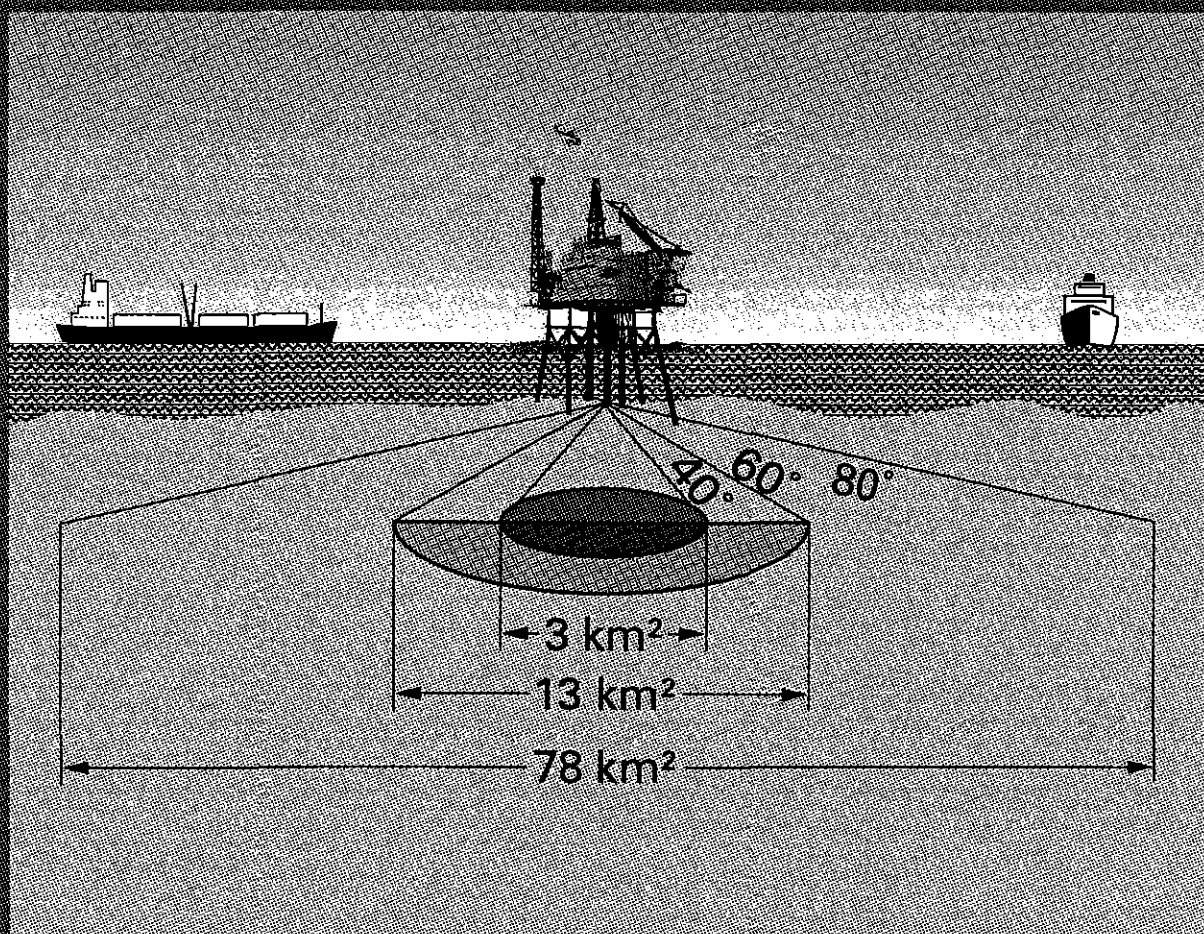


reserves-to-production ratio

1994

Fig. 2

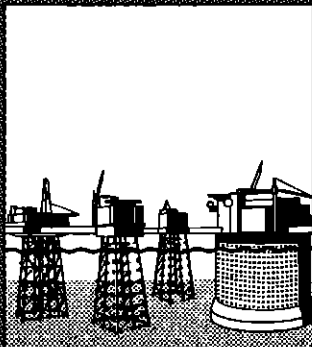
Hydrocarbon production through side-tracked wells



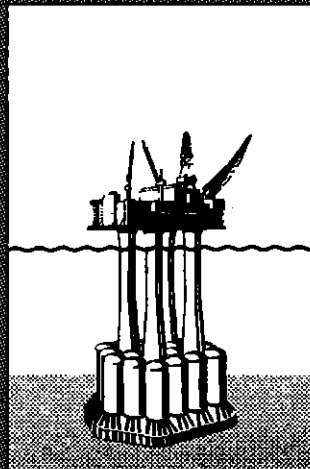
1994

Milestones in offshore production engineering

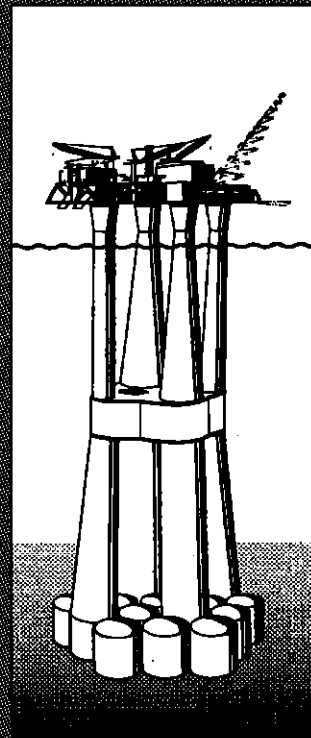
ruhrgas



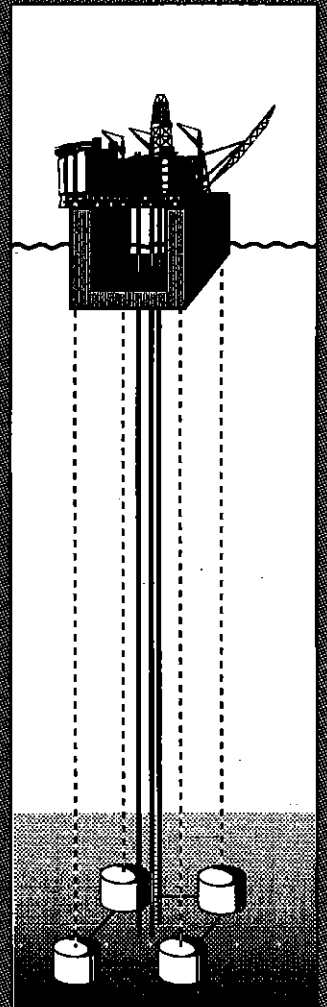
1973 Ekofisk*
total height: 140m



1979 Statfjord*
total height: 270m



1995 Troll*
total height: 470m



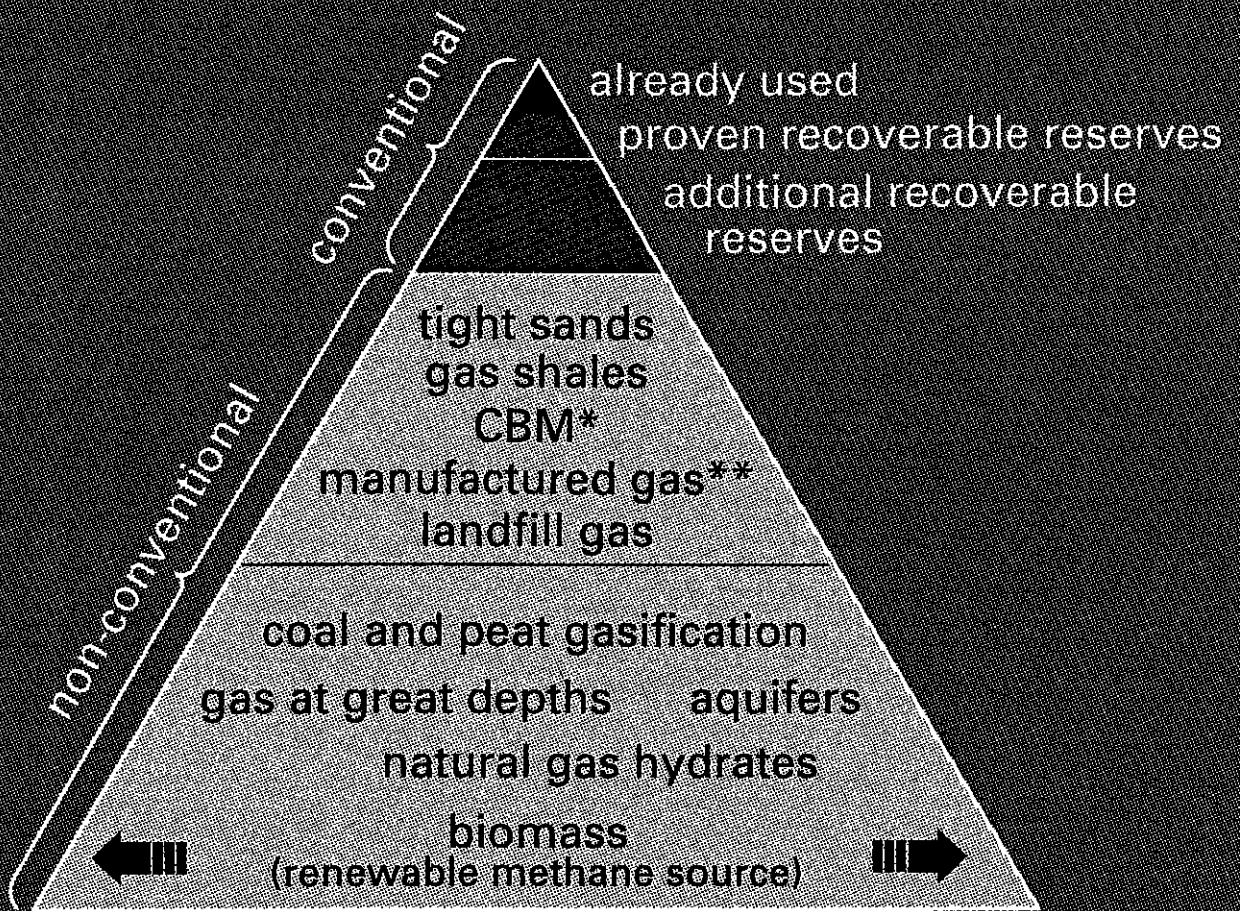
1990 Conoco**
total height: 630m

* Norwegian North Sea

** Gulf of Mexico
Tension-leg platform

Fig. 4

Conventional and non-conventional gas reserves



source: WYMAN

*coalbed methane

**from naphtha and LPG

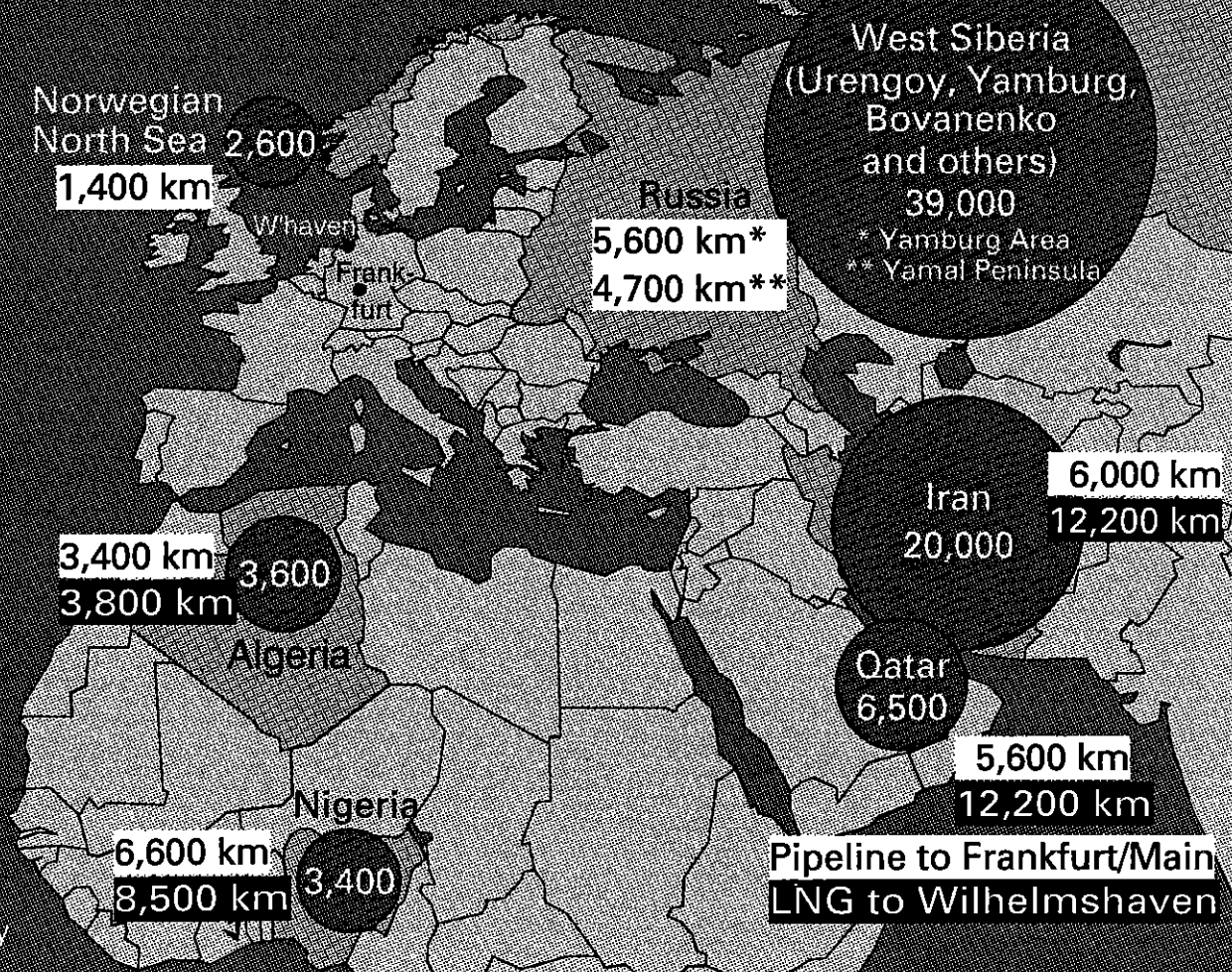
1994

Fig. 5

Natural Gas Reserves and Supply Distances

ruhrgas

in billion m³



January 1993

Source for natural gas reserves: Oil and Gas Journal, Norwegian Petroleum Directorate, others

Fig. 6

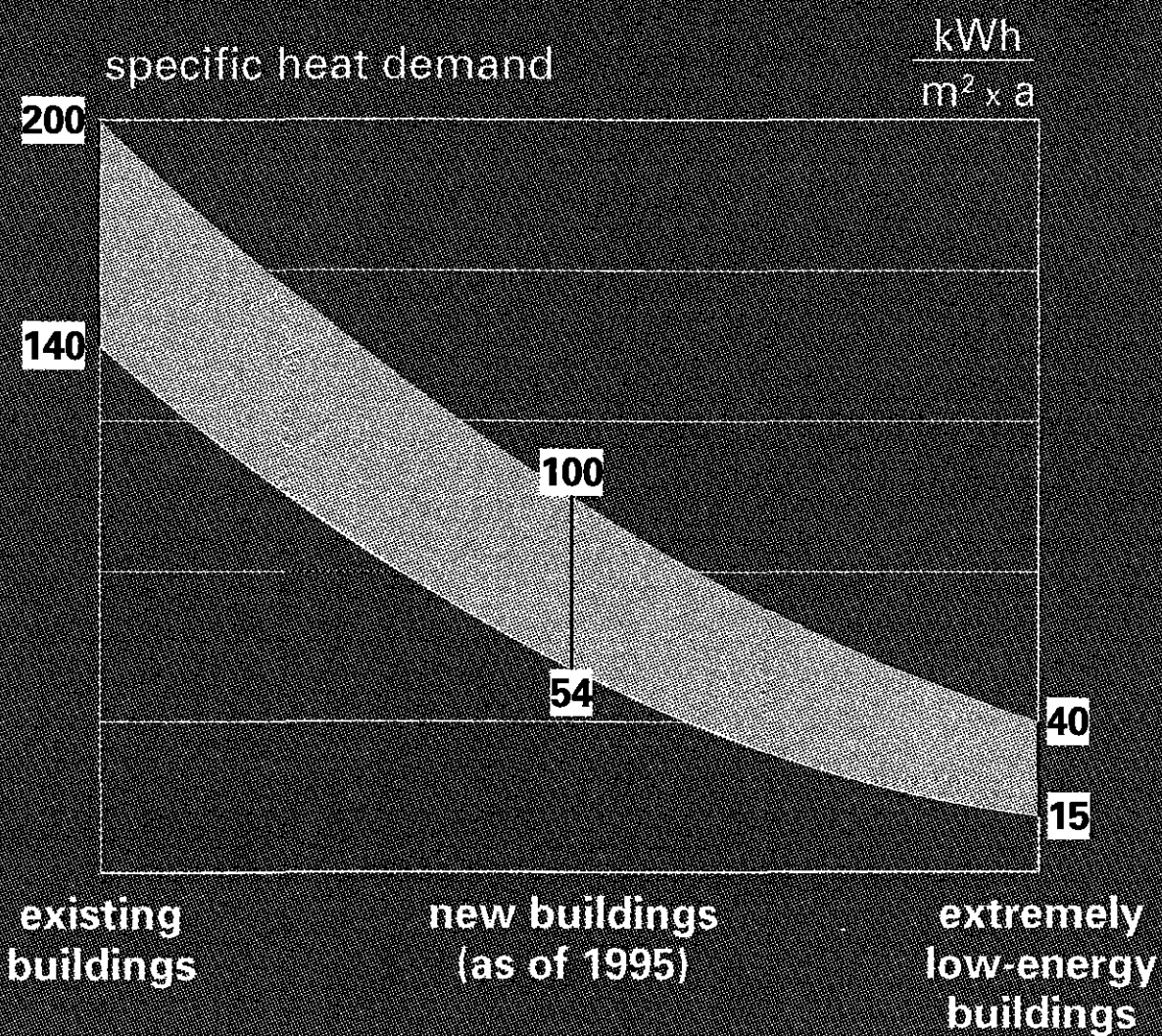
Developments in pipeline transmission



year	working pressure (bar)	diameter (mm)	annual pipeline capacity (billion m ³)	of which fuel gas for 6000 km (%)
1910	2	400	0.080	48.8
1930	20	500	0.648	31.3
1965	66.2	900	8.320	14.1
1980	80	1420	26	10.6
after 2000	120	1620	52	8.2

Fig. 7

Specific heating requirements of buildings of different standards



1994

Fig. 8

Low-NO_x High-Velocity Burner

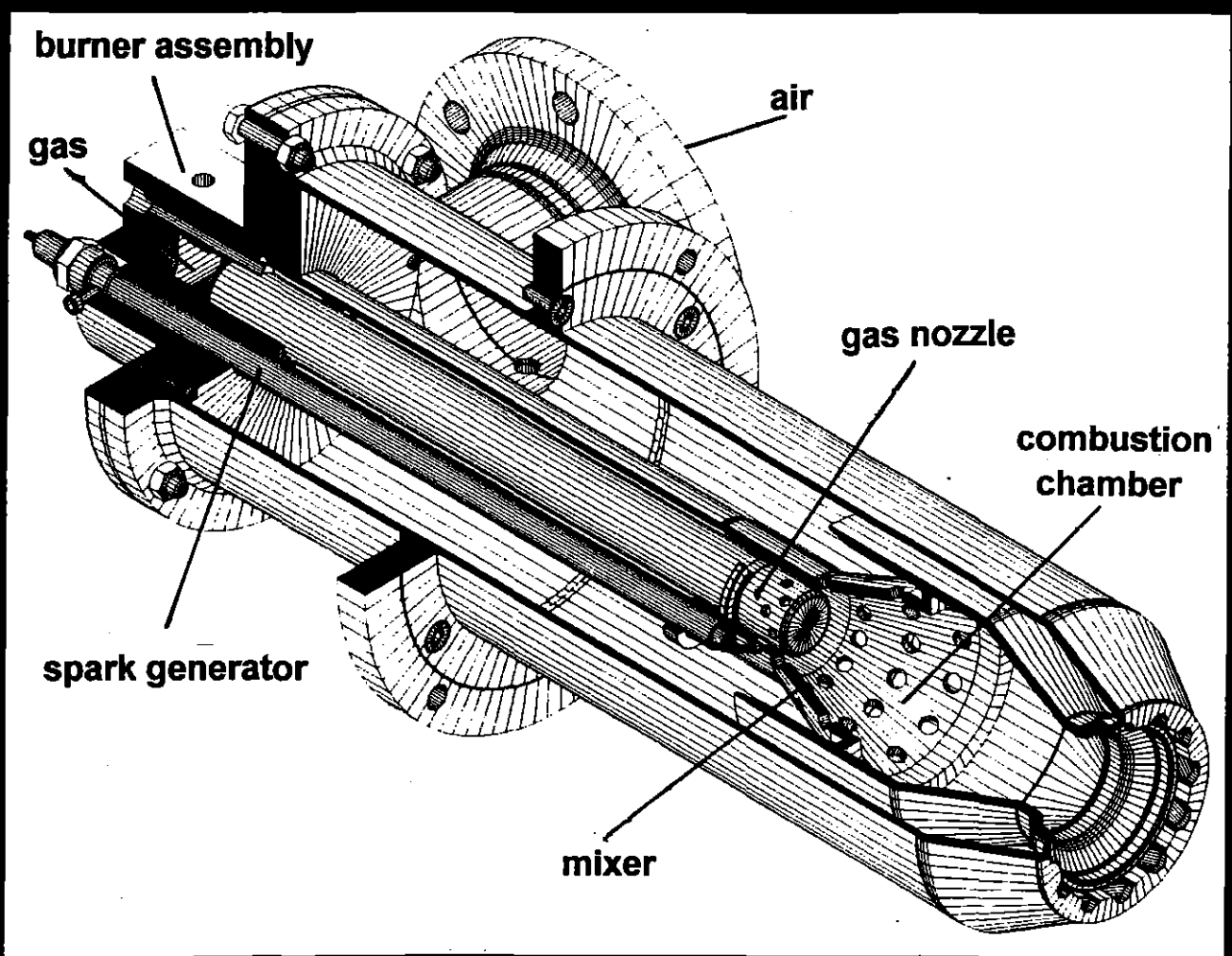
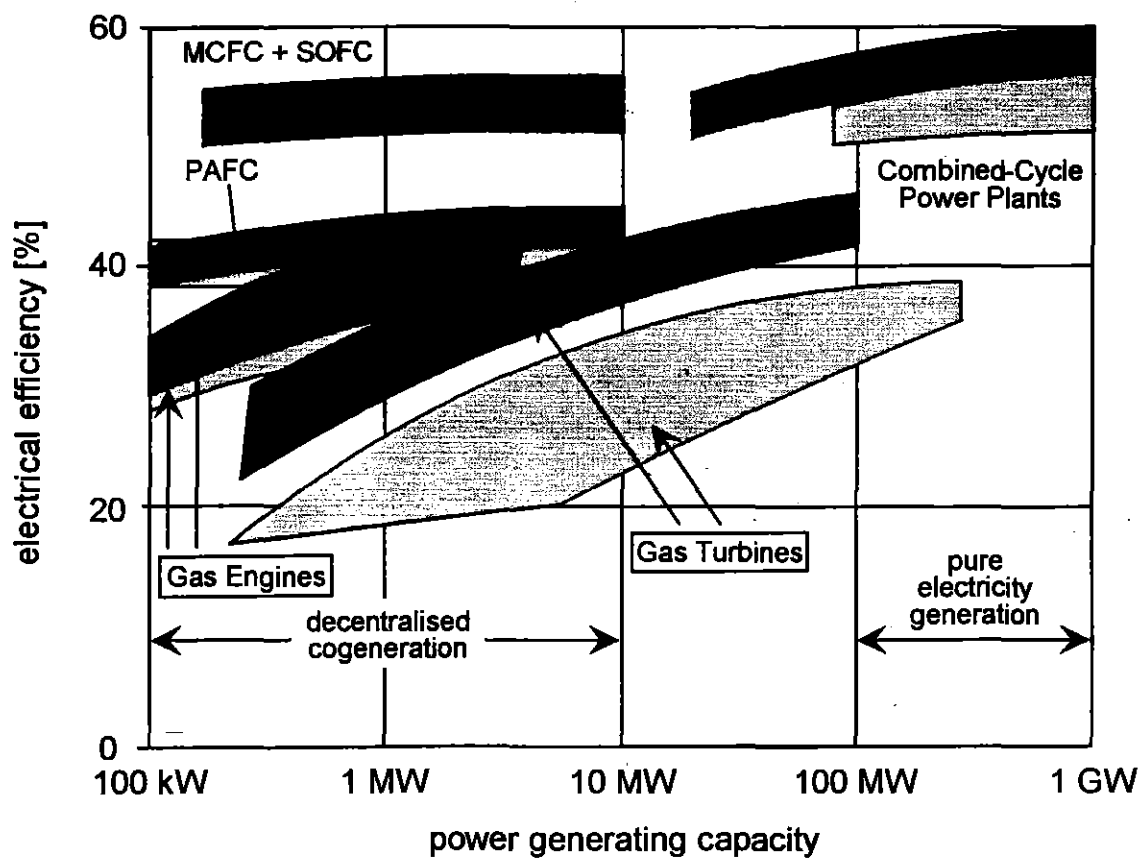


Fig. 9

Electrical Efficiency of Cogeneration Technologies (Based on Natural Gas)

ruhrgas



Current Status
Forecast for 2005

1994

Fig. 10

Ground-Level Ozone Reduction by Alternative Fuels

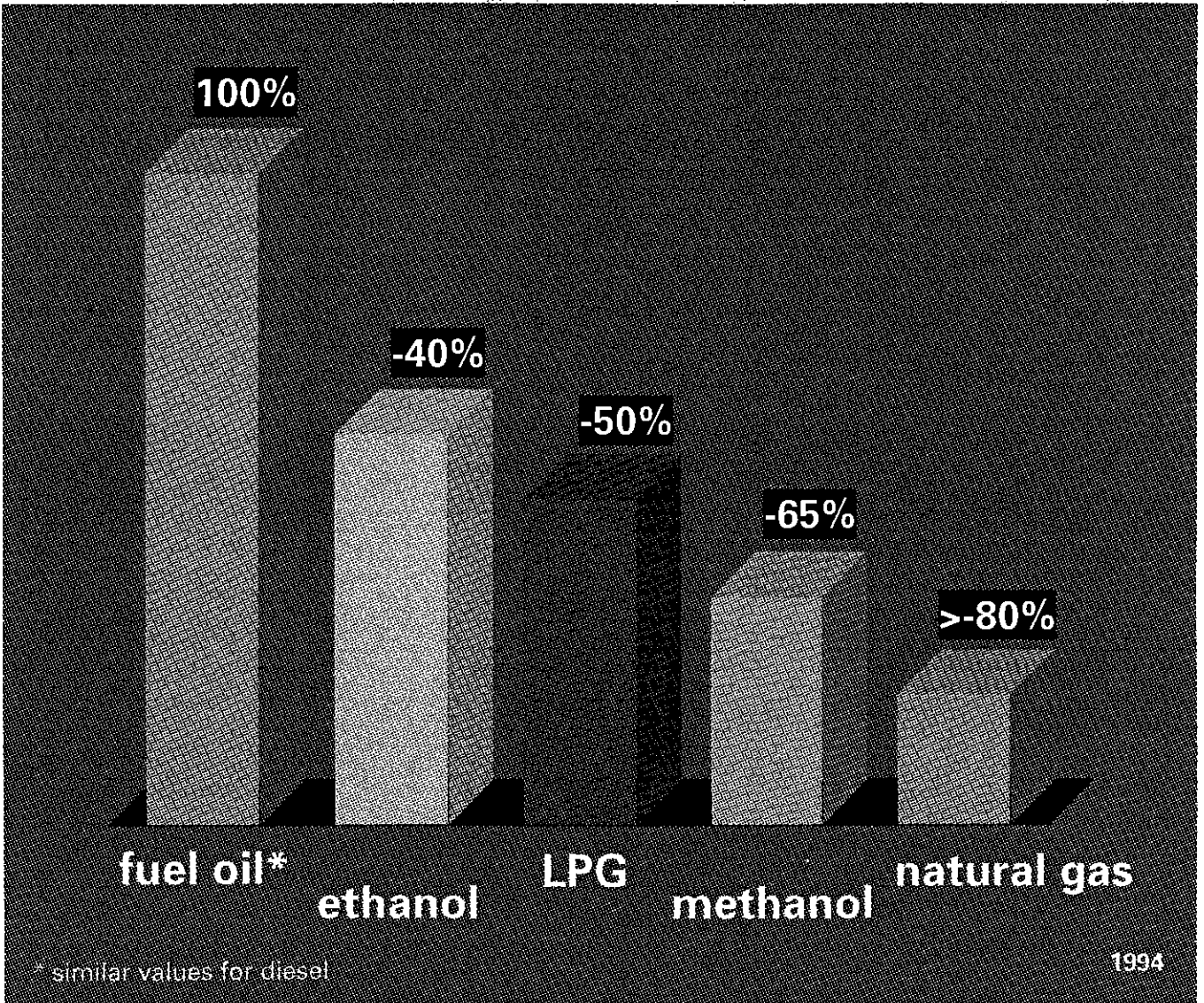
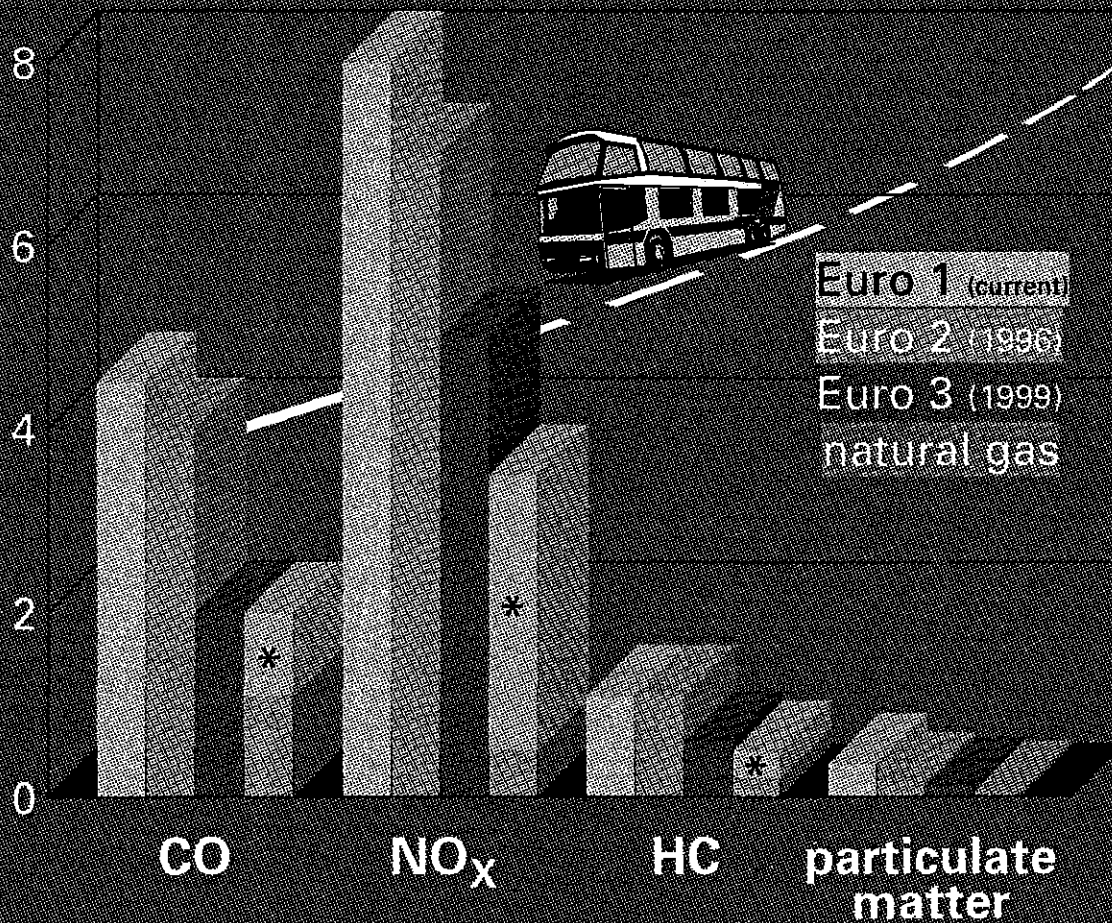


Fig. 11

NGV Emissions vs. ECE R49 Limit Values



pollutant emissions g/kWh



* Fluctuations depending on engine adjustment and age (MAN data)

1994

Fig. 12

Market Potentials of NGVs in the US and in Germany

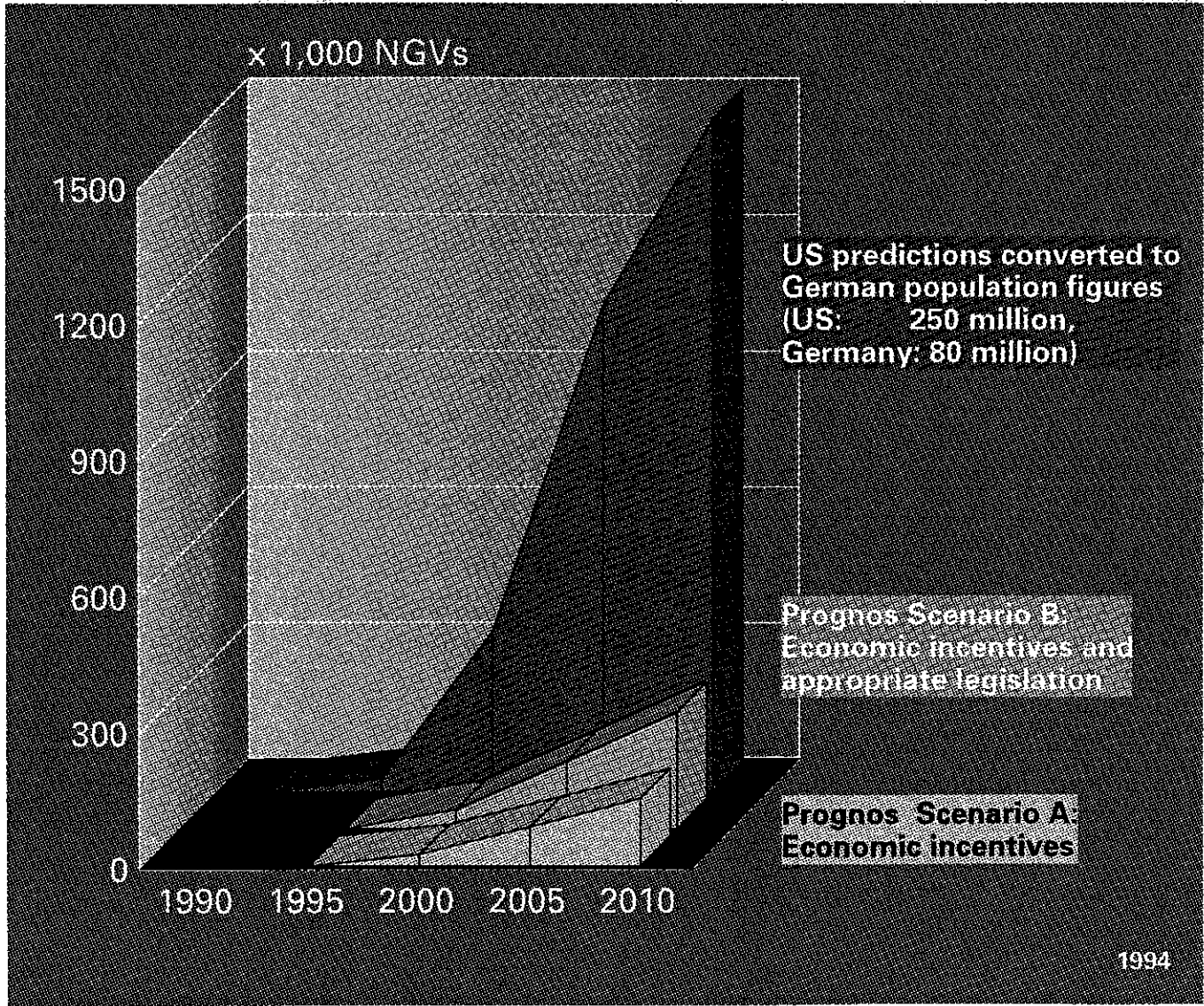
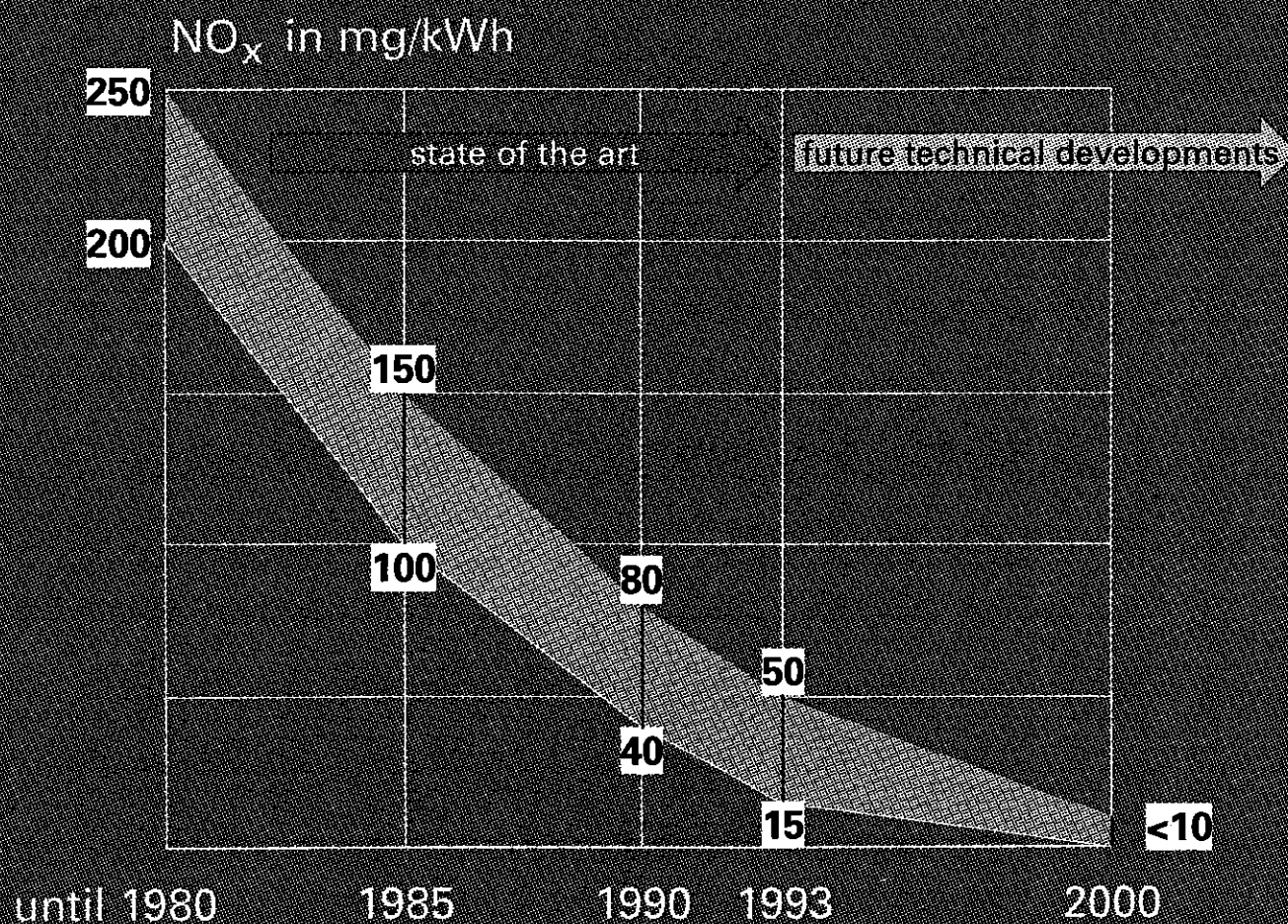


Fig. 13

Milestones in NO_x reductions for residential and commercial gas burners

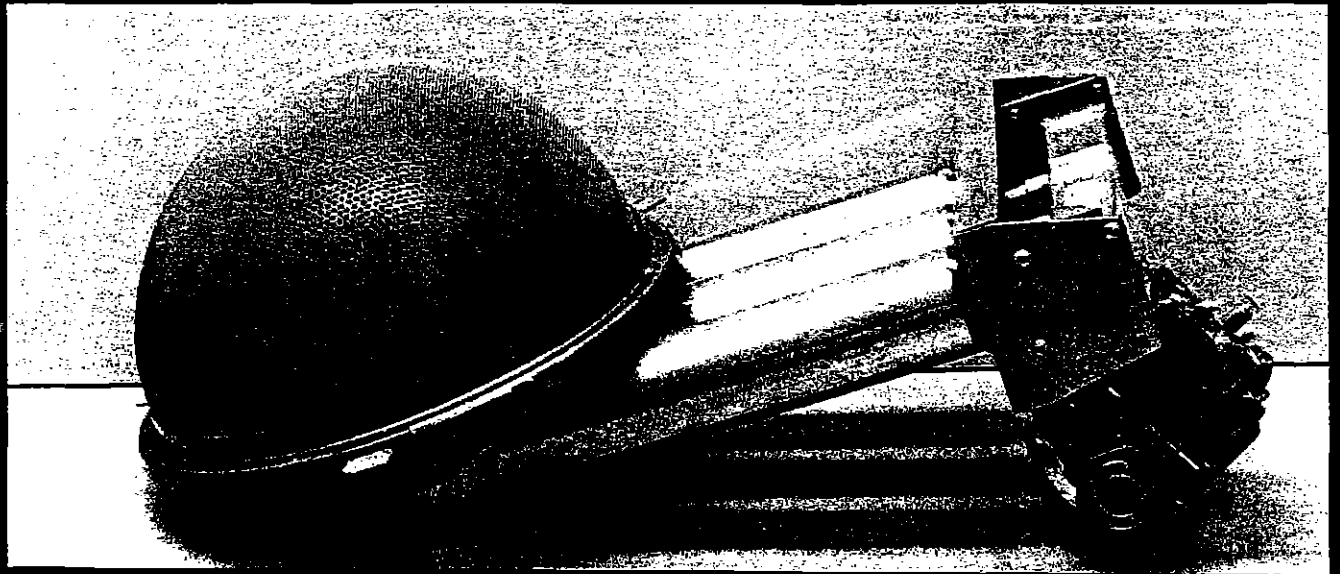


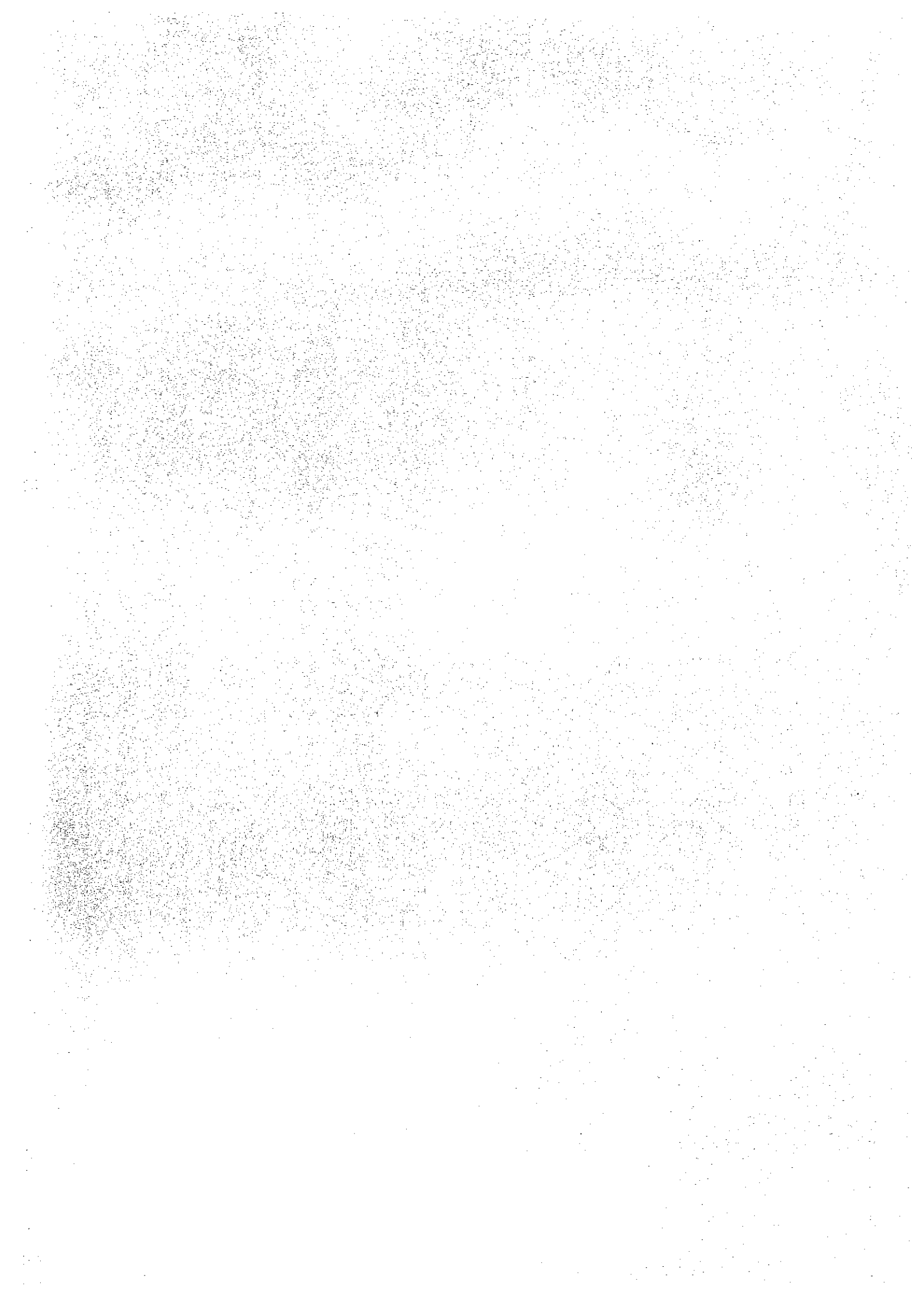
1994

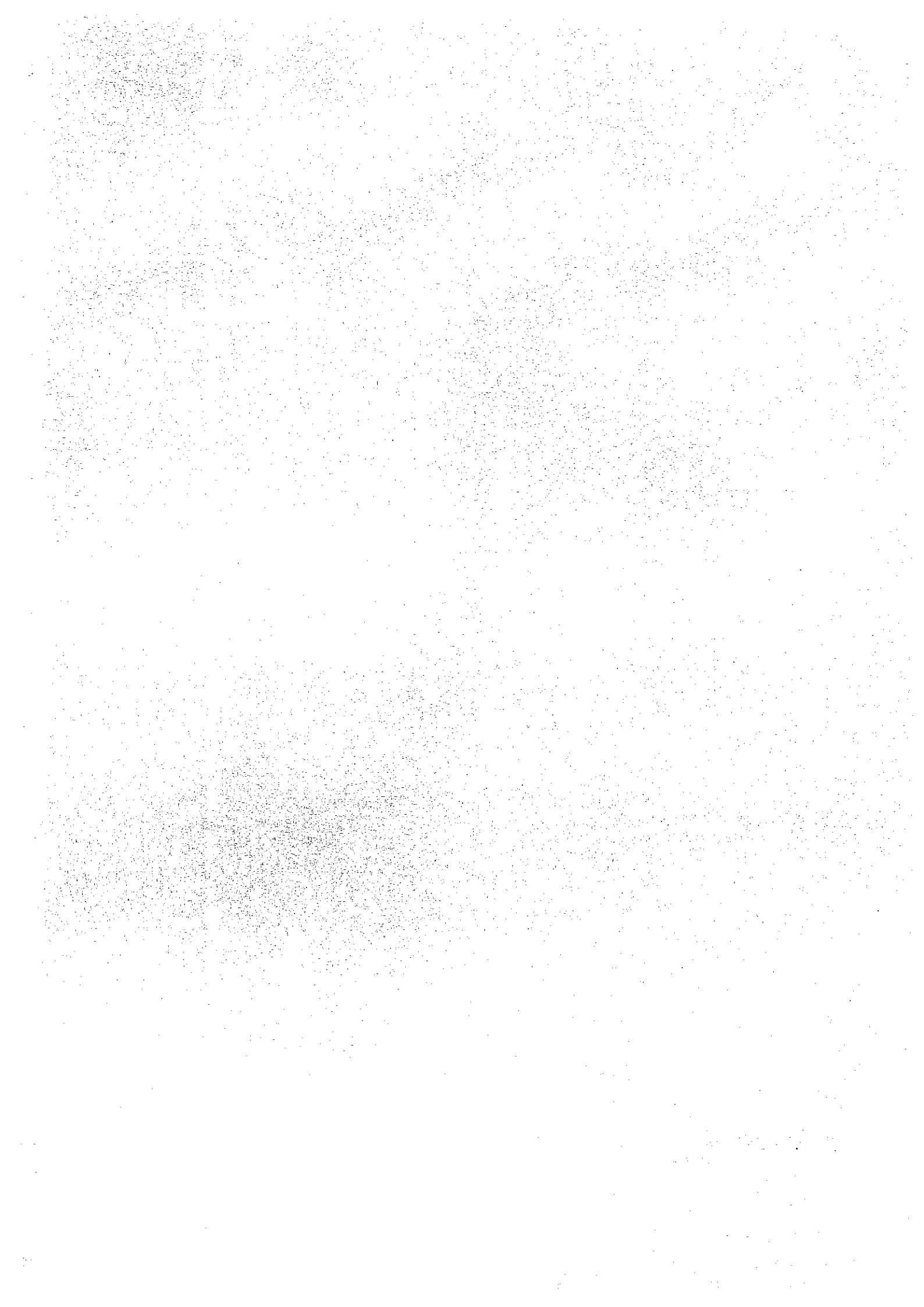
Fig. 14

Matrix Burner

ruhrgas







FUD-Workshop in Malmö, April 20th 94

NGC activities during 1993

b y

**Ingemar Gunnarsson
Energi-Analys AB**

1 Introduction

NGC was started 1988, when natural gas was in a very expansive period in the Nordic countries, to supply a long-felt demand for gasutilization-know-how. Another aim with NGC was to create better co-operation between Nordic countries and also with other partners abroad. For the moment natural gas not is expanding so fast in Scandinavia. Therefore NGC was closed down in December 1993 but still there was a lot of activities during the last year and some of them are taken over by other Nordic organisations. This R&D-Workshop is a typical example of an activity that was started by NGC and which hopefully will continue long after NGC is closed.

During the period between 1988-93 NGC carried through 96 projects in different gasutilization areas. Information about these projects and gas technology in other parts of the world was another important task for NGC. During the five years NGC distributed 20 of NGC-News and Highlights respectively to this should be added 8 special project information papers and 15 conferences and workshops. If you want to know more about the NGC-activities you can read about it in a small book called " Hvidbog - Resultater og Erfaringer fra NGCs virksomhed 1988-93".

Now I will concentrate on the activities during 1993, which was a very interesting year with many projects finished. All projects running during 1993 are listed in the table in enclosure 1. Some of them has been running in co-operation with other Nordic partners and will be presented by other speakers during this day . I have selected some of the most interesting projects not covered by other speakers for a closer presentation.

2 Reburning

Gas reburning offers a simple and effective solution to the problem with emissions of nitrogen oxides (NO_x) from refuse incineration. During the reburning, a large part of the nitrogen oxides are removed in a combustion-chemical process with methane as the reducing component. The process takes place above the primary combustion zone and is followed by the addition of burn-off air to ensure complete combustion.

Reburning is cheap to install and makes it possible to reduce NO_x-emissions by 50-60% without generating any harmful new emissions. The thermal efficiency of the plant is enhanced by implementing reburning and often it is possible to increase the total thermal effect. On the other hand the maximum capacity of waste incineration can be reduced when introducing a new second in an existing boiler plant.

The chemistry of reburning has been investigated in former NGC-funded projects and during 1992 and 93 reburning was tested in full scale at SYSAV's refuse incineration plant in Malmö, Sweden. The results showed that it is possible to cut the NO_x emissions by approximately 50 %, and it is possible to go even further in combination with SNCR. The tests also showed that it is still work to be done to make the technic robust and stable when varying the boiler capacity. The last report from these tests will soon be available.

DGC (Danish Gas technology Centre) has taken over the responsibility for the future development and is now planning a permanent installation on Herning incineration plant in Denmark.

3 Low-NO_x-burners

During several years development of low-NO_x-burners has been a main task for the suppliers of burner equipment, resulting in many "low-NO_x-solutions" both for gas and other fuels. NGC started a project to analyse the current technological status in this area.

An market survey was made showing that significant reductions of the NO_x-emission from traditional gas fired industrial boilers can be obtained. The following NO_x-reducing technologies for medium size industrial boilers were discussed:

- Water injection
- Stem injection
- Improved operational control
- Flue gas recirculation
- Low-NO_x burner technologies

A number of the methods investigated has a full load NO_x-emission in the range of 20-30 mg/MJ, which is approximately half the emission from the better traditional industrial gas burners. These low emissions

are superior compared to the NOx emission from most other fossil fuels.

However in most countries the boiler owner does not benefit from installing low-NOx equipment. Sweden is an exception because of the NOx taxation which was introduced 1992. In the report a study at a 25 MW Swedish steam boiler plant is presented. Equipment offered by various burner suppliers showed that it was possible to decrease the NOx-emissions with up to 60% with a simple pay back time of 1-3 years, due to the reduced NOx charge.

4 Recuperative crucible furnace for aluminium

In this demonstration project an efficient gas fired furnace for aluminium melting is evaluated in "Värnamo Pressgjuteri", Sweden. Measurement results show a 50% energy cut compared with a conventional gas fired crucible furnace. A calculation shows that this furnace also can compete with an electrical heated furnace by 15% lower annual cost.

Originally, the foundry had gas fired furnaces with cold air burners serving four die-casting machines. One furnace has been replaced by a recuperative, well insulated gas fired furnace, manufactured by Schmitz+Apelt LOI, type Recumelt 300, with the capacity of 150 kg/h aluminium.

The combustion air is preheated to about 400 °C in the recuperator and the energy losses are small due to the effective insulation of ceramic fibre. By measurements the energy balances have been established for the recuperative furnace as well as for the previous cold air furnace.

The installation paid off in about two years compared with a conventional cold air burner furnace and CO₂ was reduced by 50% due to lower energy consumption. On the other hand the preheated air has increased the NOx emissions with 40%.

5 The Coleshill project

Furnace design

The glass tank is a large reverberatory furnace in which the glass is melted turbulent by diffusion flames above it. A large proportion of the heat is transferred to the glass indirectly, by first heating the roof, which then radiates to the glass. According to the burner position they are called "cross fired" or "end fired" and all of them use preheated combustion air because of the high melting temperatures and the need for energy conservation. For most glass manufacturers round the world the choice of fuel is between heavy fuel oil and natural gas. Until recently the burner design was based on the criteria of improving the thermal performance in order to achieve the maximum production rate. The last few years legislative limits for emissions has given NO_x-emission levels an equal importance.

Emission limits

The introduction of emission limits has made the natural gas more competitive because it has very low SO_x, CO₂ and particulate emissions. In general, natural gas also produces lower NO_x emissions than fossil fuels, but in the case of glass melting where "thermal NO_x" formation is dominating, natural gas normally results in NO_x emissions similar to or even higher than those of heavy fuel oil (HFO). To enhance the competitive position of natural gas, a major project was initiated to develop an improved firing system which would offer lower NO_x emissions while retaining the other benefits of gas. Glass tanks are costly to modify and to make tests on so it is desirable that new burner systems should be tested on a pilot plant and could easily be fitted to existing tanks without expensive modifications.

International consortium

The concern about emissions is world-wide and in order to pursue a common interest NGC joined a international consortium comprising the following gas companies British Gas, Gasunie, Gaz de France, SNAM, Osaka Gas and Tokyo Gas. Its ultimate objective is to develop firing techniques which provide reduced NO_x-emissions while maintaining or improving the thermal performance of natural gas.

IFRF tests

At the time the consortium was formed it was decided to commission the international Flame Research Foundation (IFRF) at Ijmuiden in

Netherlands to carry out the first part of the test work. It was carried out on a box shaped furnace with one end adapted airport of a cross fired glass tank. It was found that NO_x could be reduced by selecting the right combination of gas velocity, gas injection angel or air injection angel. There were also tests with several more or less sophisticated gas injection nozzles. The results were promising but also highlighted the importance of a more realistic test furnace.

Coleshill test furnace

A model of a real crossfired glass tank was built at British Gas Coleshill test site. The furnace is a 40% scale model of one section of a real tank producing 160 tonnes/day. The furnace is a unique facility which reproduces the internal shape of the tank crown and the air ports. The only major compromise is the replacement of the glass load with a more manageable water-cooled hearth. The facility incorporates compact regenerators designed to give up to 1300 °C combustion air preheat. The furnace is fired by two burners per port and the flow reversals every 15 minutes provide cyclic firing from the two air ports as on a full scale tank. The burners can be adjusted to vary the fuel injection angle and different burner configurations as over-port, side-port through-port and under-port can be tested. A future feature of the facility is the possibility to use different fuels as oil, LPG and natural gas.

Results

Several tests were carried out with different fuels (HFO, LPG and NG), fuel angles, fuel velocities and burner nozzles. The important parameters, such as NO_x-emissions, heat flux to the hearth and furnace temperatures were logged for several reversals. Using a standard "single-hole" burner as an reference it was succeeded to rise the heat flux with approximately 15 % at the same time as the NO_x-emissions were decreased with 60-70 % at optimal use of the new gas burners.

The results showed that the best of the new gas burners has a thermal performance similar to that of best the oil burners. These new burners produces a flame with higher luminosity and at the same time much lower NO_x-formation than standard gas burners. A patent application has been filed on one of the burners and the next aim is to make a full scale demonstration.

6 Cheng cycle

The purpose of the "Cheng cycle project" was to analyse the technical and economical possibilities by using gas turbines based on the Cheng Cycle principle as production unit in the district heating stations which are planned to be converted to decentralised combined heat and power plants.

In the Cheng Cycle steam is heated in a exhaust boiler and then introduced into a gas turbine in order to rise the mass flow and produce more electricity than in an ordinary gas turbine plant. The production of electricity and the electrical efficiency with the Cheng Cycle plant depends on the forward and return temperatures in the district heating system in such a way that the lower the temperature level the higher the electrical efficiency which results in varying electrical efficiency during the year. The Cheng cycle plants are very friendly to the environment and especially the NOx-emission is low.

The city of Haderslev has taken an interest in using a Cheng Cycle turbine in connection with conversion from heat production to combined heat and power production.

7 The Nordic Methane Project

As early as 1989, the discharge of methane from the gas industry in the Nordic region was evaluated by NGC. The information was by that time based on estimates from the gas industry with varying accuracy. The aim with "The Nordic Methane Project" which then was started was to compile an estimate with a far higher accuracy and degree of documentation. NGC formed a project group in which the production, transmission and distribution companies are represented.

Logging data collected in routine operation situations and detailed data on natural gas networks have been received from transmission and distribution companies. all major emission sources have been evaluated and the final methane emission estimate must be regarded as the best available.

The biggest methane emissions from the Nordic Natural Gas System are from production platforms and some old distribution networks. The biggest losses in distribution are taken care off by rebuilding

older cast iron networks in bigger cities as Copenhagen. The losses from production are monitored all the time also from safety point of view

The average leakage rate in the Nordic region, from platforms to gas meter is 1,11 % of the consumed natural gas. By rebuilding cast iron networks the over all leakage rate will be 0,24 % before end of 1996. Which is very little especially compered to other sources around the world.

8 Conclusion

These examples of projects shows that NGC has been involved in many different aspects of gas utilisation playing an important role as meeting point for the Nordic gas industry. All project reports are available from the former owner companies or from the library by DGC in Hörsholm Denmark. Hopefully will the project results be used in your future work developing gas utilisation in the Nordic countries.

**Status pr 31.10.1993 for igangværende
NGC-projekter samt projekter afsluttet i 1993**

Projektområde/ projekt	Projekt- periode	Deltagere	Godkendt NGC-budget 1000 DKK	Supplerende ekst. tilskud 1000 DKK	Status pr 31.10.1993	Aktivitet efter 31.12.1993
Forbrændings- teknik:						
I Nitrogen Chemistry (Burn-out- Zonens kemi)	1991- 1993	DTH, GRI, SINTEF	Total: 1.300 1991: 745 1992: 255 1993: 200	1.050 fra GRI 1991: 350 1992: 350 1993: 350	Slutrapport er under udarbejdelse.	DGC fortsætter samarbejdet med GRI og DTH i det nye 3 årige projekt.
I Reburning - matematisk modellering	1991- 1993	DTH, SINTEF, Åbo	Total: 2.625 1991: 875 1992: 875 1993: 875		Slutrapport er under udarbejdelse.	DGC får ret til at benytte beregnings- modellerne.
A Reburning - Affalds- forbrænding "SYSAV"	1991- 1992	SYSAV, EER, SINTEF	Total: 1.385 1991: 1.085 1992: 350	8.000 fra SYSAV, SGC, SNV, SEU, NUTEK, GRI	Projektet er afsluttet og rapporteret.	
I Nordisk for- brændings- forskning	1991- 1993	CTH	Total: 940 1991: 100 1992: 340 1993: 500		Chalmers Tekn. Högskola: 2. fases forsøg er udført og bearbejdes nu i samarbejde med DTH. Rapport i andet halvår 1993.	
I Reburning Herning	1993	Velønd, EER, SINTEF, DGC	Total: 927 1992: 577 1993: 350	3.700 fra Velønd Ecology, Naturgas Midt- Nord, Dargas, EFP og Miljøstyrelsen	Aftalen med Herning er afklaret. Metodestudiet fra Holstebro/Struer benyttes som grundlag for projektet. Engineering fasen rapporteres inden udgangen af 1993.	NGCs deltagelse overføres til tredjepart.
A Dioxin- emission	1992	SYSAV	1992: 30	500 fra Ruhrgas	Projektet gennemføres ikke.	
A Lav-NOx- brændere	1992- 1993	DGC	Total: 250		Rapport og Bulletin er udsendt, og der er påvist flere økonomisk attraktive reduktions- muligheder.	
I Advanced Reburning	1993	SYSAV	Total: 750	Ikke afklaret.	Forsøg er påbegyndt. Testen afsluttes i 1993.	

A: Afsluttet
I: Igangværende
O: Godkendt projektoplæg

**Status pr 31.10.1993 for igangværende
NGC-projekter samt projekter afsluttet i 1993**

Projektområde/ projekt	Projekt- periode	Deltagere	Godkendt NGC-budget 1000 DKK	Supplerende øket. tilekud 1000 DKK	Status pr 31.10.1993	Aktivitet efter 31.12.1993
Kraft/varme:						
A Højtryksgas- motor demoprojekt	1991- 1993	IVO, Modigen, Wärtsilä	Total: 520 1991: 50 1992: 470	Ca 1.100 Øvr deltagere	Projektet afsluttet	
A Gasturbine & tørring, grøntfoder	1991- 1992	Vølund R&D, Ølgod Grønt, dk-Teknik	Total: 320 1991: 20 1992: 300	Ca 300 Vølund R&D, Ølgod Grønt	Afsluttet og rapporteret	
I Emissionsbegr. teknologier, fase II	1991- 1993	Wärtsilä, Marintek	Total: 1.350 1991: 300 1992: 700 1993: 350	2.400 Wärtsilä	- Sidste motorforsøg og slutrapportering i november. - Afsluttes i december	Videreføres af Wärtsilä
I Befugtning af luft til gasmotor	1992- 1993	EFP, DGC, NESA, MAN B&W	Total: 350 1992: 120 1993: 230	1.305 Øvr deltagere	- Projektet forsinket - Midtvejsrapport primo november - Projektmede i december	Afslutning - rapporte- ring udføres af de øvrige deltagere jfr EFPs direktiv - "NGCs" distribution udføres af DGC
I Gasturbine med Cheng-Cycle	1992- 1993	EFP, DFF, Naturgas Midt/Nord, Carl Bro a/s	Total: 250 1992: 150 1993: 100	ca 710 EFP, DFF, Naturgas Midt/Nord	- Lønsomheds- analyseerne færdige - Mulighederne for demonstrations- anlæg udredes - Afsluttes i januar af Naturgas Midt-Nord	Evt demo- anlæg jfr ini- tiativ fra DFF
A Anvendelse af separate overhedere Forstudie	1992- 1993	Naturgas Midt/Nord, Hede- selskabet, RH&H	Total: ca 100 1992: 100	Ca 100 Naturgas Midt/Nord, Hede- selskabet	- Projektet afsluttet - Slutrapporten under trykning	
A Effekt- og virkningsgrads- forbedring	1992- 1993	Endat, ÅF, dk-Teknik	Total: 350 1992: 275 1993: 75		Afsluttet og rappor- teret	
A Modulkraftværk	1991- 1992	IVO, IVO International	Total: 625 1991: 125 1992: 500	675, IVO	Afsluttet og rappor- teret	Evt demo- anlæg jfr initiativ fra IVO
A Katalysatorer for ottomotorer	1992- 1993	Vattenfall, NUTEK	Total: 65 1992: 65	Ca 130 Øvr. delt.	- Afsluttet og rapporteret	

A: Afsluttet
I: Igangværende
O: Godkendt projektoplæg

**Status pr 31.10.1993 for igangværende
NGC-projekter samt projekter afsluttet i 1993**

Projektområde/ projekt	Projekt- periode	Deltagers	Godkendt NGC- budget 1000 DKK	Supplerende ekat. tilskud 1000 DKK	Status pr 31.10.1993	Aktivitet efter 31.12.1993
Industriel gasanvendelse: A Rekuperativ varmegenvinding ved Al-smeltning, Värnamo	1991- 1993	Sydskraft Konsult AB	Total: 350 1991: 120 1992: 230	SGC: 150 SEU: 105 Gjuteriet: 50	Installation og målinger afsluttet. Slutrapport leveret. Studiebesøg sammen med Al-messe i Jönköping.	
I Konvertering af kupolovn til gas- drift	1991- 1993	DGC, HNG	1991: 405	710 fra det danske miljø- ministerium og DGC	Installationen gennemført i april 1993. Målingerne var begyndt, da virksomheden lukkede pga konkurs. DGC sender en slutrapport inden årsskiftet.	Evt rapportering
I Glassmeltning i digelovn	1991- 1992	Glafo Växjö, British Gas, DTI Malmö, Nordisk glasindustri, NUTEK	Total: 1.750 1991: 670 1992: 650 1993: 430	SGC: 540 NUTEK: 1.000 Term.gas 225 Glasind.: 330	Forsøgene ved Kosta afsluttet med et godt resultat. Kosta overtager ovnene før kommerciel drift. Slutrapport trykkes i løbet af november	Evt. Demo- projekt afklares i løbet af efteråret. SGC accepterer, i givet fald, at videreføre projektet.
I Simultan Lav- NOx/CO- forbrænding	1991- 1993	IFRF	Total: 450 1991: 150 1992: 150 1993: 150	16.000 Hoogovens Labein/ Ensidesa, Jærnkant. SSAB/LKAB, NUTEK, CECA	Praktiske forsøg i Holland 93 og Spanien 94. Slutrapport til efteråret 94.	SGC har overtaget NGCs rolle i projektet og overvåger resultatet.
A British Gas, Coleshill projekt	1992- 1993	British Gas, Midland Research St.	1992: 600	3.000 British Gas, Gaz de France, Gasunie, Tokyo/Osaka Gas, Snam	Forsøget i Coleshill er gennemført i december 1992. Slutrapport oversendt i juni. Resultatet præsenteres ifm besøg hos Holmegård og PLM.	

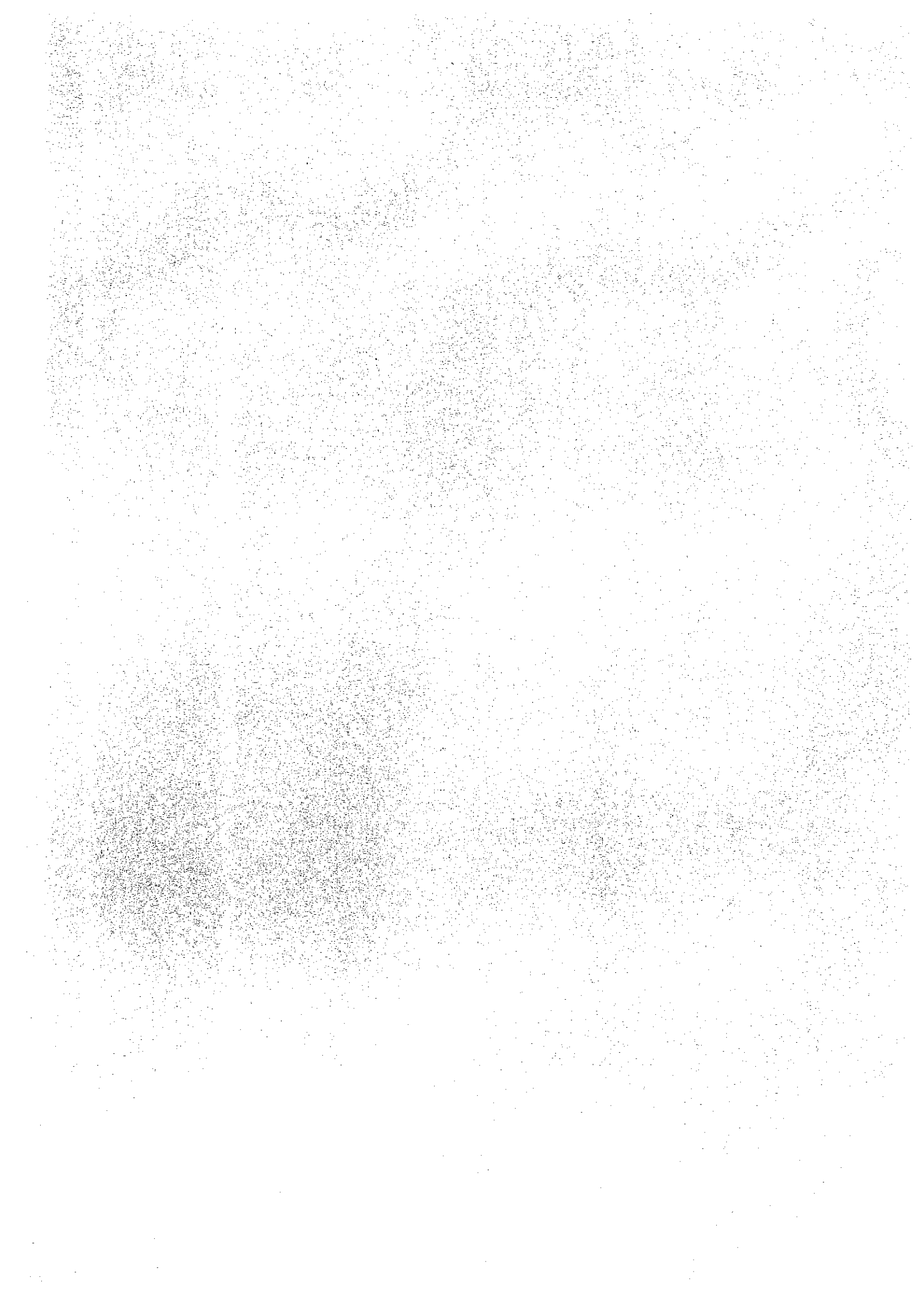
Projektområde/ projekt	Projekt- periode	Deltagere	Godkendt. NGC- budget 1000 DKK	Supplerende ekst. tilskud 1000 DKK	Status pr 31.10.1993	Aktivitet efter 31.12.1993
I GRI, Advanced Glass Melter projekt (AGM)	1992- 1994	GRI, Chicago	Total: 2.100 1992: 700 1993: 700 1994: 700	Ca 64.000 Southern California Gas, Consolidated Gas, Pacific Gas, DOE	Løbttest i gang. Pilotanlæg testes hos Knauf i efteråret. Statusrapport efter projektmede 19/10 hos GRI.	Beslutning om videreførelse i nov/dec 1993. Projektet kan i givet fald blive videreført af NGC- konsortium bestående af eksisterende ejerselskaber plus Statoil.
I AGM Ekspertvurdering	1992- 1994	Glafo	Total: 140	-	Ekspertbistand til NGC vedr AGM projektet. påbegyndt samtidig med statusrapport.	Jfr AGM
I Direkte væske- opvarmning	1992- 1994	Kemisk Apparattekn., Lunde Tekn. Høgskole	Total: 450 1992: 150 1993: 150 1994: 150	Ca 2.000 NUTEK, SGC, Värmeforsk., Sydkraft, Apparat- fabrikanter	Litteratur- studierne er gennemført og beregningerne er i gang. Ekspertiment pågår. Demonstration ved industrireference gruppemøde 2/12-93.	Afsluttende eksperiment samt rapport- skrivning er aftalt videre- ført af SGC.
I Modo Husum - vurdering af IR- tørring	1992- 1993	SGC, NUTEK, MoDo, Neste Gasol, DTI Malmö	Total: 150 1993: 150	Ca 300 SGC, Modo, Nutek, Neste Gasol	Projektet er forsinket bl.a. p.g.a. tekniske problemer. Mulig NGC besparelse på 100-150 DKK, hvis projektet ikke gennemføres i 1993.	Evt afsluttende eksperiment og rapport- skrivning overtages af SGC.

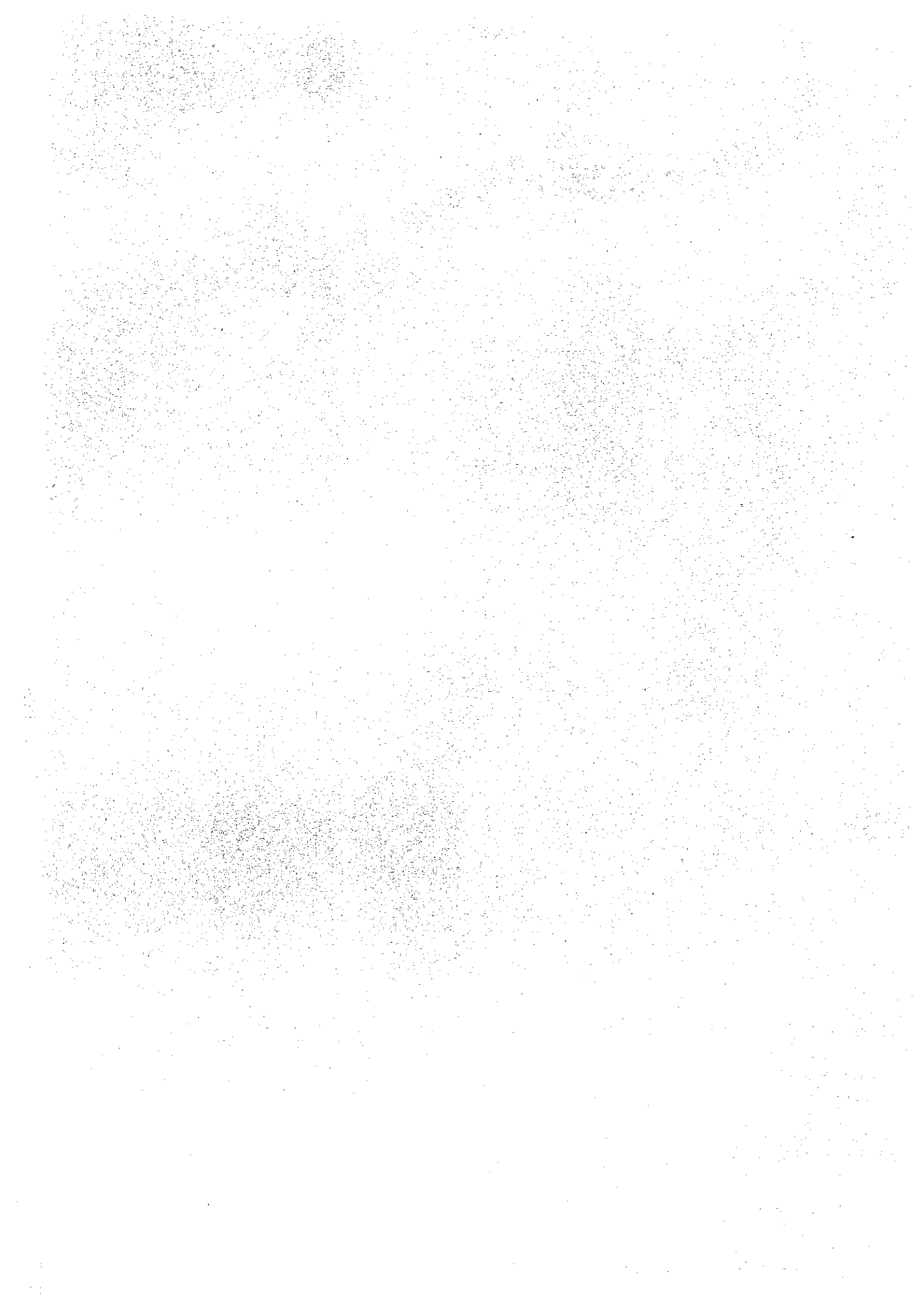
A: Afsluttet
I: Igangværende
O: Godkendte projektoplæg

**Status pr 31.10.1993 for igangværende
NGC-projekter samt projekter afsluttet i 1993**

Projektområde/ projekt	Projekt- periode	Deltagere	Godkendt NGC-budget 1000 DKK	Supplerende ekst. tilskud 1000 DKK	Status pr 31.10.1993	Aktivitet efter 31.12.1993
Energi- og miljøanalyser: A Naturgas til færger	1992	DTI, Naturgas Midt-Nord, Marintek	Total: 140 1991: 106 1992: 34	25 fra Naturgas Midt- Nord	Projektet vil ikke blive realiseret, fordi Miljøstyrelsen kun har bevilget 15% af det ansøgte beløb.	
A CO2-teknologi	01.08.92- 31.12.92	NGC	1992: 179		Projektet er afrap- porteret marts 1993.	
I Methanudslip i Norden 1992	01.02.92- 01.10.93	NGC, DGC, GRI, ejere	1992: 300	GRI vil bidrage med egne ressourcer og konsulent- ressourcer	Projektet afrapporteres i november/december 1993	
I LNG til lav- emissions otto- motor	01.03.92- 01.06.93	NGC, Marintek	Total: 500 1992: 260 1993: 290	12.200 NOK fra SPUNG- projektet	- Arbejdet med slutrapporten i gang. - Afsluttes i december	
A Nordisk Gasbus- projekt, Fase II	08.09.91- 01.06.93	Trafik- selskaber, Nordisk Industrifond, Gasselskaber Motorpro- ducenter, NGC	Total: 527 1991: 200 1992: 327	3.373 DKK fra trafikselek., myndigheder og motorprodu- center	Slutrapporten trykt. Afsluttes i december.	Videre nordisk informations- udveksling/ projekt- samarbejde varetages efter behov af Sydgas AB

A: Afsluttet
I: Igangværende
O: Godkendte projektoplæg





Danish Gas Technology Centre a/s 1993-1994

By Peter I. Hinstrup, President

Presented at the Nordic R&D Workshop 20 April 1994, Malmø. Arranged by SGC AB

Introduction

DGC was established in 1988 as the Danish gas companies' institute for consultancy and development in the field of gas utilization. DGC is owned by Dansk Naturgas A/S (47%), Hovedstadsregionens Naturgas I/S (18%), Naturgas Sjælland I/S (7%), Naturgas Fyn I/S (7%), Naturgas Midt-Nord I/S (15%) and Københavns Belysningsvæsen (6%).

DGC carries out consultancy, measurements, tests, computer simulation, etc. concerning small and large boiler plants, industrial gas utilization, cogeneration, and other fields of gas utilization.

The clients are Danish and international gas companies, power and heating utilities, manufacturing industries, public authorities, international organizations, consultants, etc.

DGC participates in joint European research and standardization collaborations and is project coordinator on a number of international projects in the framework of EU.

DGC has its offices and laboratory at the Natural Gas House in the Science Park at Hørsholm north of Copenhagen, Denmark.

DGC's laboratory is accredited under DANAK to perform testing of gas appliances as well as to carry out flue gas analyses.

DGC has a staff of 31 and an annual turnover of approximately 20 mill. DKK.

Residential Utilization

Introduction

By the end of 1993, approximately 225,000 single-family houses in Denmark were heated with natural gas. The number of new customers was approximately 15,000 in 1993. In 1994, a similar increase can be expected.

The end-goal with regard to single-family house customers is upwards of 300,000.

The field of residential utilization will thus still be developing in the coming years, and one of DGC's roles is to participate in securing that the quality and safety of the new installations are as high as possible. Furthermore, DGC will support the gas companies with technological service and consultancy in connection with the continued marketing effort and by solving problems in existing installations.

In the long run, an annual replacement of approximately 15,000 boilers can be expected. DGC's role in this connection will be to improve the standard and functionality of the installations through testing and development of new products and through offering consultancy to gas companies, installers and manufacturers.

Conculty and Technological Service

In 1993, DGC carried out laboratory tests of small gas consuming appliances such as domestic boilers, gas convectors and gas ovens. The tests comprise safety, efficiency, emissions, functionality and quality evaluation.

In connection with the introduction of a new requirement in the Danish Gas Code on installation of flue gas discharge safety devices on boilers with fan-assisted burners, DGC made a number of tests of these devices. At the end of 1993, standardized test requirements for this type of testing was agreed upon with the Danish Governmental Gas Institute.

In 1993, a number of preliminary tests of different types of gas and carbon monoxide detectors were initiated.

Safety in connection with vents on domestic boilers was an important issue in 1993. In the light of a number of malfunctions where vents had clogged up due to impractical design and insufficient maintenance, DGC prepared investigations and guidelines on this matter for the gas companies. On the basis of tests, a proposal for a new type of flue terminations has furthermore been presented. This work has been done in close collaboration with the Danish Governmental Gas Institute (DGP). In the first six months of 1994, DGP will manage an extensive random sample survey on this subject in which DGC will participate.

Work on developing the PC based consultancy tool, GASPRO, continued in 1993. In a dialogue with the user, GASPRO defines requirements to the gas boiler installation in a single-family house. On the basis of these requirements, the program suggests a number of boiler solutions and makes financial computations, etc. on these. The program is still only used sparsely outside the circle of the gas companies as it is not available in its final format and only comprises data on a limited number of boilers. These matters will be sought rectified in 1994, and the program will be marketed more widely.

In 1993, DGC carried out a study of the risk of ice formation in vertically balanced flues on domestic boilers. It can be concluded that ice formation only will constitute a problem in exceptional cases and under extreme weather conditions of rare occurrence.

Two guidelines were issued in 1993 on safety and quality in the field of domestic boilers.

The laboratory carried out a number of tests to examine the function of older gas appliances when exposed to different gas compositions.

Research and Development

At the beginning of 1993, DGC signed a contract with EU on the implementation of a significant joint European project on measurement of the efficiency of domestic boilers. Through theoretical examinations and tests, the 15 participating laboratories will attempt to harmonize their measuring methods so that the results of their measurements will be easier to compare in future.

In the middle of 1993, DGC was promised financial support under EU's SAVE programme for a project dealing with the development of common definition and calculation procedures regarding the annual efficiency of domestic boilers.

Both projects are supported financially by the EU because their completion will contribute to the technological harmonization in the field of natural gas and thus the realization of the single market.

DGC's long-term boiler development project supported by the Danish Ministry of Energy was completed at the end of 1993 with the publication of the final report. The project has led to the development of a new type of domestic boiler, and prototypes are planned produced in 1994.

The demonstration project on optimum combination of electricity and gas in a single-family house continued the compilation of data throughout 1993. The project was completed at the end of 1993.

DGC has worked on developing a new measuring method for the determination of methane emissions from small gas consuming appliances.

In 1993, DGC had talks with GASTEC in the Netherlands on the implementation of two development projects. One regarding the development of new labelling systems for domestic boilers and one comprising an examination of the reliability and durability of domestic boilers.

At the end of 1993, a study of the efficiency of fan-assisted burners at different operation parameters was initiated. The study will show the efficiency variation at different loads and thus which load is optimum for the individual boiler.

Large Boiler Plants

Introduction

In recent years, district heating plants and large boilers have to a wide extent been converted from coal and oil firing to firing with natural gas. The Danish gas market for district heating is on the whole fully devel-

oped and will in future mainly be characterized by partial conversion to cogeneration. For large industrial boilers, a switch to industrial cogeneration has become an interesting alternative after the introduction of the Danish CO₂ tax.

The technological development in the field of "large boiler plants" is thus modest and characterized by the solution of problems related to the operation, e.g. in connection with the transition to peak load unit or reserve load unit. In general, gas operation means a reduction in the emissions; there is e.g. no sulphur dioxide emission. This also entails that it is cheaper to install special equipment to enhance the energy efficiency as this equipment does not have to be constructed to sustain sulphurous flue gases. The enhanced energy efficiency may result in an additional reduction of the emissions.

**Conculty and
Technological
Service**

In 1993, work continued on the development of energy consultancy tools for improvement of the energy utilization in large gas-fired boiler plants. A catalogue on boilers and associated gas burners has been prepared. The optimum plant designs are described for different typical sizes of plants over 135 kW. The catalogue can be used both in the design of new plants and serve as a basis for comparison of existing plants before and after a planned renovation. The catalogue contains a description of the possible components and auxiliary equipment that can contribute to increase the energy efficiency and reduce the environmental pollution. A PC program exists in connection with the catalogue.

For Nordic Gas Technology Centre, DGC carried out a general analysis of the NO_x reduction technologies for large gas-fired industrial boilers as well as worked out a preliminary project on the NO_x reduction for a specific 22 MW industrial boiler installation in Sweden. In the report technological, financial and environmental conditions regarding flue gas recirculation, water/vapour injection, and low-NO_x burners are examined. Examples of typical emissions are presented as well as how the emissions depend on operational and adjustment conditions. On the basis of the preliminary project, it can be concluded that because of the Swedish environmental taxes considerable savings can be achieved by

reconstructing the boiler installation; most of these with simple payback periods of one to three years.

Research and Development

Over the last couple of years, DGC has worked on a large development project on noise attenuation in large boiler units. The project is carried out together with a number of collaborators and is supported financially by the Danish Ministry of Energy.

The project comprises three sub-projects.

The sub-project, *active noise attenuation*, aimed at counteracting combustion pulsations by controlling the gas or air supply. This principle has been demonstrated in simple tube burners but the tests showed that this is not possible in industrial and more complex burner geometries.

The sub-project, *source studies*, has developed a pulsator and a method for determination of the acoustic impedance of boilers as well as for calculation and measurement of the pulsation amplification of the burner (admittance). On the basis of these characteristics, the objective is to be able to assess the tendency of the entire unit to go into pulsation resonance. The first measurements were carried out at the end of 1993 and they are in the process of being evaluated.

The sub-project on the *origin and range of the noise* has developed a measuring system which is especially suited for determination of the noise range in the flue system from boiler to top of chimney. In addition, free field measurements on a burner have been made.

The project is scheduled for completion in 1994.

Industrial and Commercial Utilization

Introduction

It is expected that the use of natural gas for process purposes will increase significantly in Denmark over the coming years. One of the reasons is that the CO₂ legislation, which took effect for the manufacturing industries on 1 January 1993, has improved the competitiveness of natural gas compared to oil and coal. This has also boosted the incentive

to establish industrial cogeneration which in some cases will replace the decentralized gas application in the process. Different natural gas technologies may thus in some situations be competing against each other. The decentralized direct application in the process does however often offer a number of possibilities for improving the production methods and optimizing the energy consumption in the process.

There continues to be a need to develop new solutions for industrial and commercial gas utilization and to illustrate the advantages of the new solutions through demonstration projects. DGC assists the gas companies with establishment and implementation of demonstration projects and with consultancy, measurements and tests on safety, energy and environmental aspects.

Consultancy and Technological Services

In 1993, preliminary design, measurement assignments and laboratory tests on a number of existing and planned industrial and commercial installations were carried out. Examples hereof are dehumidification of process air, baking, preheating of combustion air, radiation heat units and cooling.

A technical note on cooling has been published which outlines the possibilities of constructing cooling systems based on natural-gas firing. The technological possibilities, the financial aspects and the potential gas sales are analyzed. The conclusion is that gas use first and foremost is feasible in medium-size and large industrial boiler plants. With regard to the smallest installations where the market today is dominated by electrically operated hermetic compressors, gas firing is hardly a feasible technical alternative.

DGC has carried out efficiency and environmental measurements on a natural-gas fired dehumidifier. The dehumidifier had previously been driven on electrically heated air. The conversion from electricity to natural gas has meant that the net energy cost of process air-drying has been reduced to 1/3 of the cost of electric operation.

Work on a safety random sample survey programme for gas-fired process installations continued in 1993 in the framework of the natural gas

companies and DGC. A total of about 80 random samples has been carried out. Reporting is scheduled for completion in the beginning of 1994.

In 1993, a prototype of a PC based fault registration system for large gas-fired installations was made. The prototype is tested by the regional gas companies. The system is expected completed in 1994.

Research and Development

The demonstration project on partial conversion of a cupola furnace continued in 1993. All installations were completed and tests showed that the technical concept functioned satisfactorily. A test run with the partially converted furnace with a conversion degree of about 15% was carried out. The test produced a fair quality smelted iron as well as showed that the smelting capacity had increased because of the conversion. Because of the closure of the enterprise the project had to be stopped and the test program was thus only partially completed.

Over a number of years, DGC has worked with infra-red burner technology both in theory and practice. In 1993, this led to a demonstration project scheduled to start in the beginning of 1994 and to a significant EU funded research project. The demonstration project comprises installation of gas-fired IR panels in a traditional convective oven for drying of powder painted subjects. It is expected that the gas based system will result in a 20 per cent reduction of the energy consumption per produced unit as well as increase production capacity with up to 25 per cent.

The EU research programme is carried out in cooperation with The Netherlands Energy Research Foundation (ECN). The objective of the project is to further develop and optimize gas-fired IR panels for industrial purposes. It is the plan to tailor the radiative properties of the IR panels so that they are adapted to the individual heating processes. Theoretically, it will then be possible to increase the total efficiency with up to 20%. A natural-gas fired IR system will thus become an attractive alternative to the best electrical IR systems.

Combustion Engineering and the Environment

Introduction

The total natural gas consumption in Denmark amounted to 2.2 bill. m³ in 1993. The consumption is divided between district heating plants (1/4), domestic boilers and larger boilers (1/3), and industry (1/3). Upwards of 6 per cent are used for electric power generation. In most cases, natural gas has replaced coal or oil. It is estimated that natural gas utilization resulted in the following reductions in emissions in 1993: 1.8 mill. tonnes of CO₂, 31,000 tonnes of SO₂ and 3500 tonnes of NO_x when compared with the fuels natural gas has replaced.

Natural gas offers particularly good possibilities for controlling the combustion process and optimizing energy and environmental conditions. DGC offers consultancy and carries out research projects on these possibilities.

Consultancy and Technological Services

In 1993, DGC assisted Nordic Gas Technology Centre (NGC) with a number of projects in the areas of combustion engineering and the environment.

In 1993, NGC started a detailed study of methane emission in the Nordic countries. DGC has assisted in the compilation and reporting of data. It is concluded that the total Nordic methane emission from production, transmission, and distribution of natural gas can be assessed at approximately 30,000 tonnes annually. This is the equivalent of an average leakage rate of approximately 1 per cent of the natural gas consumption which is in the same order as the current global leakage rate. The main part of the methane emission comes from joints in the old cast iron network in the Copenhagen area. The ongoing relining of the network is scheduled for completion in 1996. The methane leakage rate in the Nordic countries will then have been reduced to approximately 0.2%. The study did not include methane emissions from gas appliances but DGC is presently working on this problem (cf. Residential Utilization). The report concludes that the existing leakage rates are so small that it continuous to hold true that natural gas is superior to coal and oil with respect to the greenhouse effect.

On behalf of NGC, DGC has furthermore carried out a functionality test of a new edp simulation program for reburning calculations. NGC financed the development of this program at SINTEF in Norway. Reburning is the name for the technology where natural gas is used to reduce the NO_x emission from e.g. refuse incineration (cf. Research and Development below).

As part of a follow-up programme in the field of biogas, the Danish Energy Agency had asked DGC together with Naturgas Midt/Nord I/S to work out an investigation into combined use of biogas and natural gas. The work was reported in June 1993. The report concludes that it is technically possible to remove the water vapours, carbon dioxide and hydrogen sulphide contents from biogas and thus upgrade biogas to natural gas quality. It will be fairly costly to cleanse biogas to a degree where it has the same combustion characteristics as natural gas. Whether such an upgrading is necessary depends on the planned field of application. By far the most severe demands to upgrading are made when biogas is to be mixed with natural gas in the natural gas network. This possibility, however, entails considerable operational advantages for the biogas unit since it can be designed and operated independently of the local gas market. At the end of 1993, DGC was asked by the Danish Energy Agency to prepare a supplementary investigation into upgrading of biogas. It will comprise a detailed outline of technological and financial aspects in connection with upgrading to natural gas quality as well as the possibilities for transport through the natural gas network.

Research and Development

In 1993, it was decided that DGC would become involved in the field of reburning as a consequence of the closure of Nordic Gas Technology Centre (NGC) at the end of the year. Over some years, NGC has in collaboration with external researchers gathered knowledge and experience on an international level in this field. DGC will attempt to continue this involvement and combine it with its own expertise especially on combustion modelling. DGC's strategy is - while offering financial support to external research activities - to attain an active part in simulation and design of installations with reburning technology.

Together with the Gas Research Institute (GRI), USA, DGC entered into an agreement with the Department of Chemical Engineering at the Technical University of Denmark at the end of 1993 on support and collaboration on an empirical and theoretical project on examination of nitric chemistry at low combustion temperatures. The aim of the project is to gain additional understanding of the reaction between hydrocarbons and nitrogen monoxide in order to optimize the reburning process. The project is a continuation of the department's work on reburning which up to now has been supported by NGC and GRI.

In the field of reburning, DGC furthermore expects to become involved in model computations and control measurements at a future refuse incineration plant. Tests already made at an existing refuse incineration plant have shown that it is possible through reburning to reduce the NO_x formation at combustion of coal and refuse with approximately 50%.

Over a number of years, DGC has with support from the Danish Ministry of Energy's Research Programme worked on edp simulation of combustion and fluid engineering phenomena. The purpose has been to compile knowledge and experience on these advanced computational tools with a view to application in development and consultancy assignments. In cooperation with others, computations of the dispersion of gas from a leakage in a confined space have been carried out in a joint research project. The computations can be used for risk assessments and determination of the point in time when the explosion limit is reached after leakage of gas. Furthermore, the computations can be used for appropriate positioning of gas leak detectors as well as positioning and dimensioning of vent holes.

Cogeneration

Introduction

By the middle of 1993, approximately 130 local cogeneration plants with a capacity of around 400 MWe had been built. 50 medium size and large plants are scheduled.

Upwards of 70 per cent of the capacity of electricity production is gas-fired. There are 120 natural-gas fired plants with a total of 200 gas

engines and 16 gas turbines. The cogeneration development will continue in the coming year where an increase in the number of industrial cogeneration plants can be expected.

The days of breaking new technological ground for small cogeneration plants are over. The various technologies have been tested and the technological interest focuses on the possibilities of continuous improvement of the energy efficiency and emissions. DGC is engaged in two research projects in these areas and has continued the gathering of experience on existing plants through the carrying out of a number of measurement assignments.

**Consultancy and
Technological
Services**

Approximately 10 new measurement projects have been carried out on gas-fired engine plants. The measurements comprise conditions concerning the environment and efficiency in connection with handing-over environmental certification and the like.

Today a considerable amount of knowhow exists at DGC on the operation of these plants. This knowhow constitutes the foundation in the ongoing solution of special consultancy assignments in this field.

**Research and
Development**

In cooperation with others, DGC carries out a demonstration project where the effects on efficiency and emissions of humidifying intake air for gas engines are examined. The test results up to now seem promising with regard to NO_x reduction.

The project on new catalysts for Lean Burn gas engines continued in 1993 with the establishment of a test facility, and DGC has carried out the first measuring series.

Both projects are co-funded by the Danish Ministry of Energy and are scheduled for completion in 1994.

In 1993, measurements on two buried horizontal heat accumulation tanks each containing 70 m³ water were carried out. The tanks form part of a 500 kWe cogeneration plant and are equipped with a new diffusing system which has proved to work satisfactorily. Filling and emptying

tests have been carried out on the tanks in series and parallel connection, respectively. Series connection turned out to yield the best tank utilization. The test results have now been implemented in the production of these tank systems at several suppliers.

DGC supports a project at Aalborg University Centre on the installation of a vibrationless single cylinder engine/generator unit for use in connection with small cogeneration units in e.g. single-family houses.

Other Activities

Pipelines

DGC is assisting the gas companies' Technical Committee on Pipelines with administration of projects on plastic and steel pipelines but has no projects of its own in the area.

With regard to plastic pipelines, projects have dealt with repair methods, safety regulations, design basis for PEM pipelines, assessment of tracing equipment, material specifications, etc.

As regards steel pipelines, DGC has participated in a joint European project on repair methods.

Meters, etc

In 1993, DGC constructed a test rig for long term testing of new types of gas meters for domestic installations. Three different meter manufactures were being tested at the end of the year; at that time they had undergone half of 5000 hours of constant operation under maximum gas flow.

Another test rig will be established because four more meter types are required tested.

A number of tests have been started in the laboratory for the examination of pressure reducers that fail in frosty weather. The tests will comprise both new and used reducers.

Furthermore, DGC has participated in the preparation of an inspection guideline for large meters; and in the evaluation of data gathering and transmission devices for remote meter read-off of large consumers.

**Gas in the
Transportation
Sector**

The transportation sector contributes substantially to the pollution in Denmark; e.g. more than a third of the total nitric oxide pollution (NO_x) derives from this sector. This considerable strain on the environment is closely connected to the extensive energy consumption in this area. More than one third of the total Danish net energy consumption is used in the transport sector. Both from an environmental and a commercial point of view, the sector is thus interesting in relation to gas. In the beginning of 1993, the gas companies behind DGC sat up a working group to examine this subject. In October 1993, this working group published a report on the situation. In this report it is concluded that the Danish transport sector's considerable strain on the environment can be reduced if natural gas is introduced in diesel fuelled buses and other commercial vehicles such as lorries and vans. Today some buses are produced specially for natural gas operation and a similar production of vans, lorries and cars is rapidly emerging. The commercial availability of such tailor-made vehicles for natural gas operation is considered to be an essential parameter in the development of the market. Today natural gas is uncompetitive as fuel for vehicles compared to petrol and diesel. This is due to the high cost of conversion of vehicles and establishment of filling stations. In addition, petrol and diesel are relatively cheap fuels in Denmark. It will be up to the politicians to decide whether the additional pollution caused by petrol and diesel warrants a tax regulation that will force up the price level of these fuels.

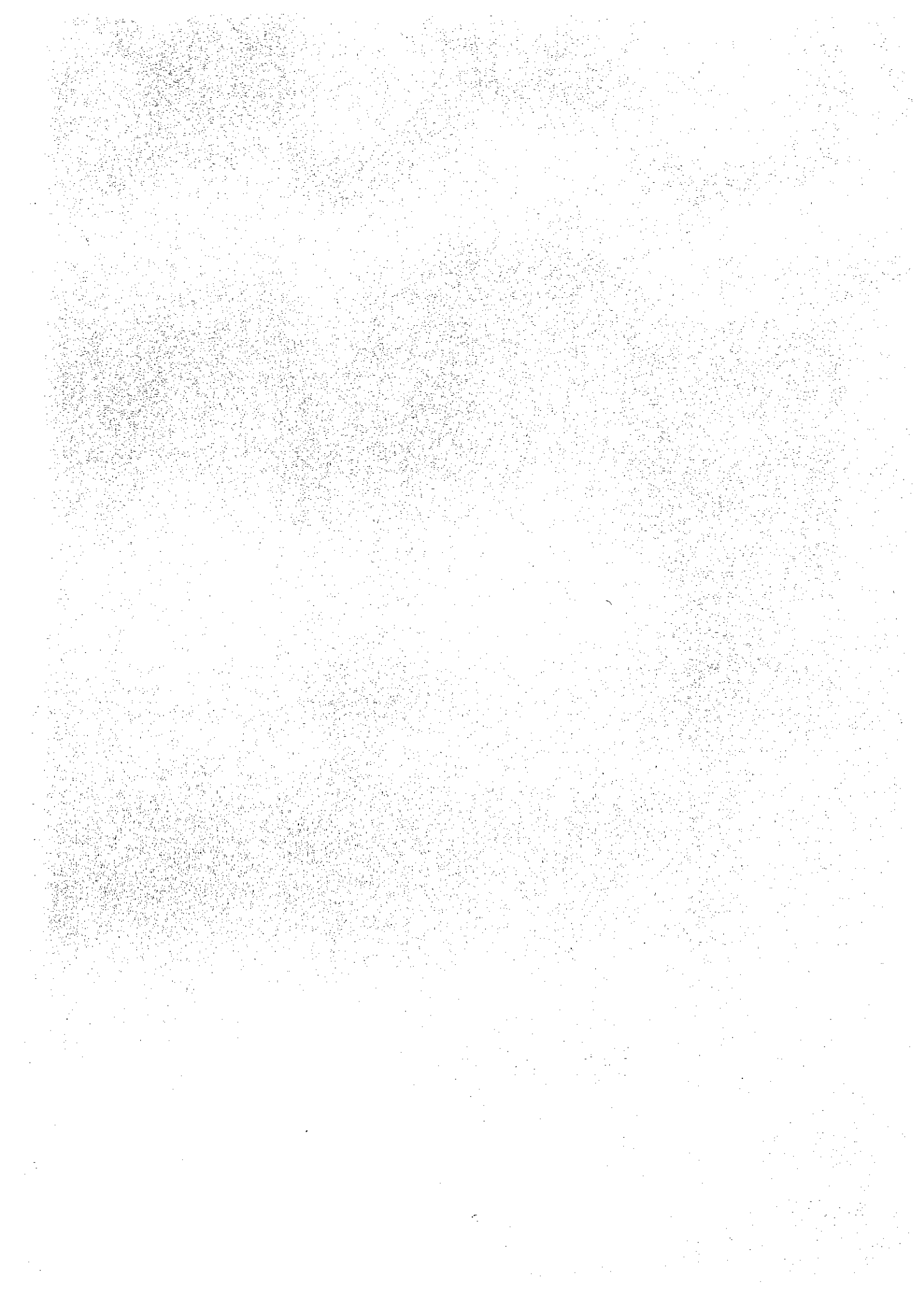
Today natural gas is used in vehicles all over the world (about 3/4 mill. vehicles), and over the last couple of years, this field has experienced great increase in the interest internationally. In the beginning of 1994, the Danish gas companies' working group will propose a strategy for the companies' further activities in the field.

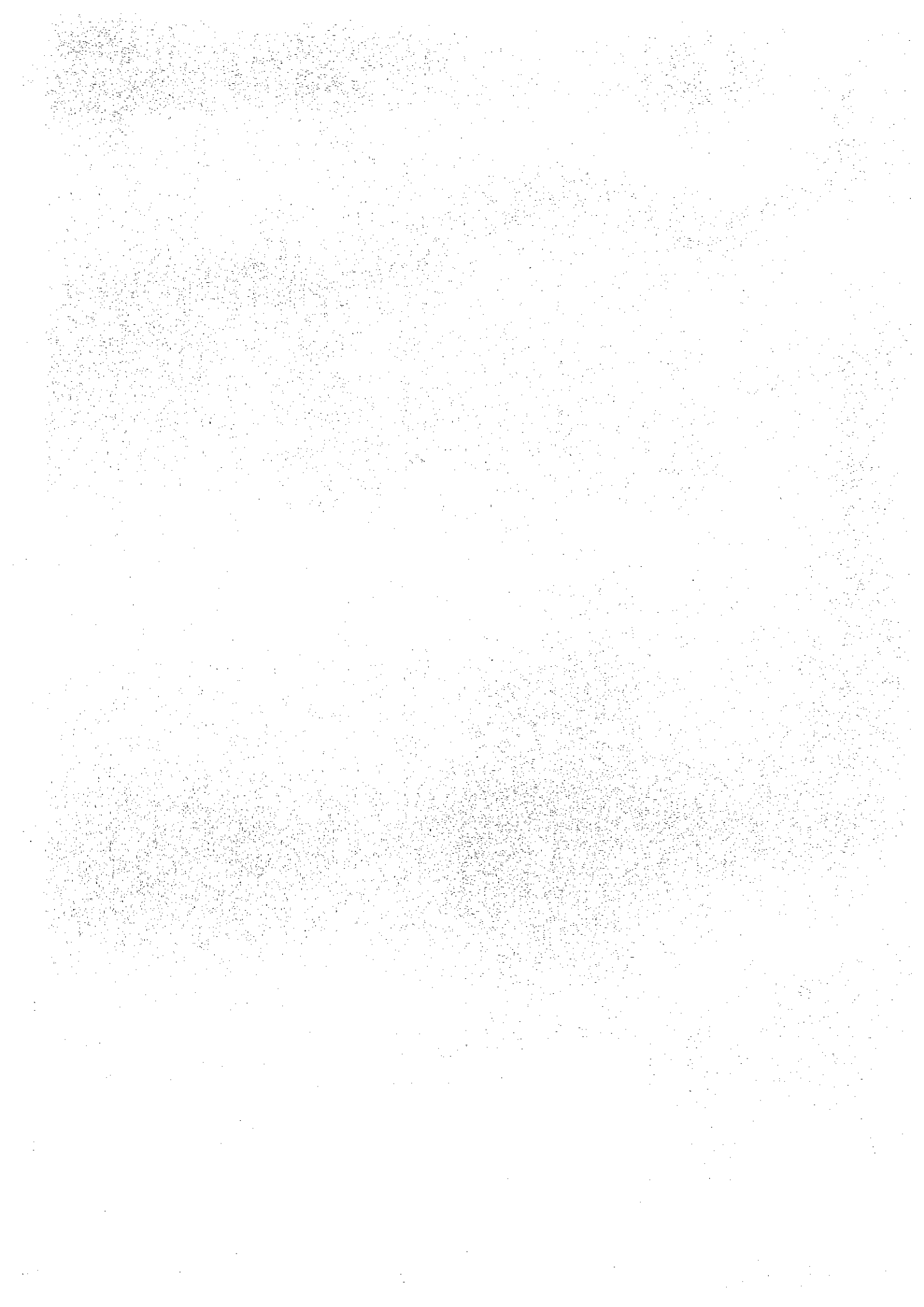
Through 1993, the gas companies and DGC ran a demonstration project on domestic filling stations for natural gas fuelled vehicles. A total of three filling stations have been established and five more will be established. The stations are to service seven vehicles that have been converted to natural gas operation. One of the stations is situated at the Natural Gas House for servicing of DGC's measuring van that has been converted to natural gas operation. Approximately seven months of experience with

the running of the filling stations have not given rise to any serious problems. The project continues in 1994.

**Danish Gas
Association**

DGC handles the practical secretariat work for the Danish Gas Association (DGF) and manages the running of the association's supplementary training programme. DGF's course programme comprises approximately 20 training courses, and other events.





Gas Technology R&D within Finland

Dr Pekka Särkkä
Neste Oy Natural Gas

GAS TECHNOLOGY R & D WITHIN FINLAND

Dr. Pekka Särkkä*
Neste Oy Natural Gas

The activities in Finland during the last year show slightly more interest in research, development and demonstration than in the preceding one. The areas of interest may be divided into two major groups:

- the further development of already commercialised products, like
 - gas diesels and their applications
 - new ways to assemble LNG tanks
 - the use of LPG in heavy traffic
- the development of new uses or new equipment for gas industry, like
 - the use of natural gas in the heating or cooling of houses in Finland
 - different ways to diminish the VOC (Volatile Organic Compound) emissions

The latter group has mainly newly begun projects with no results yet, the former however has reached some interesting breakthroughs in the last year.

GAS DIESEL TECHNOLOGY

In terms of efficiency no other engine type can compete with the diesel. Fuel accounts for most of a power plant's operating costs, typically about 60 to 70 %. Although this may vary from one application to another, high efficiency is still the most important feature of a prime mover (Fig. 1). Furthermore, the gas diesel is the only prime mover suitable for part load operation (Fig. 2).

Existing regulations for nitrogen oxide emissions do not necessarily guarantee the health of the planet and its inhabitants. Legislation is more likely to reflect what is feasible at reasonable cost and with existing technology. Stricter regulations will be passed as fast as technology is improved.

From this point of view emissions of nitrogen oxides from the gas diesel are just as bad as those from standard versions of any other engines. The latest test results with Wärtsilä Diesel's gas diesel show however, that with different primary methods such as engine tuning, EGR and secondary methods such as SCR technology, the gas diesel can reach extremely low levels of NO_x without excessive penalties in fuel consumption. Based on these technologies, a NO_x level of 0.2 g/kWh is already a reality (Fig. 3).

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Multi-fuel capability makes it possible to switch fuels, without any loss in efficiency. This guarantees continuous economic power production even with rising fuel prices or supply problems.

Gas Diesel

The designation Gas Diesel refers to how fuel is introduced into the cylinder and ignited. Fuel is injected at high pressure, normally more than 300 bar, directly into the combustion space as in a normal diesel engine. Due to the relatively high ignition point of the gaseous fuels (natural gas, petroleum gas) a small amount of diesel oil or heavy fuel (3 % of total fuel oil consumption) is used as an ignitor. Both fuels are injected into the cylinder close to the "top dead centre" of the piston at the end of the compression stroke. This is achieved with a specially designed dual-fuel injection valve located in the centre of the cylinder head (Figs. 4 and 5).

The gas injection is controlled by the control oil system, a hydraulic system, which opens and closes the gas injection valve and hence regulates the amount of injected gas according to the load on the engine (Fig. 6).

All gas pipes on the engine are of the double wall type, which prevents any gas leakage into the open air. The annular space is continuously vented and equipped with a hydrocarbon sensor for detection of any leakage.

Every cylinder on the engine is equipped with a mechanical shut-off valve, acting on differential pressure. This quick closing valve will interrupt the gas supply to the cylinder if the gas injection valve is stuck open, thus preventing the cylinder from being overloaded.

An electronic control system is used to perform several different tasks. The system controls speed and load, and starts the compressors. In the event of an interruption in gas supply or any other disturbance, the engine will switch over to operation on the back-up fuel (diesel or heavy fuel oil) without change in frequency or alternator output (Fig. 7).

The rest of the main components are "state-of-the-art" equipment designed to withstand the severe conditions during heavy fuel oil operation. This means that following diesel engine characteristics are preserved:

- Higher efficiency than in any other prime mover. The difference compared with gas turbines is even more pronounced on part load. The very flat efficiency curve of the gas diesel makes it excellent for both base load operation and peak shaving.
- Very good ability to pick up load rapidly. Time from start of the engine to full power can be less than 30 seconds, including synchronisation to the grid.
- Fast reaction to load changes which is particularly important in parallel operation with several engines.
- Insensitive to a wide range of gas and oil qualities.
- Efficiency and output insensitive to changes in ambient conditions (Fig. 8).

Emissions

Due to complete combustion with high efficiency, the emission of hydrocarbons and carbon monoxide are on lower level than those from other prime movers. A pollutant of growing interest is CO₂, because CO₂ is by far the largest contributor to the greenhouse effect. As a consequence of the low fuel consumption of the gas diesel, the CO₂ emissions are much lower than for any other prime mover using fossil fuels (Fig. 9). The amount of unburned hydrocarbons and CO from the gas diesel are also low, and because natural gas usually contains no sulphur, the SO_x emissions are not a problem. Test results with the gas diesel equipped with EGR (Exhaust Gas Re-circulation) show that emissions can be reduced by 65 %, with only a small loss in efficiency. With the addition of SCR technology the NO_x emissions can be reduced to less than 0.2 g/kWh, which should satisfy all future standards.

Different ways of expressing the amount of pollutants in exhaust gases can sometimes cause confusion. PPM and "mg/MJ fuel" are most often used. To determine the actual impact on the environment the expression g/kWh (kWh produced electricity) is more adequate. Differences in exhaust gas mass flow and efficiency may obtain a given emission level to look quite different depending on how it is expressed.

Fuel flexibility

The Wärtsilä Vasa engines have an excellent performance in heavy fuel operation, too. The Vasa 32 was the first medium speed diesel engine in its class to be designed for heavy fuel operation. More than 1300 engines have been delivered since 1978, with more than 5600 MW in service today.

The Vasa 32 gas diesel is based on the same engine, and with only minor modifications to the injection system. The same basic engine can now be operated on fuels such as diesel oil, heavy fuel oil, natural gas and LPG. The ability to switch between fuels makes it possible to counter fuel price rises or supply problems. High efficiency is maintained regardless of fuel type.

Field experience

Development of the high pressure gas injection concept started in 1987. After extensive R&D including laboratory tests, three different pilot installations were selected. All of these were delivered to customers during 1990. These were the first gas engines to run according to the gas diesel concept with high pressure gas injection.

An extensive field follow-up program was set up to make optimal use of the initial information from "real-life" operation. This program includes mapping of performance data such as heat balance, emission levels and the mechanical performance and wear values for the relevant engine components.

The results from these pilot installations prove that the gas diesel concept also works in real operation, with both high reliability and with a minimum of maintenance. In terms of performance values, the high expectations have also been met. Based on the positive results from two years of operation of these pilot plants, the Vasa 32 gas diesel was released in 1993 for commercial sale.

Further development - the VASA 46 gas diesel

The Wärtsilä Vasa 46 was introduced in 1987 and is now also a prime mover in large power plant applications. As a consequence of the positive feedback from the pilot installations with Vasa 32GD, the development of the larger Vasa 46GD was started in 1991.

The Vasa 46 Gas Diesel will to large extent have the same conceptual design as the Vasa 32. The injection system will, however, have electronic control (Fig. 10). This means greater freedom for adjustment and optimisation of fuel consumption and emissions.

The initial tests with the Vasa 46GD were started in July 1992. The results are promising and the contract for the first pilot installation was signed at the end of 1992. The installation will be located in the centre of London, and will comprise two 18 cylinder Vasa 46 gas diesels. The electrical output from these engines will be 32.5 MW. The main fuel will be natural gas and heavy fuel will be used as a back-up fuel. At the moment more than 100 MW of Vasa 46GD are under installation.

The commercial operation with LPG as the main fuel was started in the end of 1992 at Oskarshamn in Sweden. This installation consists of an 18 cylinder engine with an electrical output of 7.3 MW.

Another goal of intensive development work is to eliminate the need for pilot fuel as an ignition source. This would be useful for example in remote areas such as in pipe line compressor stations, where the transport of the pilot fuel may be costly and troublesome.

Gas diesel compressor stations

A few years ago Wärtsilä Diesel started to look into a totally new application area, compressor stations for natural gas pipelines based on gas-driven Vasa engines. The work has resulted in two compressor station versions based on the Vasa 32 and Vasa 46 gas diesel engines. These are simply called gas diesel compressor stations (GDC) /1/.

When work began on the conceptual design, it was agreed to do two versions of the GDC stations, one for distribution purposes and another for transmission. The first one was based on the Wärtsilä Vasa 18V32 and the second one on the Wärtsilä Vasa 18V46. Both use a conventional configuration comprising three gas diesel compressor sets. Two of them are running and one is on stand-by.

The gas system basically conforms with the designs required for these stations. The gas compressors for both GDC stations are of a 2-stage centrifugal type with a pressure increase ratio of around 1.5. In general, compressors of this size are only built as centrifugal types. They are shop-assembled on a base frame, including all the auxiliaries needed and equipped with lubrication oil systems, instrumentation and controls. The capacity of the compressors is controlled by varying the engine and compressor speed with an electronic control system.

Shaft speeds for centrifugal machines are many times higher than for the diesel engines. Consequently there must be a gear-box between the engine and compressor to bring the engine speed for the 32 type from 750 rpm up to approximately 10 500 rpm and for the 46 type from 514 rpm up to 7 200 rpm.

The both engines are equipped with the direct gas injection technique used in the ordinary Vasa gas diesels. The technique is advantageous for this application, because high inlet gas pressures (approximately 70 bar) can be used for the small fuel gas compressors feeding gas to the engines. The fuel is taken directly from the pipeline and provides a small compressor with a small internal electrical consumption. The compressor is still designed for feeding gas with an inlet pressure of about 30 bars, due to the rare low pressure situations in the pipeline.

The station is designed for remote control with separate control and automation units for the diesels and the compressors. These units are all connected to a single main station control system.

The power for the station's internal electrical consumption is supplied by cable from a common electrical grid. However, a full size back-up generating set installed on site is also considered in the planning. The electrical back-up increases the redundancy on the electrical system and significantly contributes to the reliability of the GDC station.

GDC installations in industrialised countries also have to meet official requirements for exhaust gas emission, noise and safety. These have been considered in the conceptual designs. In many countries the requirements are not so strict and simpler systems for emission control and automation can be used.

The conceptual GDC station comprises of two buildings (Fig. 11). The main building houses the gas equipment, main engines and auxiliaries. For safety reasons all electrical equipment and the control room have been located in a smaller building together with a work-shop a short distance from the main building.

An economical feasibility study was completed after the design, showing that GDC stations for distribution and transmission purposes are competitive compared with gas turbine solutions. The investment costs as well are in a good range for both GDC station types.

CONSTRUCTION DEVELOPMENT OF LNG TANKS

Kværner Masa-Yards has systematically built up LNG shipbuilding knowledge during the last four years. This process has included design tools for purely technical and techno-economical purposes. Extensive development work has been carried out to increase productivity and quality of manufacturing of spherical cargo tanks over the past years. Main efforts have been concentrated around forming and welding of thick wall aluminium plates.

Moss type LNG carriers

A Moss type LNG carrier is basically a ship constructed around a row of spherical LNG tanks. It provides alternatives as to tank number, size and their arrangement. A profitable end product, a favourable ship combination, requires balance between the cargo containment system and a number of other technical solutions such as speed and power of the vessel, light weight, hull lines, other tank arrangements, terminal requirements, seaworthiness etc. and production techniques as well as low operational costs.

Manufacturing development

Development of alternative production methods of large LNG-spheres started in 1989 at Turku New Shipyard. After a number of shop tests in miniature and full scale, shell parts of spherical 15 000 m³ and 33 750 m³ LNG tanks were produced by using new methods.

The entirely new method consists of the use of large multiplated welded panels. After high energy MIG welding in flat (1G) position, the panel is precision cut by NC plasma arc cutting machine and then heat die-formed to an exact spherical curvature.

The application of high energy MIG welding in flat position makes 55 % of the total welding. Fig. 10 indicates the new concept of large segments and the welding lengths on spherical shell.

The new manufacturing process of plate segments is described in Fig. 12 as follows:

1. The flat raw plates are machined using accurate stationary bevelling machine to achieve desired edge preparation prior to butt welding.
2. Parts of the segments are cut by using NC water injected plasma arc cutting machine.
3. The plates are joined together and welded on a vacuum clamping table by using automatic high energy MIG welding in flat position.
4. Welded multiplated shell segments are precision cut to the correct shape by using wide track NC water injected plasma arc cutting machine. An automatic plasma bevel unit is used for specified edges prior to 3G welding at assembly stage.
5. The multiplated segments are formed to exact spherical curvature by using new thermal process developed and tested during an extensive R&D project.

The construction of heat forming dies is unique compared with conventional hot forming dies. The frame structure of female and male parts is designed and manufactured as units. The curvature has been compensated for springback based on test results and finite element analysis. The construction of the frame is rigid enough to prevent deflections and at the same time open enough to save energy and process time. In addition the new method offers easy change of radius compared with conventional hot forming to reasonable costs. The Unit Manufacturing method guarantees high accuracy using NC water injected plasma cutting combined to automatic 4-fillet welding of the frame crossings. A pair of actual size dies for 15 000 m³ and 33 750 m³ spheres has been successfully manufactured as a part of shipyard's extensive R&D project. The 15 000 m³ tank test production die and formed plates are shown in Fig. 13.

Integrated dimension control of the manufacture and assembly of spheres is one of the key points in reducing total costs. Advanced software technology combined to 3-D shape measuring system has been developed for on-site measurements. New programmable optical coordinate meter measures distances by pulsed time-of-flight (TOF) principle with an accuracy of 1 mm. Measurement results can directly be compared to design values. The new system is much more user-friendly and accurate than the conventional ones.

Welding and bending technology

Welding as well as bending are key technology areas in the production of spherical LNG tanks. The thickness range 30 to 70 mm of used material (A 5083 aluminium alloy) doesn't have a large number of other applications. This seems to have resulted to quite a stationary status of these technologies after strong development period in late 60's and early 70's. Limited competition might also contribute to slow technological development. This situation has created a market for development work to raise technology level distinctively to match the 90's or even that of the next decade's.

Large plate and section sizes have both in tank building and shipbuilding a strong impact on productivity. Another known factor is the importance of accuracy in size and shape. These two factors are important separately, but especially together. The difficulty has been that when the level of one is raised the other tends to descend. This discrepancy forces to find a solution where these two main factors support each other rather than conflict.

High productivity of welding requires often high accuracy of the parts to be welded. High accuracy can also be maintained for the next work stage. This justifies well the application of high energy MIG or other advanced processes with above mentioned ordinary features in the early stages of tank production. This is as well an obvious reason to extend "the early stages of production" as far as possible which leads to the use of multiplated panel and new bending technology. However, the further the production proceeds the more difficult it is to maintain accuracy and thus high productivity in welding. Therefore new welding process had to be available to allow higher tolerances without loss of productivity. Electro-gas welding (EGW) process has besides these characteristics been experienced to produce welds with very low defect rate in shipyard production. This suggested to develop EGW process for thick A 5083 alloy. After several years of R&D work it is now possible in both laboratory and production conditions (Fig. 14).

New bending technology was developed to allow the use of multiplated panel. This requires the ability to bend large welded panel over 100 m² without unreasonable investment cost. Additional requirement was set on high accuracy after bending. Small scale testing and non linear FEM calculations using ADINA programs in Cray super computer were applied to establish the technology for sphere shape bending of large multiplated panel. FEM calculations and metallurgical studies suggest to apply heat and mechanical force simultaneously whereas previous known technologies apply either mechanical force or heat separately.

First FEM calculations indicated relatively large spring back and elongation values. Combining the advantages of FEM calculations and small scale testing it was possible to reduce both elongation and spring back value to approximately 1/10 of those originally calculated. Spring back values correlate to process temperature and thickness to curvature radius (t/R) ratio when heating and force cycles synchronisation is kept constant. For chosen temperature the tested t/R ratios vary between 1/333 to 1/625 where 135 000 m³ tanker t/R values are around 1/400.

Bending plates to a part of 15 000 m³ spherical shell showed that advanced bending dies (Fig.13) give good result and the tolerances given earlier can be reached.

Welding

High energy MIG process has been used earlier with good results at many shipyards. With the possibility of bending large multiplated sheets the process can be applied now on flat panel (Figs. 12 and 15). The welding can be done without tilting jig and machining of weld grooves can be done with powerful plane bevelling machine. This makes it easier to apply also more complex groove shapes (Fig. 15) to improve weld quality.

The used groove forms (Fig. 15) allow one pass welding on each side with high amperage (app. 700 A). A productive welding speed, 25 cm/min for 46 mm thick plate and very low defect rate and welding distortions can be achieved. Welding of balanced passes on both sides with vacuum clamping provides angle deformation close to zero. Other deformations (longitudinal and transverse) do not affect the accuracy in next production steps as plasma cutting of the multiplated panel follows flat position welding.

At assembly stage the hot formed large multiplated panels will be automatically welded in 3G and close to 3G position with high efficiency EGF process (Fig. 14). Advantages of this process are high productivity, very low deformation and relatively large weld groove tolerance (Fig. 16).

LPG FUELLED HEAVY DUTY VEHICLES

The three-way catalyst has dramatically reduced emissions from gasoline fuelled passenger cars. In contrast technology that could cut emissions to a corresponding degree for diesel engines is not currently available. One way to meet the most stringent emission requirements is to convert the diesel engine to use a gaseous fuel.

The Technical Research Centre of Finland and a Finnish truck manufacturer, Oy Sisu-Auto Ab, have in this project converted the diesel engine of a two-axle truck into a spark ignition engine fuelled by LPG. The converted engine was a six-cylinder 185 kW Valmet 612 diesel with turbocharging and intercooling.

Both LPG and compressed natural gas (CNG) have similar potential for low emissions but LPG is easier to store, distribute and refuel. Compared with diesel, LPG requires twice the tank volume for the same driving distance and can be stored in one third of the volume required for CNG at 200 bar.

The principle

The original diesel injection system was replaced by a distributor and spark plugs. The combustion chamber was changed and thermal stresses were reduced by improved cooling of the cylinder heads. A closed-loop controlled gas system including an oxygen sensor was used to meter fuel. A Kemira three-way catalytic converter was also fitted.

The output of the naturally aspirated 7.4 litre engine was 135 kW following conversion. Peak torque was 580 Nm at 1000 - 1200 rpm and the compression ratio was 10 to 1. Two LPG fuel tanks with a net volume of 173 litres held sufficiently fuel for roughly 350 km. Refuelling takes place in a conventional way, except that a pressurised filling hose and connector are used.

The situation

The converted truck weighed 5600 kg with a maximum load of 11 400 kg. Over a period of two years it was tested both in laboratory and in commercial use by the Technical Research Centre of Finland. The truck was used for maintenance and garbage operations around Helsinki, in Finland, and covered about 30 000 km in 1000 hours of service.

During tests the truck performed well. The converted engine has an ideal torque curve for a truck engine. The useful engine speed range starts from 600 rpm which allows for good acceleration from a stationary position. Torque was not limited at low engine speed as it is in turbocharged diesel engines to reduce smoke emissions. Cold starts were easy.

The acceleration and final speed of the vehicle were roughly 15 % lower than those of a turbocharged and intercooled diesel vehicle. This was better than anticipated. The maximum thermal efficiency of the converted engine was 37 % which is slightly lower than that of a conventional diesel engine. Emission values (Fig. 17) were well below ECE-R49.01 limits imposed for the original diesel fuel and also well below the forthcoming Euro II limits for 1995 - 96. No smoke or bad odours were emitted.

Although the fuel consumption is higher than that of a diesel engine the emission of carbon dioxide does not increase; LPG has less carbon in proportion to hydrogen than diesel. The total emission of greenhouse gases, if production of the fuel is included is lower for LPG than for diesel. The noise level was 74 - 78 dB compared with 80 - 82 for a diesel engine.

Encouraged by the results, Oy Sisu-Auto Ab has delivered six more trucks for further tests in five Finnish cities. Small scale commercial production of the truck has planned to start in 1994.

Conversion of the diesel engine costs USD 10 000. In mass production the price of the truck will be about 10 % higher than that of a diesel truck.

During the two-year test the truck consumed about 50 litres of propane per 100 km. In terms of energy this is equivalent to 33 litres of diesel fuel - 20 % more fuel than an ordinary truck would use. The cost of operating the LPG truck in Finland is similar to using diesel fuel, as LPG is nearly a third cheaper than diesel fuel in Finland.

Development

In the Greater Helsinki area a gas fuelled MAN/ÖAF bus was tested in 1991 - 1992, during which the bus travelled altogether 150 000 km /2/. This distance was driven without any significant damages or faults. The operation was disturbed primarily by minor faults related to electric equipment, and also by small mechanical faults. The faults were in part due to the lack of experience of the service personnel, and in part due to the fact that the chassis was the first MAN chassis with a rear mounted gas engine.

The efficiency of the original catalyst started to fall around 80 000 km. This corresponds to the experience from Vienna. At 100 000 km, a fault in the lambda sensor occurred, and it had to be replaced. This was indicated by a slightly rich mixture. At 125 000 km, the catalyst was replaced with a new one from Kemira Oy.

With the original catalyst, the emission levels stated by the manufacturer were never achieved. The deterioration of catalyst efficiency was clearly seen also in the "real" exhaust emission measurements. Also here can be seen that small fluctuations in the air/fuel ratio will shift the balance between CO and NO_x.

The Kemira catalyst improved emission quality drastically. For the first measurement, the sum of CO and NO_x expressed in g/kWh was 3, for the second measurement only 1.5.

The MAN LPG bus met the expectations and surpassed them. Both the drivers and the passengers were satisfied with the silent, vibrationfree and odourless bus. No serious faults or damages appeared in the bus. On the other hand, the reliability of the bus was lowered by numerous minor faults.

However, the operating company does not see any obstacles for the further use of LPG fuelled buses. The MAN bus is still in service, and has accumulated more than 200 000 km. The company is negotiating to have mid-size (8.5 m) buses equipped with a Valmet LPG engine.

This bus, ECOBUS was launched in March 1994. The vehicle combines mid-size, low emissions, low noise, low floor and recyclable materials (Fig. 18).

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THERMAL EFFICIENCY OF GAS ENGINE POWER PLANTS

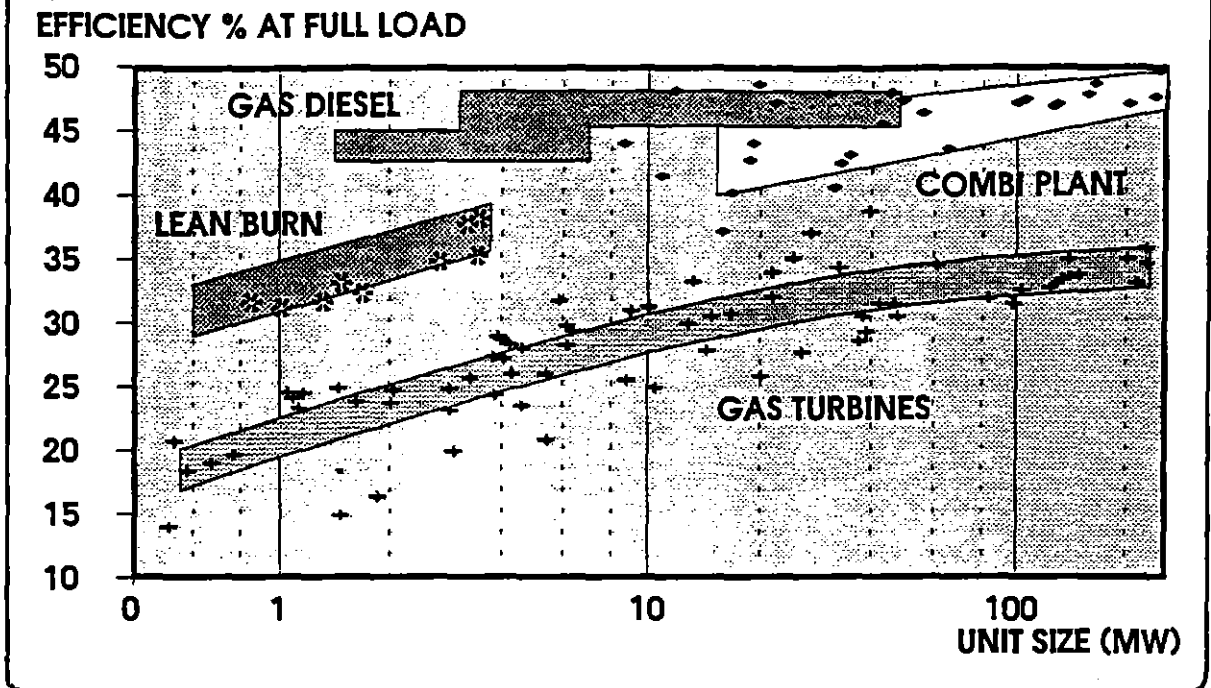


Fig. 1. *Efficiency of different prime movers*

THERMAL EFFICIENCY OF GAS ENGINES AS FUNCTION OF LOAD

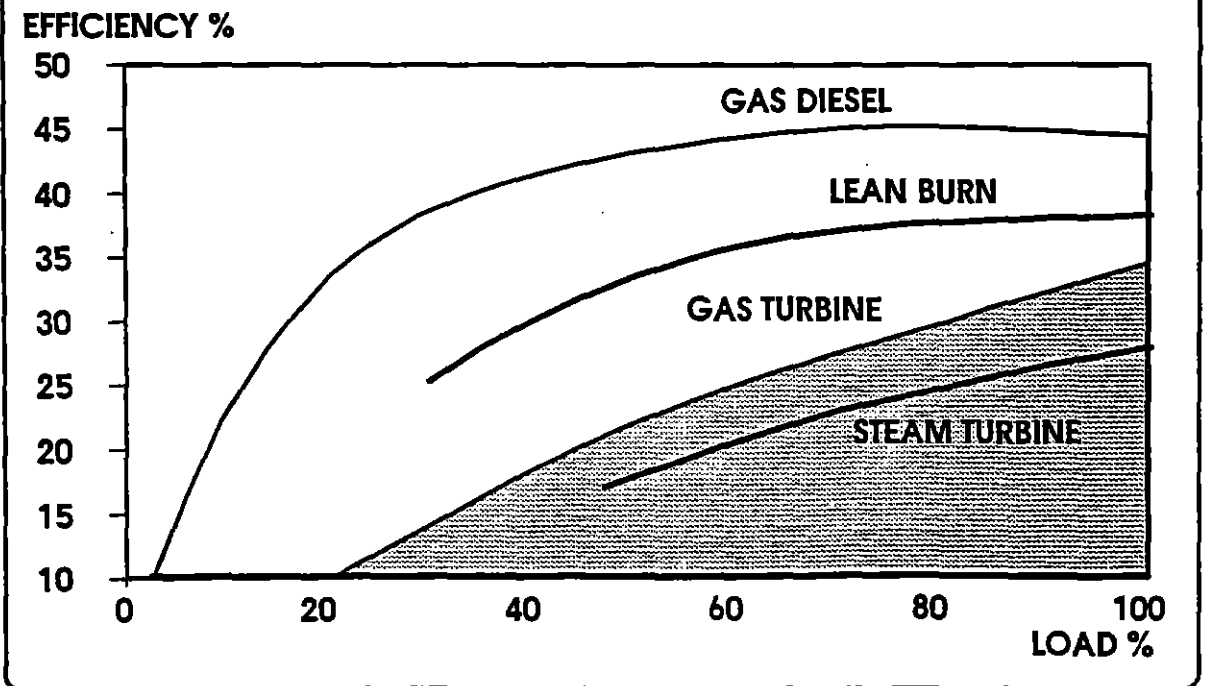


Fig. 2. *Thermal efficiency as a function of load*

**GAS
DIESEL**

**WÄRTSILÄ DIESEL
TECHNOLOGY**

**NOx REDUCTION POTENTIALS/METHODS
VASA 32GD**

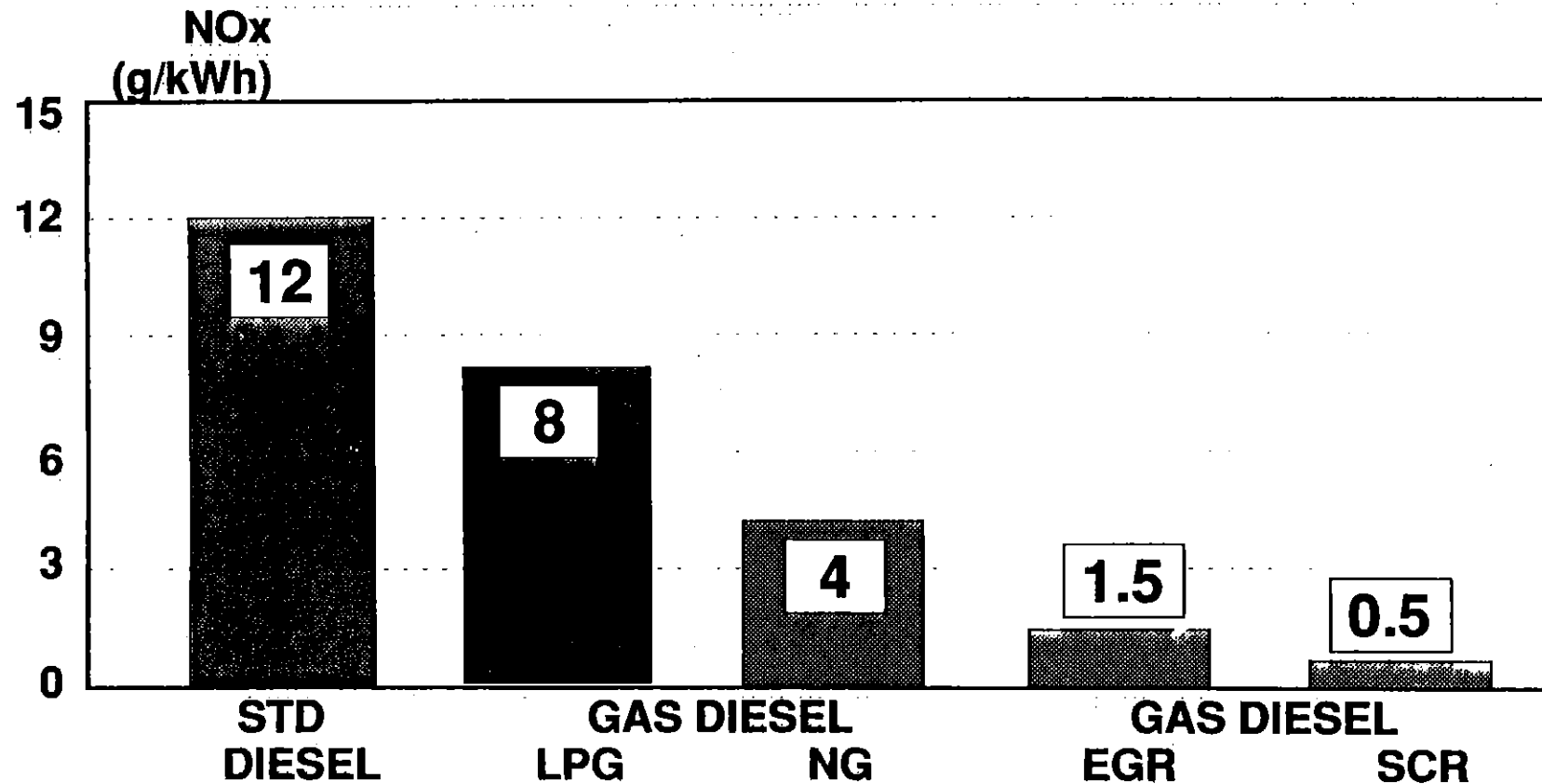


Fig. 3.

WÄRTSILÄ DIESEL TECHNOLOGY

Lean Burn

Working Principle

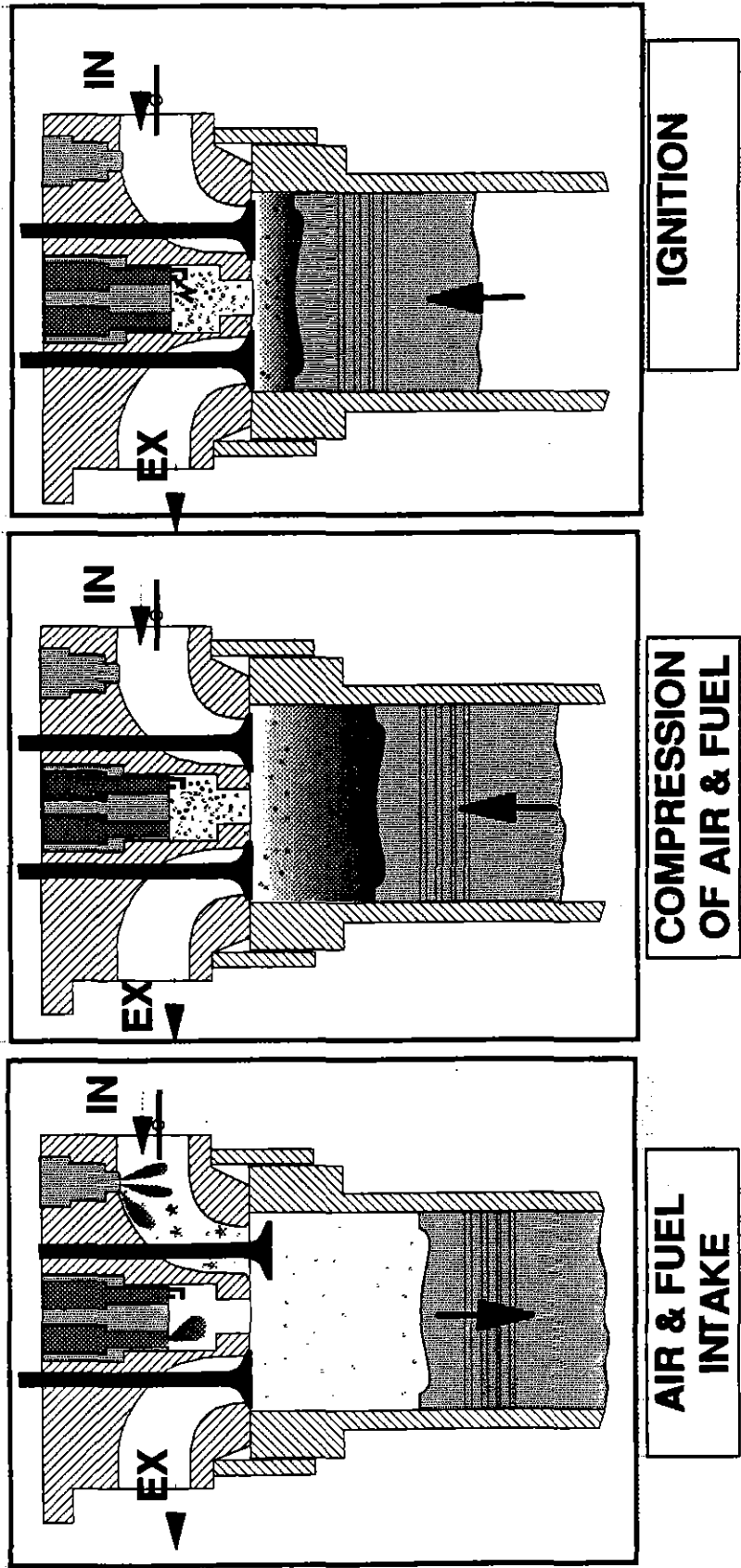


Fig. 4.

WÄRTSILÄ DIESEL TECHNOLOGY

Gas Diesel Working Principle

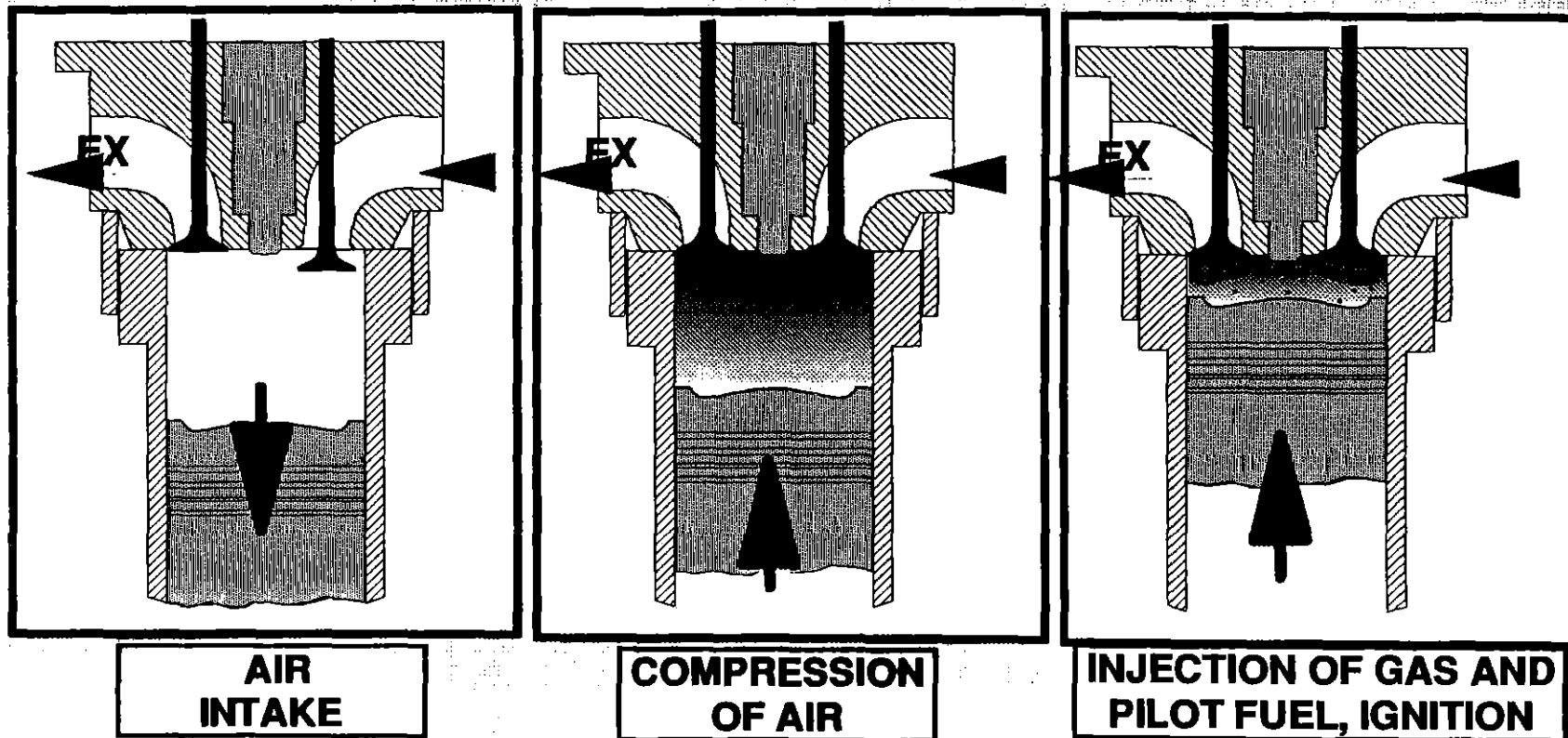


Fig. 5.

CONTROL OIL SYSTEM MECANICAL-HYDRAULICAL SYSTEM

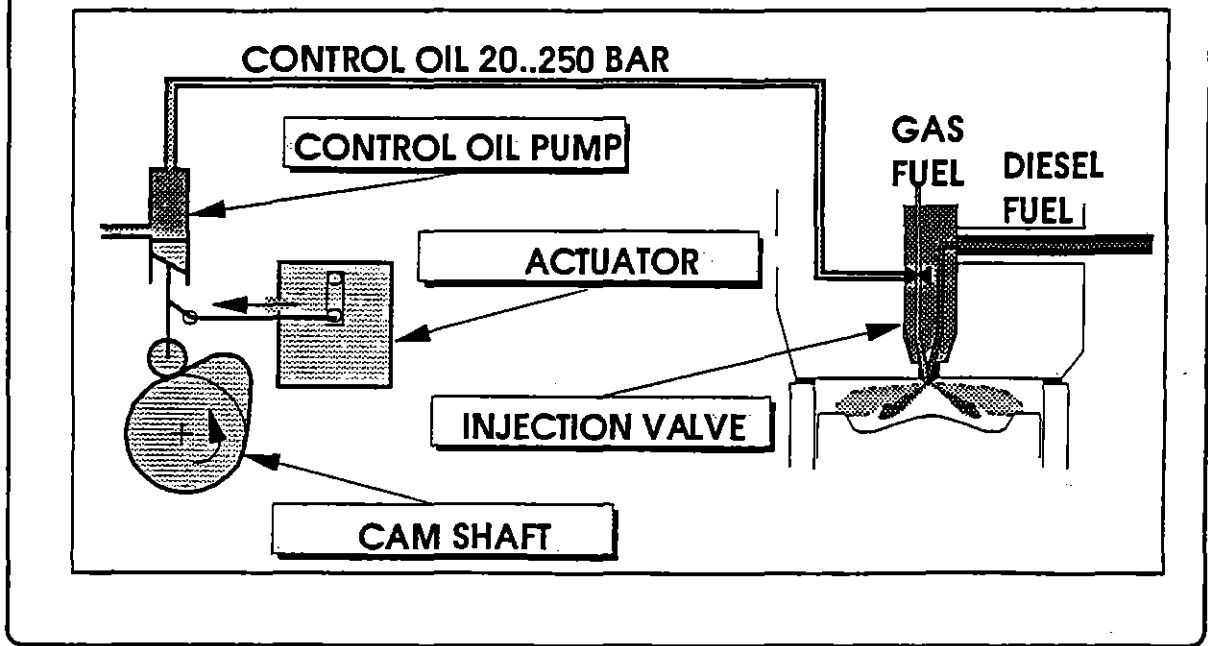


Fig. 6. *Control oil system*

OVERVIEW OF GASDIESEL CONTROL/SAFETY SYSTEM

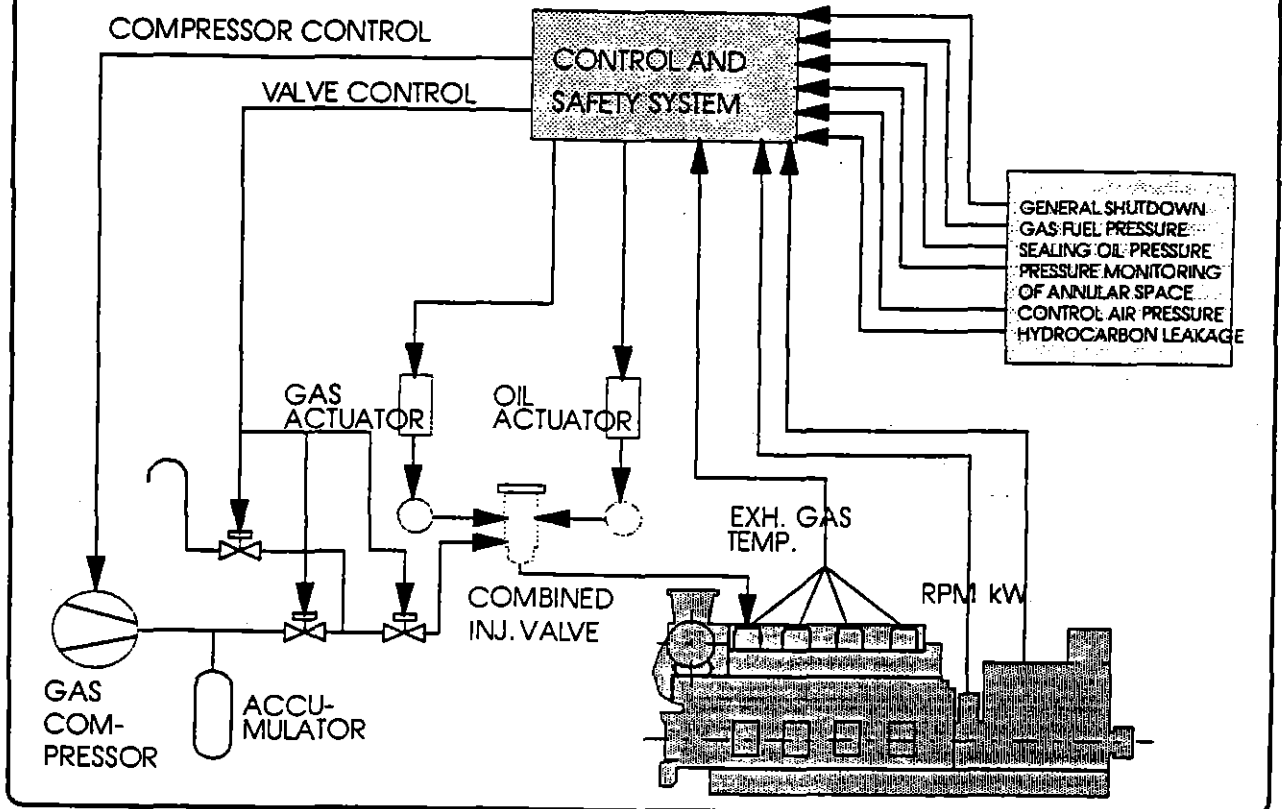


Fig. 7. *Control/Safety system*

**GAS
DIESEL**

WÄRTSILÄ DIESEL
TECHNOLOGY

THE GAS DIESEL CONCEPT

PURE DIESEL PROCESS

- high efficiency, above 45%
- high power weight ratio
- conversion of existing engines easy

MULTI FUEL CAPABILITY

- "fuel of the well", natural gas, LPG, heavy fuel, crude oil
- 100% output, same efficiency on all fuels

ENVIRONMENTALLY FRIENDLY

- lowest possible CO₂ emissions
- competitive NO_x levels
- no sulphur

CO₂ EMISSIONS /kWh FOR DIFFERENT TYPES OF PRIME MOVERS

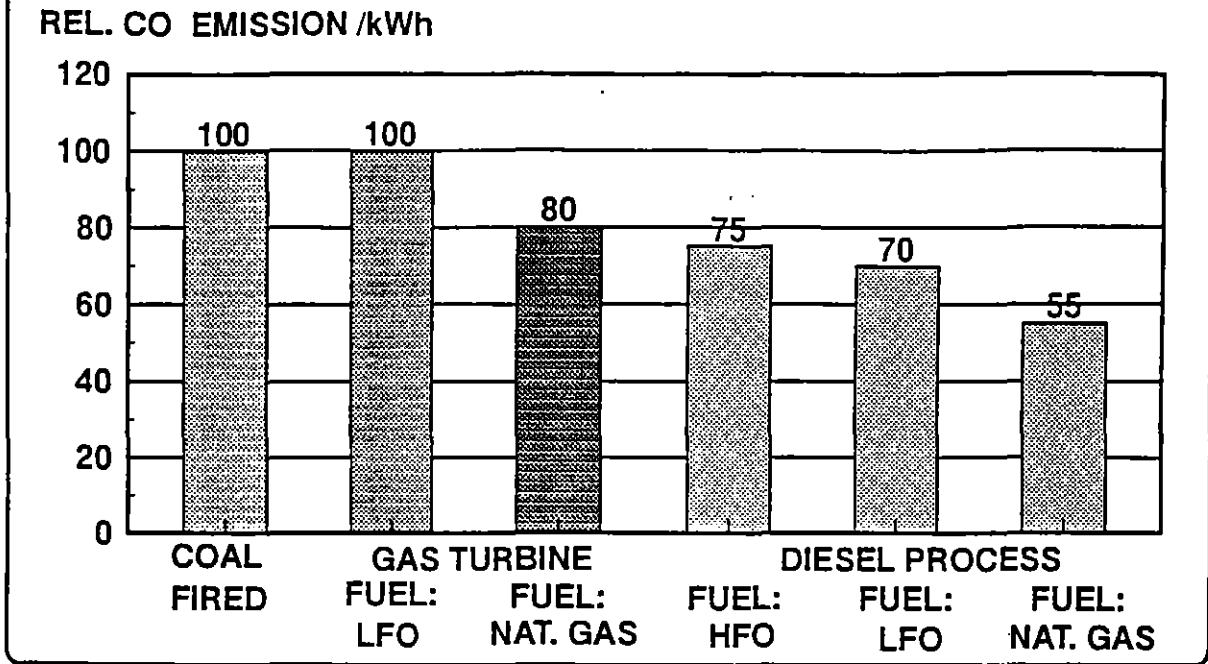


Fig. 9.

CO₂ emissions for different gas engine types

HIGH PRESSURE GAS INJECTION BASIC PRINCIPLE - VASA 46GD

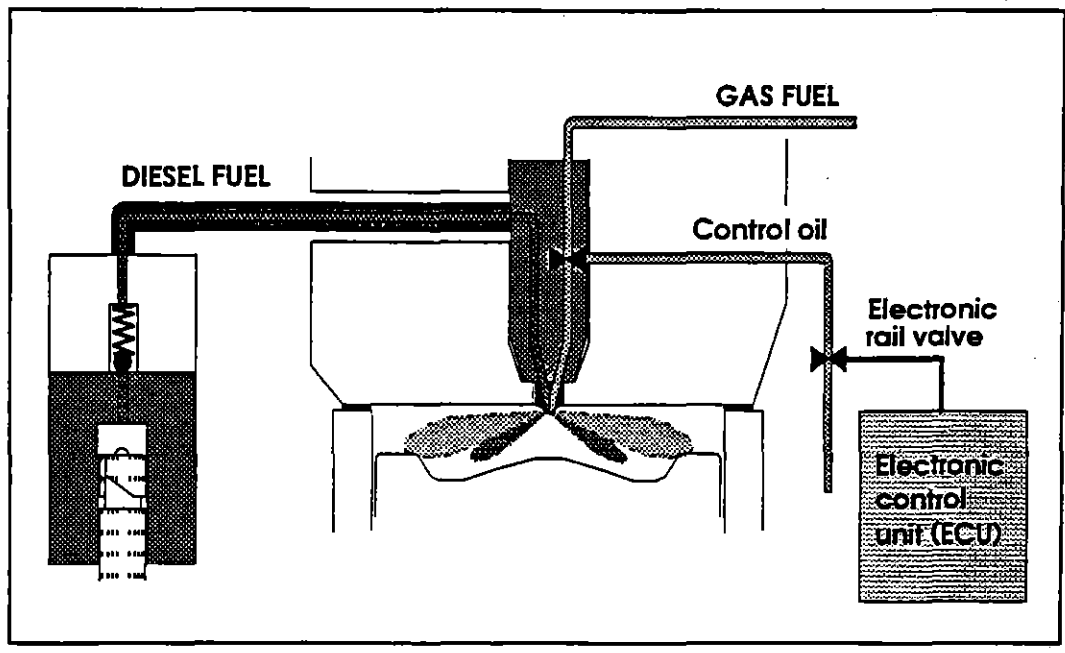


Fig. 10.

Electronic control of high pressure gas injection

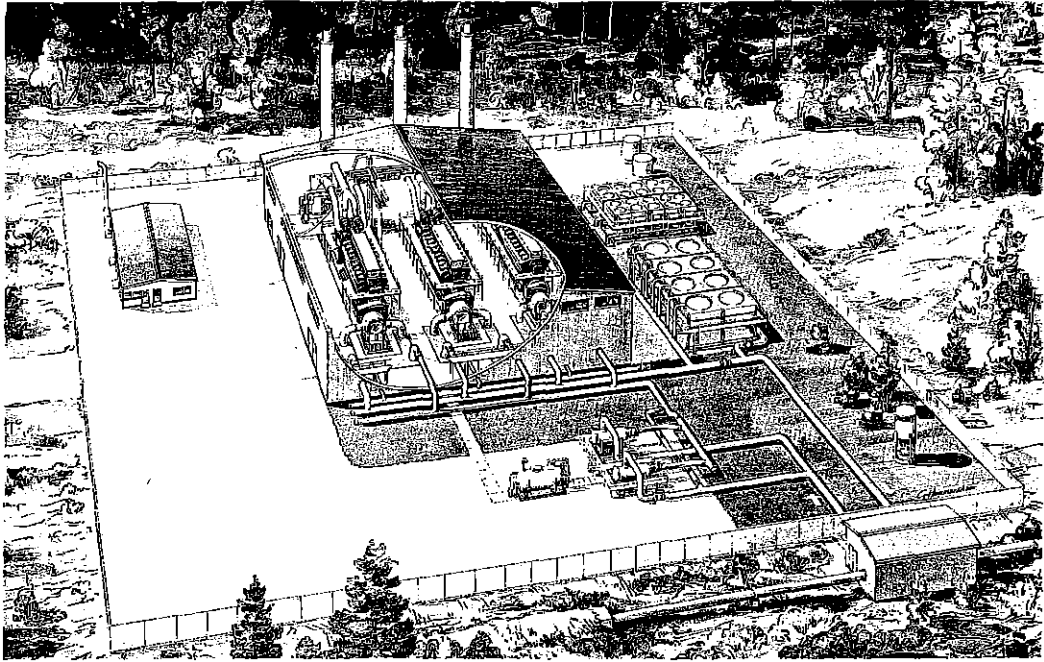
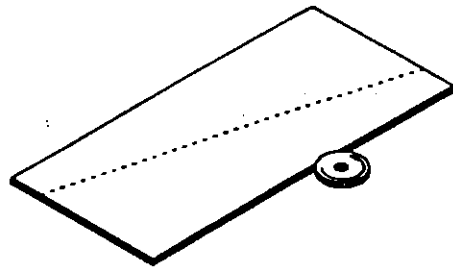
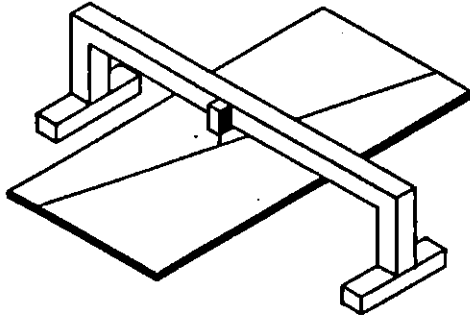


Fig. 11. *Artist's impression of a GDC station with Vasa 18V32GD engines.*

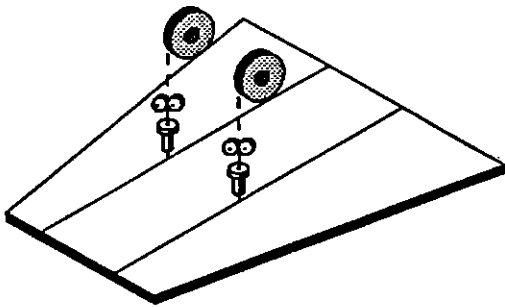
MANUFACTURE PROCESS OF PLATE SEGMENTS



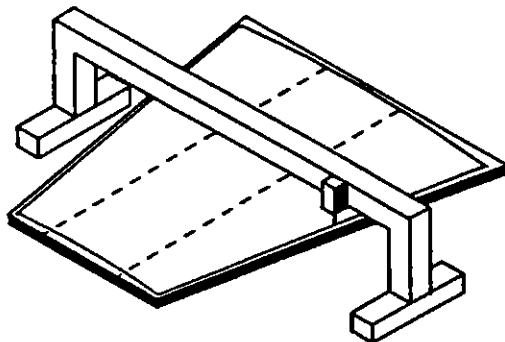
- 1** EDGE PREPARATION OF RAW PLATES BY BEVELLING MACHINE



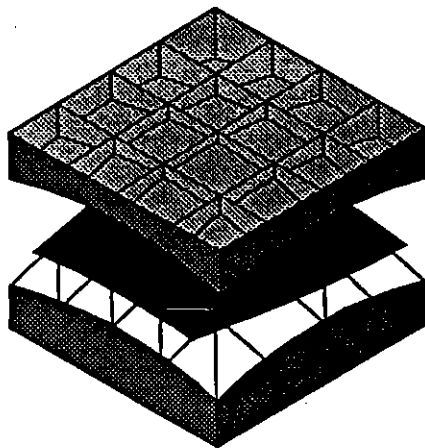
- 2** PLASMA ARC-CUTTING OF PART PLATES



- 3** HIGH ENERGY MIG WELDING OF BUTT JOINTS



- 4** PRECISION CUTTING OF WELDED PLATE SEGMENT BY WATER INJECTED PLASMA ARC



- 5** HEAT DIE-FORMING OF WELDED PLATE SEGMENT TO EXACT SPHERICAL CURVATURE

Fig. 12. Manufacture Process of Plate Segments

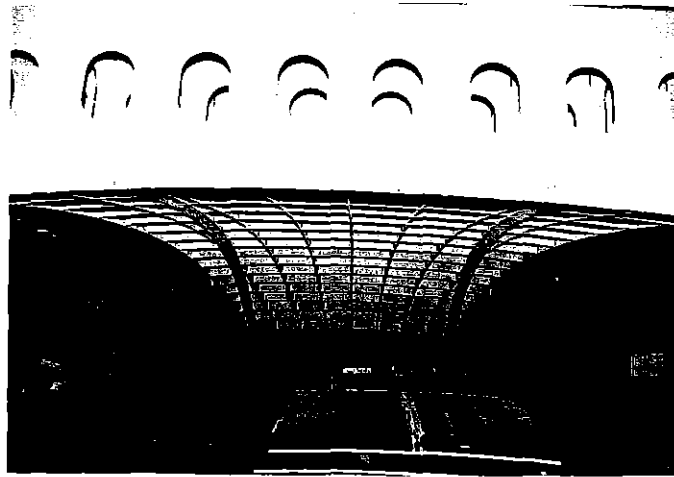
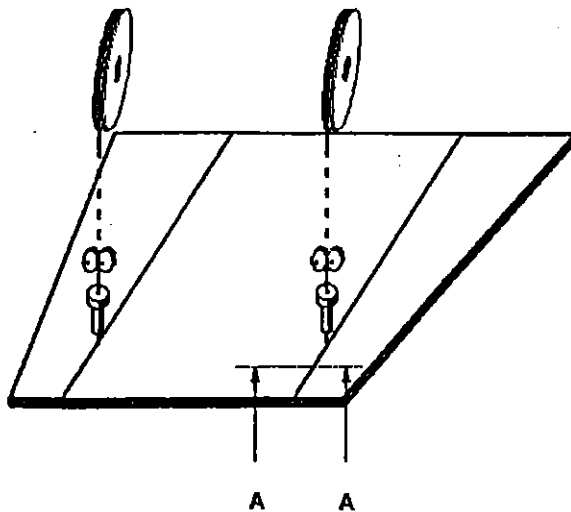


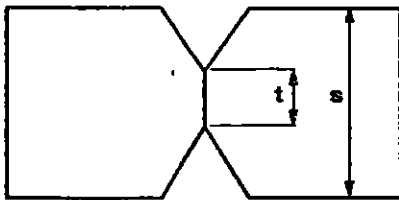
Fig. 13. Test Die and Formed Plates



Fig. 14. Automatic High Energy EGW Process at 3G Position



A-A, SKETCH OF GROOVE



Zone	s	t
1	48	23
2	44	20
3	46	23
5	37	20
6	29	15
7	30	15

A-A, SKETCH OF GROOVE

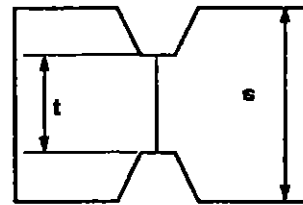


Fig. 15. Welding large flat panels gives possibilities to easy high productivity welding and variation of groove shape. Straight edges can be machined rapidly using simple existing powerfull turning mill.

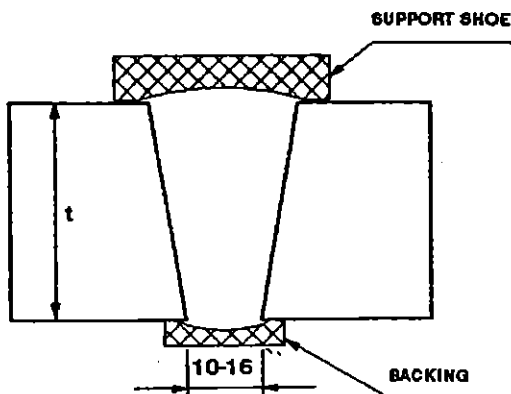


Fig. 16. Weld groove shape for vertical (3G) position welding using EGW process gives high tolerance compared to other high productivity processes.

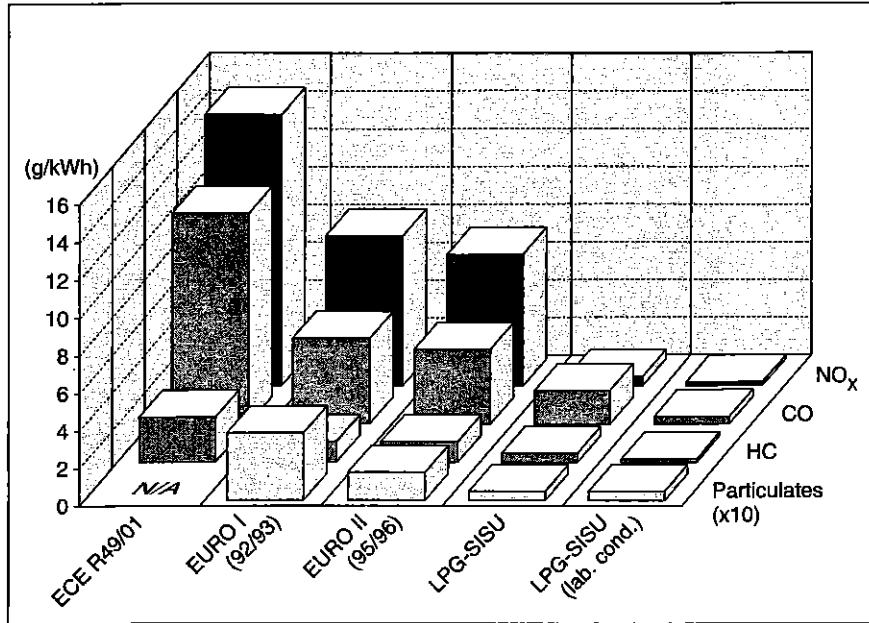


Fig. 17.

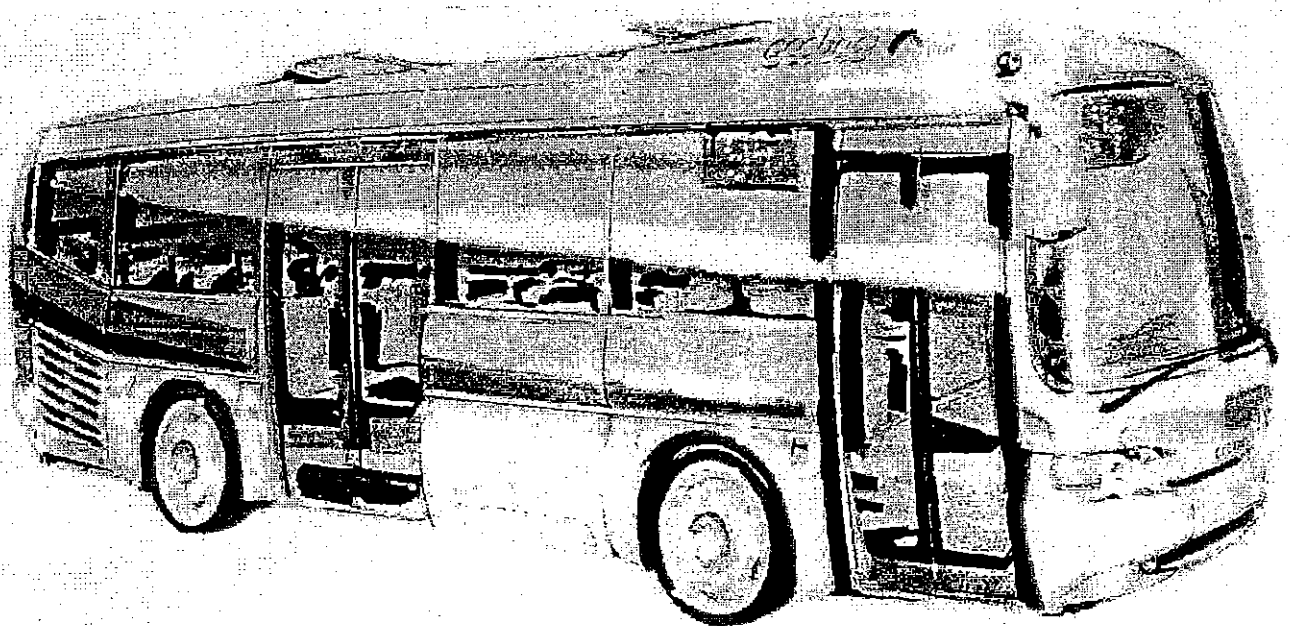
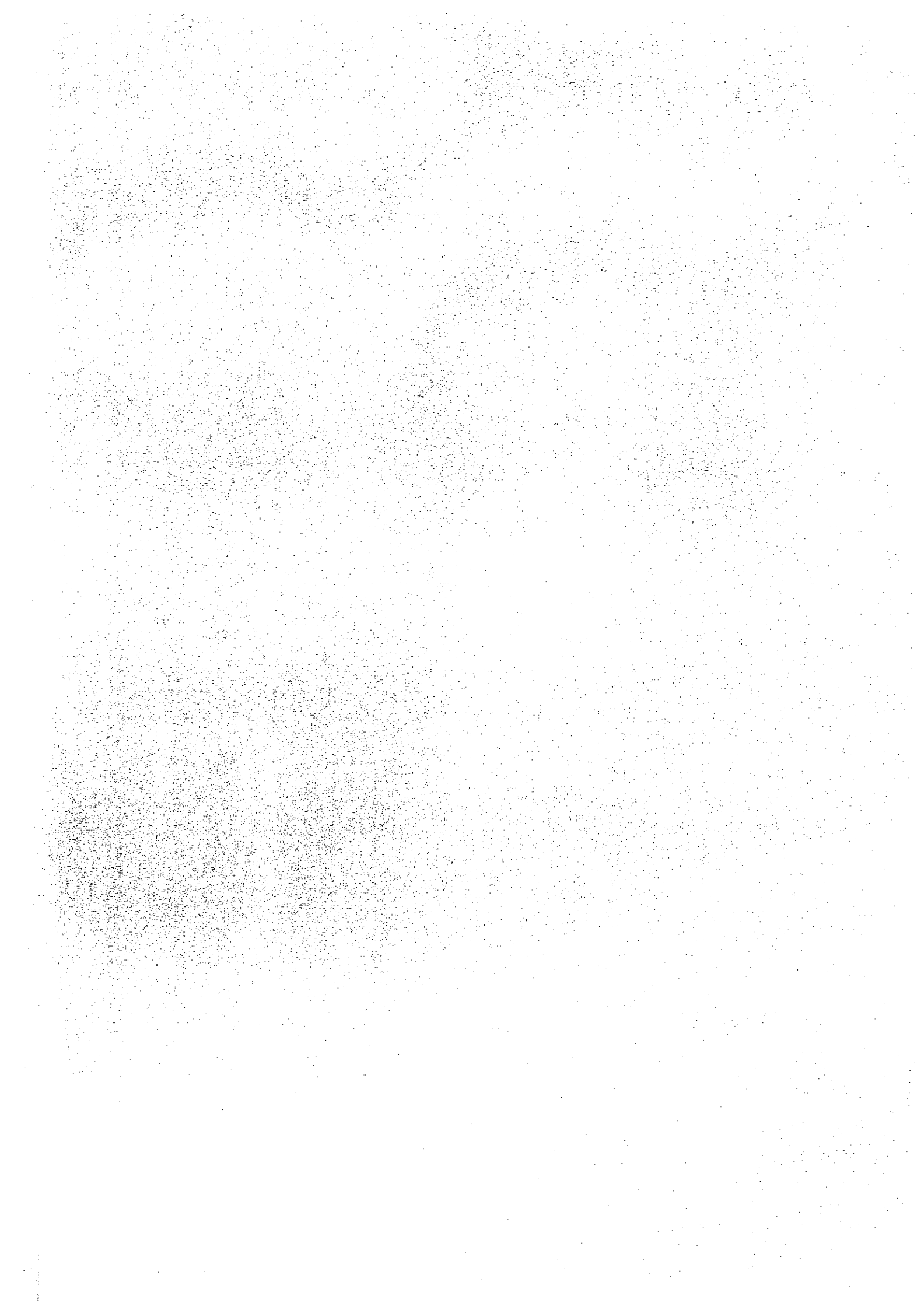
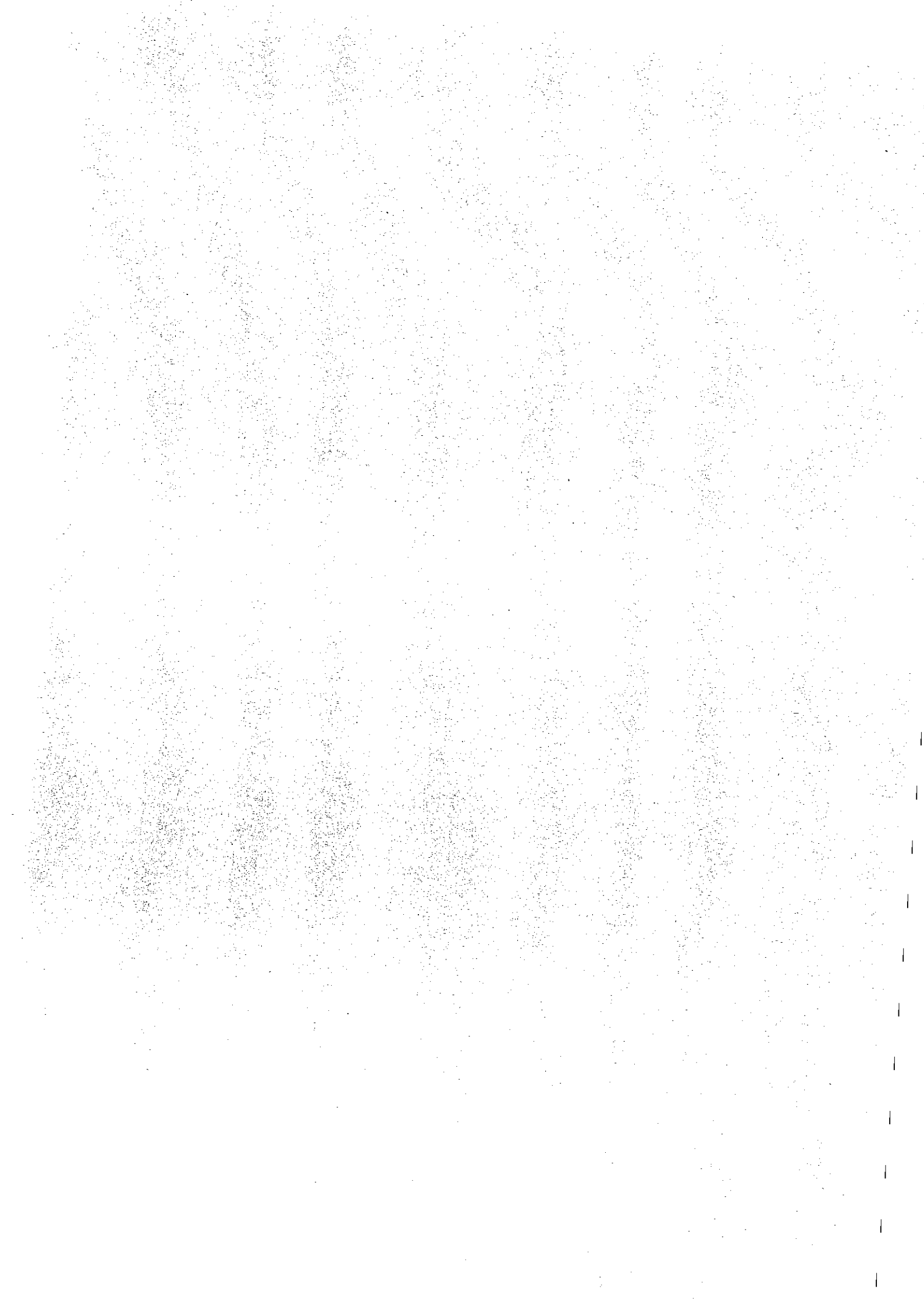


Fig. 18.





Gas Technology R&D in Norway

Asle Lygre

The Research Council of Norway

GAS TECHNOLOGY R&D IN NORWAY

by

Asle Lygre

The Research Council of Norway
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phone +47 55574267, fax +47 55574041

Introduction

Gas research in Norway is carried out both as independent industry projects and within research programmes managed by the Research Council with mixed funding from the industry and the Research Council.

From 1987 to 1993 the research programme SPUNG was carried out with funding both from the industry and the Research Council. The SPUNG programme aimed at establishing fundamental competence on gas technology at the Universities and the research institutions in Norway.

In 1994 the Research Council is launching two new programmes within gas technology; "Gas Research-Products and Services (GAVOT)" and "Chemical Conversion of natural gas".

In the following a brief outline of some aspects of gas research in Norway is given. It should be noted that this paper does not give the complete picture of the ongoing research within gas technology in Norway.

Onshore gas consumption

With the exception of the transportation sector, electricity generated by hydro power plants is the main energy source in Norway. Norway has a sparse population, and wide spread use of natural gas distributed through a national gas grid is not likely. However, a strategic element in the development of the gas technology industry in Norway is to establish local distribution of gas in the vicinity of the landing sites of the gas produced off the Norwegian coast.

At Tjeldbergodden, the landing site of the gas from the Heidrun Field off Mid-Norway, a small scale LNG plant is planned. A pilot study under the GAVOT programme, is now under way aiming at identifying consumers of LNG both in the research community, in the transportation sector and in the industry.

At Kollsnes, the landing site of the gas from the Troll Field west of Bergen, a similar pilot study under the GAVOT programme, has been initiated in order to investigate the possibilities of local use and distribution of compressed natural gas in the Bergen area. Four locally based industry companies in co-operation with the local authorities, are now in the process of establishing a commercial company, Vestgass, in order to handle the local distribution of gas from the Troll Field.

At Karmøy, the landing site of the gas from amongst other the Statfjord Field, the distribution company Gasnor delivers gas to Norsk Hydro's aluminium plant through a low pressure pipe. Further gas sales to the company Pronova is also expected to take place in the near future.

Gas engines

Ulstein Bergen in co-operation with MARINTEK, Trondheim, has developed a lean burn otto gas engine which has been commercially available for some years now.

Based on this gas engine, Ulstein Bergen has installed several power plants in Denmark, where both electricity and hot water is produced. In co-operation with the GAVOT programme the lean burn gas engine is now being further developed with the objective of increased efficiency, lower emissions and larger engines.

Fuel cells

There are two projects in Norway aiming at developing solid oxide fuel cells (SOFC) for the conversion of natural gas to electricity. SOFC-technology is preferred because it is not necessary to reform the natural gas before it is fed into the fuel cell.

In the Mjøllner project Statoil in co-operation with Bergen based Prototech, is now in the process of developing a 10kW pilot plant which will be installed and tested at Statoil's gas processing plant at Kårstø in

1995.

In the Norcell project funded by Elkem, Norsk Hydro, Saga and the Research Council, a 1.4kW cell has been developed and tested. The research partners in this project are IFE at Lillestrøm, SINTEF in Trondheim and Oslo and NTH in Trondheim. Discussions are now under way concerning the continuation of the project.

Gas instrumentation

K-Lab is a high pressure calibration and testing laboratory situated at Kårstø, north of Stavanger. The laboratory is a joint venture between Statoil and Total. In the past few years Statoil has tested a range of new gas flow meters at K-Lab. The unique features of the laboratory is the high pressure, up to 150 bar, and the possibility to vary the gas temperature. Similar laboratories in Europe typically have a maximum pressure of 60 bar and no or very limited possibilities to vary the temperature.

Christian Michelsen Research, Statoil and the flow meter manufacturer Fluenta have co-operated on developing a new ultrasonic gas flow meter for custody transfer of natural gas. The project is now also funded by the Research Council, Norsk Hydro and Phillips. The meter will be introduced on the market in 1995.

Kongsberg Offshore manufactures large scale gas metering stations for the national and the international market. In co-operation with the GAVOT programme the company is now undertaking a pilot study to identify new possibilities within gas instrumentation.

Rogaland Research in co-operation with Corrocean is now developing a system for monitoring the corrosive properties of the gas in pipe lines. The project is carried out under the GAVOT programme.

Gas turbines

Ulstein Turbine in co-operation with Volvo Flygmotor and Turbomeca has developed a new 2.5MW gas turbine, the EURO DYN. Two prototypes of the turbine will be installed and tested in a ship now being built at Ulstein's shipyard at Hareid.

Basic research on combustion and design of gas turbines is carried out at SINTEF and NTH in Trondheim.

LNG-technology

The LNG-tankers developed and manufactured by the Kværner company is a market leader in the world within ship transportation of LNG. In co-operation with the GAVOT programme Kværner is now carrying out a pilot study to investigate the possibilities of improving their LNG transportation technology.

Basic research on LNG-technology is carried out at SINTEF and NTH in Trondheim.

Equipment

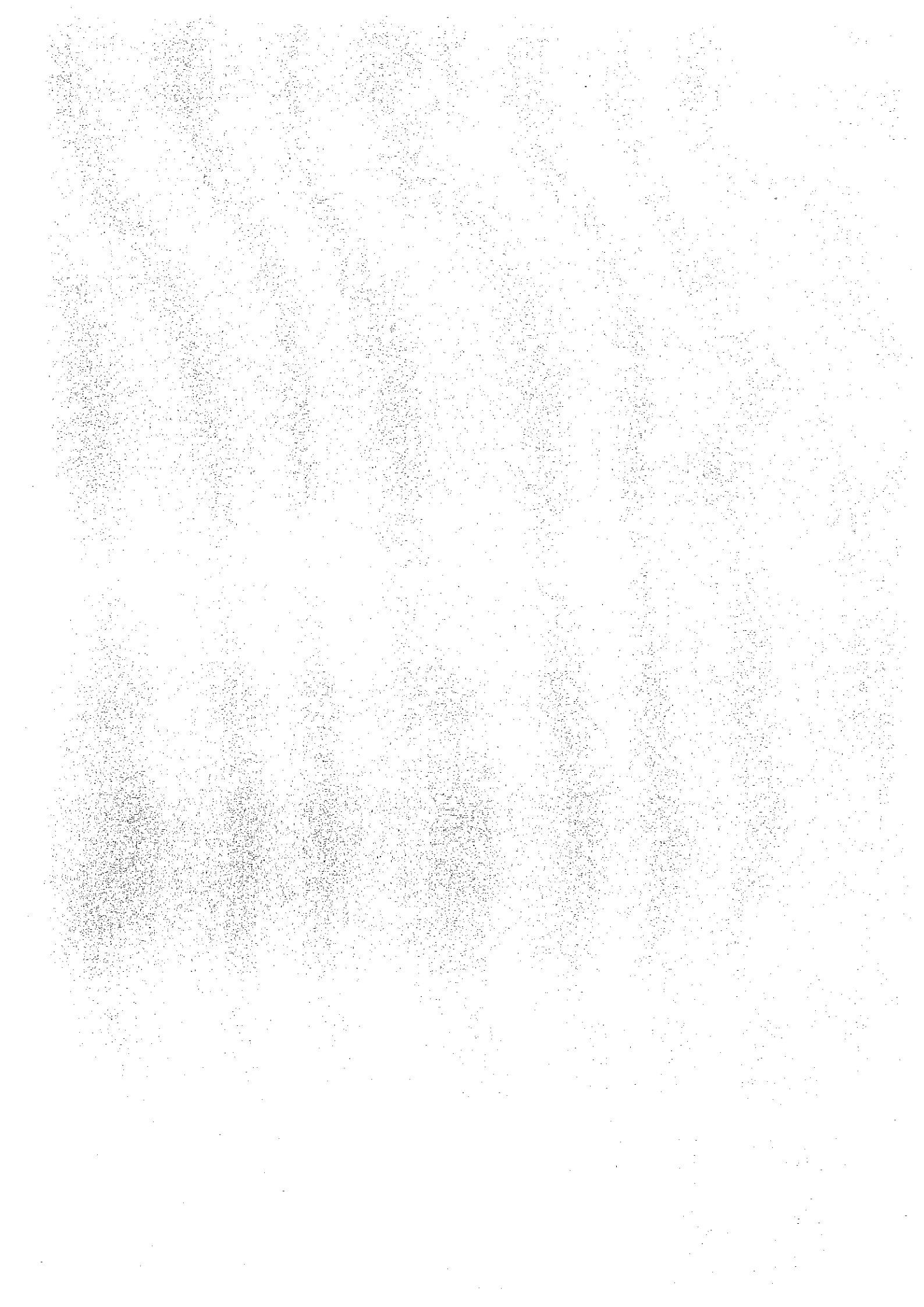
One goal of the new GAVOT programme is to stimulate to the development of new equipment connected to the distribution, storage and use of natural gas.

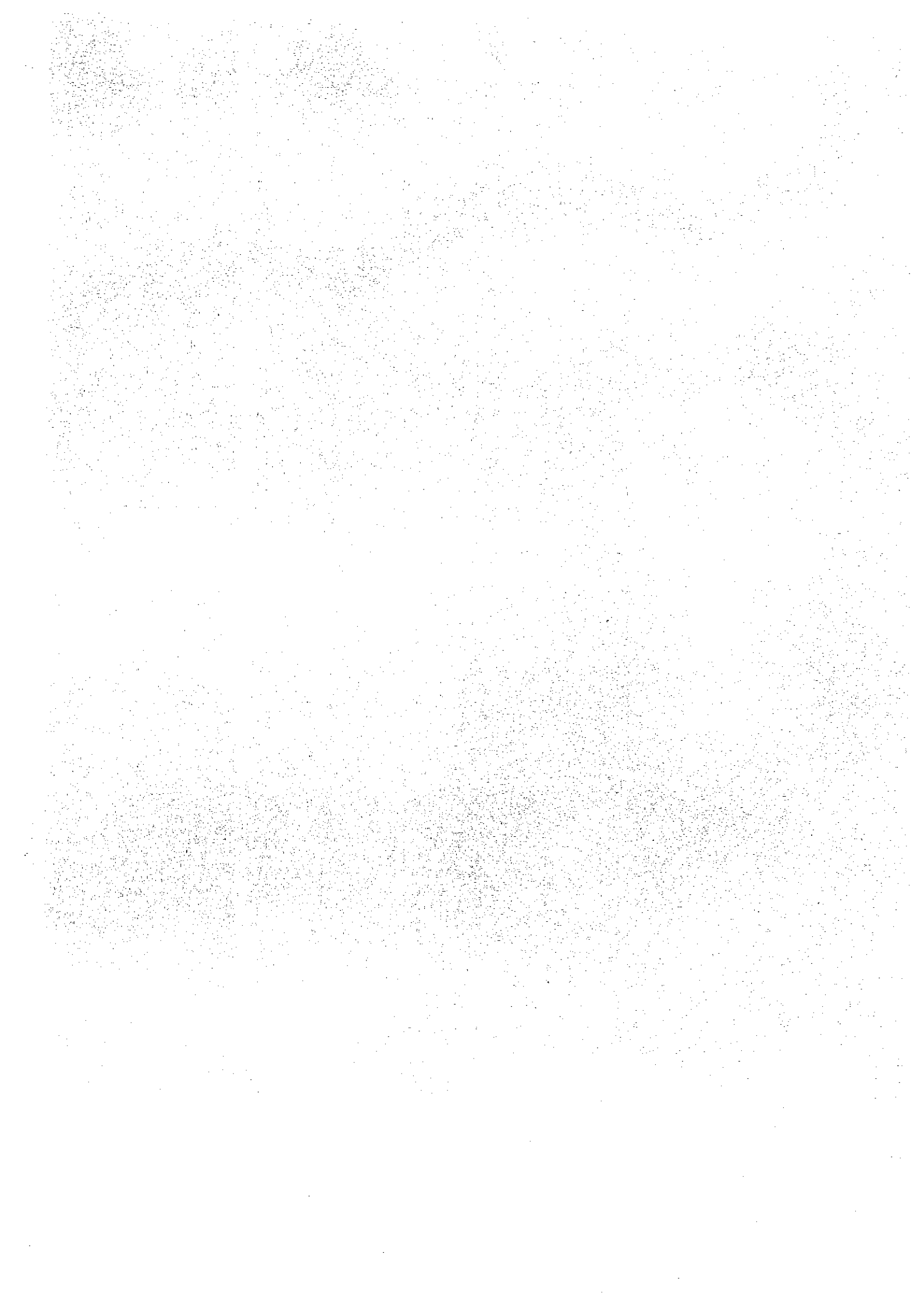
Raufoss has developed a pressure vessel for compressed natural gas (CNG) based on composites and aluminium. This pressure vessel is now being further developed in order to reduce weight, production costs and qualify the technology for the market. This project is carried out under the GAVOT programme.

Gas burners is an area where the company Fremo is active. In co-operation with the GAVOT programme, Fremo is planning a development project with the objective of improving the company's burner technology to allow for reduced emissions in compliance with the European regulations.

Gas Explosions

Christian Michelsen Research, Bergen, has carried out extensive work within gas explosions in co-operation with major international oil and gas companies. Based on small and large scale laboratory experiments and computational fluid dynamics, advanced 3D computer codes have been developed for simulating gas explosions in real process modules. The simulation programme μ -FLACS is now commercially available on PC.





Gas Technology R&D in Sweden

Per-Arne Persson

Swedish Center of Gas Technology (SGC)

Presentation at the R&D-workshop on April 20, 1994
arranged by Swedish Centre of Gas Technology

During the next 30 to 40 minutes I will try to summarize what has happened within Gas Technology R&D in Sweden since last April.

Already last year, at the R&D-workshop held in Hørsholm, Denmark, Jörgen Thunell told that the Swedish Center of Gas Technology (SGC) had got a new structure of ownership and that the Research Programme for Gas Technology which had been run jointly with the Government (represented by NUTEK = Närings och Teknikutvecklingsverket, i.e. the Swedish National Board for Industrial and Technical Development) in the Institution of Värmeteknisk Forskning (Värmeforsk, i.e. Thermal Engineering Research Institute) was ended on June 30, 1993.

During this last year has instead negotiations between SGC and NUTEK led to an agreement implying that NUTEK and SGC establish a joint R&D-programme. This programme will include projects to a total of 5 million SEK/year of which NUTEK contributes with 40% and SGC with 60%.

The projects within this programme will be administrated by SGC. Decisions on which of the projects are to be financed from the programme are taken in a programme board with four members. Two members represent the gas industry, Mr Arne Andersson from Göteborg Energi and Mr Lars Nilsson from Sydgas. The other two, professor Lennart Thörnqvist, at the University of Lund, LTH, and professor Marku Lampinen, at the Helsinki University of Technology, are representing NUTEK.

The projects financed within this programme, should have long-range goals and preferably be connected to a Technical High School.

Beside this cooperative programme between NUTEK and SGC, other projects which SGC wholly finances are carried out as normal. Regarding these projects the owners of SGC take independent decisions on their participation. SGC has not a fixed budget for these projects. The amount of money available depends on the quality of the project ideas and the owner's interest in them.

I will now give you an account for the projects which have been finished respectively started up since our last workshop in April 1993 both within the programme of Värmeforsk and within our own organisation, SGC.

I will show you some Overheads over the titles of the projects. I will not go into any details concerning the individual projects on this stage, for a simple reason, I am not familiar with all the projects and their results. But if you find any of the projects interesting and want to get some more information of

course we will be happy to help you. One way to get this information is to buy the booklet "Project Reports" published by Värmeforsk or SGC. We at SGC have lists of all the relevant reports from Värmeforsk and all SGC reports together with order forms. The lists over SGC projects and reports also contain a short summary of the project results respectively a short description of the project.

Another way is to contact the author of the report or the person responsible for the project and he or she will also help you with that if you wish. Now I have to admit that most of our reports are written in Swedish, sometimes though with an English summary

During the period of April 1, 1993 to April 20, 1994 the following projects have been closed:

The Värmeforsk programme of Gas Technology 1990-1993

G8-816 Prototype of a Condensing Boiler

A report is published by Värmeforsk (Värmeforsk no 487) The title of the report is "Experimental investigation of a Condensing Boiler with Thermomax Burner and Flue Gas Reheating".

The author of that report is Mr Mikael Näslund, present here today. I suggest that you consult him if you find the title interesting and have further questions regarding this project.

G1-103 Catalytic Burner for Natural Gas. Continuation project, Phase 1.

This project is also reported by Värmeforsk no 475. The title is "Development of a Catalytic Burner" by Mr Fredrik Ahlström.

G1-104 Methods to determine the total efficiency for Infra-Red Dryers

I will come back to this project later on when I present those projects financed by SGC, since this is co-financed by both SGC and Värmeforsk. No report is published yet.

G1-118 Corrosion of inner stainless steel tubes in smoke stacks

This project is also co-financed by SGC and Värmeforsk. A report is published by SGC and the author of this one is also Mr Näslund.

G1-202 Catalytic layers in heat exchangers for industrial applications

A report is published by Värmeforsk no 496. "Catalytic Heat Exchangers for Industrial Applications". The authors are Fredrik Ahlström and Tihamér Hargitai.

You may recognize the name Ahlström from the other project concerning catalytic burners. This is because of the fact that both projects are carried out by the same company, i.e. KATATOR, in Lund. The other author, Mr Hargitai, is also present here today, so if you have any questions concerning this project I suggest that you contact him.

G1-207 Landfill Gas Technology - A review of experiences, technology and development

At the end of 1992, still 300 000 SEK was remaining of the project budget that the Gas Technology programme had at it's disposal for the period 1990-1993. It was then decided to invite a number of companies, institutions etc to submit project proposals that were within these cost limits.

The winning proposals was submitted by Jerker Delsing at the Institution for Heat and Power Engineering, LTH. The name of the project is: "On-line measurement of energy content in Bio- and Natural Gas".

The idea of the project builds on the fact that the sound velocity in gas is proportional to the molecular weight of the gas. The sound velocity has a frequency dependance which is different for different kinds of molecules. The gas composition can be determined if one makes use of these facts. Then the energy content of the gas can be calculated from different known correlations.

Swedish Centre of Gas Technology

As we have broadened the scope of this workshop to include even distribution of gas and gas storage, I will include the projects financed by SGC in these areas too.

The following projects have been finished and reported during the period of April 1, 1993 to April 20, 1994:

90.60 Testing of PE-pipes exposed to LPG condensate.

*90.63 Methods for determination of overall efficiency for IR-radiators.

- *90.64 Gas fired IR-radiators in paper coaters. MoDo Husum plant
- *90.70 Nordic pot furnace project.
- *90.12 Corrosion of inner stainless steel tubes in smoke stacks.
- 91.16 CO₂ plant cultivation with exhaust gases from natural gas fired greenhouse burners.
- 92.08 Introduction of GT-Pak Gas Pressure Booster.
- 92.02 Evaluation of Design Methods for Gas Distribution Pipes.
Literature Search.
- Pulsating Combustion for Drying Purposes.
- Organisations within the Area of Gas R&D.
- 91.05 Field sorting of filling mass when laying PE-pipes with a laying box.
- The influence of Landfill Gas on PE pipes.
- Use of Natural Gas within the Plastic Industry. Plan of Action.
- 92.11 PA 11 as material in gas distribution pipes.
- 90.68 Increasing the efficiency of a condensing boiler at high return temperatures.
- Use of Natural Gas in Paint Shops.
- 91.11 Conversion of standby diesel generators to natural gas fuelled CHP.
- Mature Technologies for Gas Installations in One-Family Houses.
- *94.01 Gas Fired Air Heaters. A comparison of two installations at Arlöv Sugar Factory.

During the same period a number of new projects have been started up both within the areas of gas utilization and gas distribution:

- 93.01 Guidance for Installation of Gas Fired IR-Heaters.
- 93.02 Small Scale Cogeneration.

- 93.03 Natural Gas on Wheels. Strategic Analysis.
- 93.04 Catalysts for Lean-Burn Gas Engines.
- 93.05 Three-way Catalysts for Stationary Gas Engines. Development potential.
- 93.06 Design of a Burner for Catalytic Combustion.
- 93.07 Natural Gas and Oxy-Fuel Technology.
- 93.08 Advanced Reburning in Waste Boiler.
- 93.09 Inner Steel Tubes in Smoke Stacks. Design with regard to Corrosion.
- 93.11 Emissions from Natural Gas respectively Biomass Fired Plants.
- 93.12 Membership in the "Jernkontoret".
- 93.13 IR-panels in connection with Industrial Powder-painting.
- 93.14 Catalogue of gas technology RD&D projects in Sweden.
- 93.15 The Natural Gas model for Smoke Stack Calculations.
- 93.16 Gas Detection Systems.
- 94.02 NO_x-reduction through Natural Gas Injection and Reburning in a Waste Heat Plant.

Now I have chosen three projects, all co-financed by SGC, which I will give a more detailed presentation.

Enclosures

The Värmeforsk program of Gas Technology 1990 - 1993

During the period of April 1, 1993 to April 20, 1994 the following projects have been finished:

G8-816 Prototype of a Condensing Boiler

G1-103 Catalytic Burner for Natural Gas. Continuation project, Phase 1

G1-118 Corrosion of inner stainless steel tubes in smoke stacks

G1-202 Catalytic layers in heat exchangers for industrial applications

G1-207 Landfill Gas Technology – A review of experiences, technology and development

On-line measurement of energy content in Bio- and Natural Gas

- The sound velocity in a gas is proportional to the molecular weight of the gas.
- The sound velocity has a frequency dependence which is different for different kinds of molecules.
- The gas composition can be determined .
- The energy content of the gas can be calculated from different known correlations.

Swedish Centre of Gas Technology

The following projects have been discontinued and reported during the period of April 1, 1993 to April 20, 1994:

- 90.60 Testing of PE-pipes exposed to LPG condensate
- *90.63 Methods for determination of overall efficiency for IR-radiators
- *90.64 Gas fired IR-radiators in paper coaters. MoDo Husum plant.
- 90.68 Increasing the efficiency of a condensing boiler at high return temperatures.
- *90.70 Nordic pot furnace project
- 91.05 Field sorting of filling mass when laying PE-pipes with a laying box.
- 91.11 Conversion of standby diesel generators to natural gas fuelled CHP.
- *91.12 Corrosion of inner stainless steel tubes in smoke stacks.
- 91.16 CO₂ plant cultivation with exhaust gases from natural gas fired greenhouse burners

- 92.02 Evaluation of Design Methods for Gas Distribution Pipes. Literature Search.
- 92.08 Introduction of GT-Pak Gas Pressure Booster
 - Pulsating Combustion for Drying Purposes
 - Organisations within the Area of Gas R&D
 - The influence of Landfill Gas on PE pipes
 - Use of Natural Gas within the Plastic Industry. Plan of Action.
- 92.11 PA 11 as material in gas distribution pipes
 - Use of Natural Gas in Paint Shops
 - Mature Technologies for Gas Installations in One-Family Houses
- *94.01 Gas Fired Air Heaters. A comparison of two installations at Arlöv Sugar Factory

Swedish Centre of Gas Technology

During the same period a number of new projects have been started up both within the areas of gas utilization and gas distribution:

- 93.01 Guidance for Installation of Gas Fired IR-Heaters
- 93.02 Small Scale Cogeneration
- 93.03 Natural Gas on Wheels. Strategic Analysis
- 93.04 Catalysts for Lean-Burn Gas Engines
- 93.05 Three-way Catalysts for Stationary Gas Engines. Development potential.
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- 93.15 The Natural Gas model for Smoke Stack Calculations
- 93.16 Gas Detection Systems
- 94.02 NO_x-reduction through Natural Gas Injection and Reburning in a Waste Heat Plant

Methods for determination of overall efficiency for IR-radiators
Gas fired IR-radiators in paper coaters. MoDo Husum plant.

Some years ago a so called FTIR-spectrometer was bought to the Department of Control and Maintenance (DTI) at the University of Lund with the purpose of measuring the spectral distribution from different types of IR-radiators.

One example of such a spectrum can be seen in figure 1. It is measured with the FTIR-instrument on a gas fired IR-radiator. For comparison you can also see two black body spectra with different temperatures. In the spectrum from the IR-radiator you can see two peaks. These peaks are due to the hot gases in front of the radiating surface, and originate from water vapor and CO₂-gas.

With the help of this instrument it is possible to determine the radiation efficiency for different IR-radiators. DTI has for example measured the radiation efficiency for a radiator with ceramic fiber to 60% and to 55% for a smaller ceramic radiator intended for space heating.

The goal has from the beginning been to make this instrument mobile so that measurements actually can be made in the field, for example at a paper machine, in order to measure the the total efficiency for an IR-dryer.

As can be seen from the drawing in figure 2 the free space between the paper web and the IR panel is very small, about 50 - 100 mm. If you want to measure the radiation interchange between paper and radiator you must be able to put a measuring probe into this narrow space.

Such a measuring probe, a so called Light-Pipe, has been designed and manufactured by DTI (figure 3). It is built around a coppertube with a diameter of 42 mm and the length of 1.5 m. Inside the pipe is a brassfoil tube coated with gold on the inside, i.e. a cylindrical mirror to minimize reflection losses. In both ends there is a 90° knee with a parabolic mirror and a sapphire lens. The Light-Pipe is cooled with water passing in four 8 mm copper tubes soldered to the Light-Pipe.

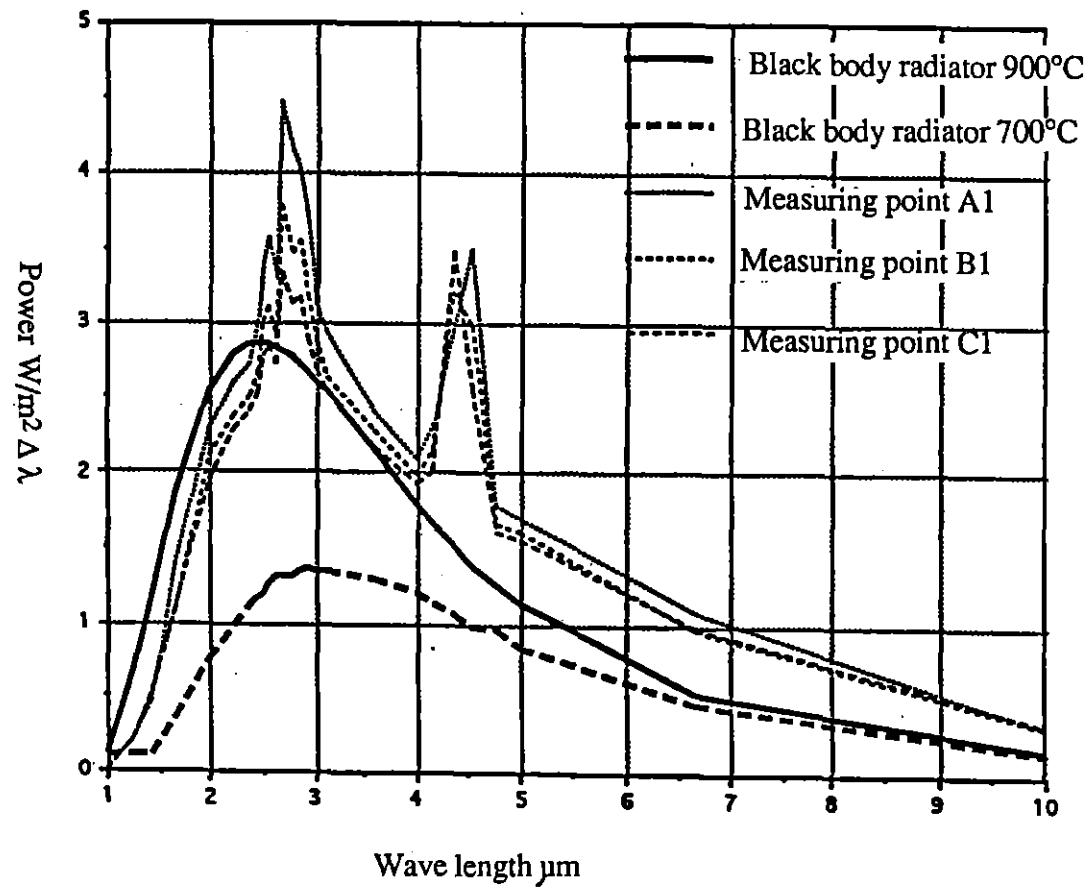
When this equipment was working in a satisfactory way and DTI felt that they could control accuracy, stability and so on the equipment was transported to a paper coater with a gas fired IR-dryer at a paper factory. The process flow sheet for the dryer installation is shown in figure 4. The dryer has two IR-panels one on each side of the paper web. Each panel consists of two rows of radiator elements, 48 in each row. Total width of the paper web is 6,700 mm.

In figure 5 you can see two spectras measured on an old (operating time about 11 months) respectively a new (operating time about 2.5 months) emitter plate. In the same diagram you can also see the IR radiation transmitted through the paper from the two emitters.

At the same time as the measurements with the FTIR was carried out, the personnel from the Department of Chemical Engineering, LTH, measured the input power, scavenging air and flue gas losses for the dryer. Temperature and moisture contents of the paper were also measured before and after the dryer. This made it possible, with the help of a mathematical model developed by KAT, to make a total energy balance over the dryer and to calculate the total energy efficiency.

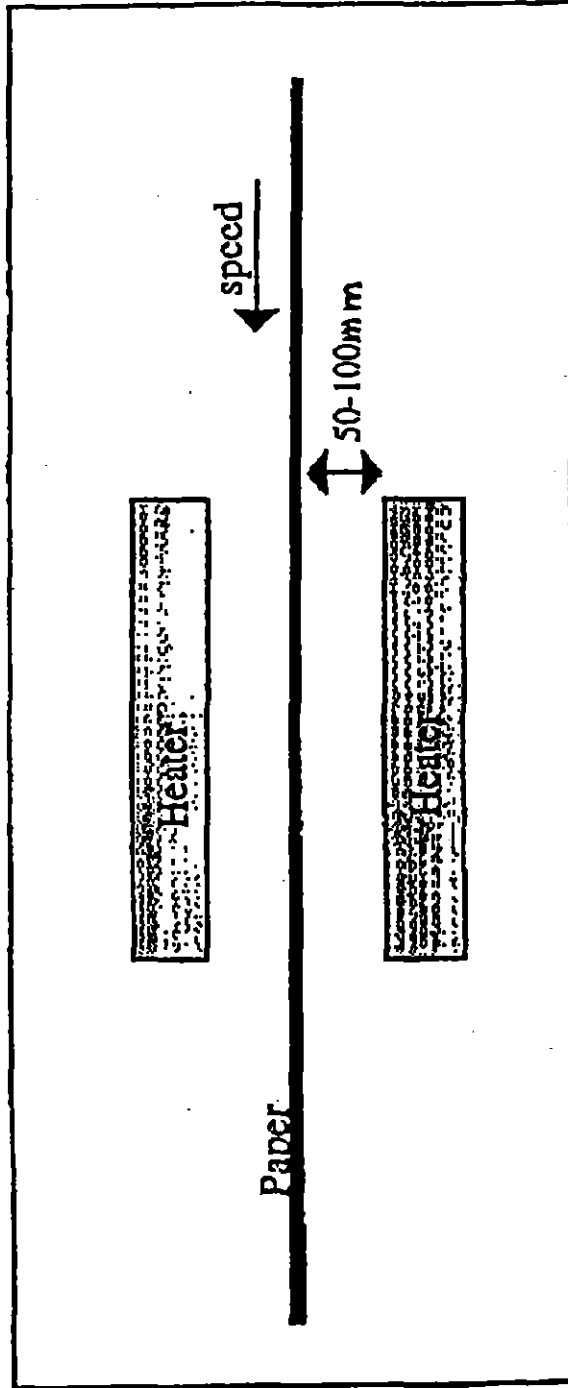
In the next figure, number 6, the results from the energy balances are shown both with two and four emitter rows in operation. Also a comparison is made with results from measurements made by CTP in France on their pilot coater in Grenoble. These results correspond very well.

Emission Spectra from IR-radiator

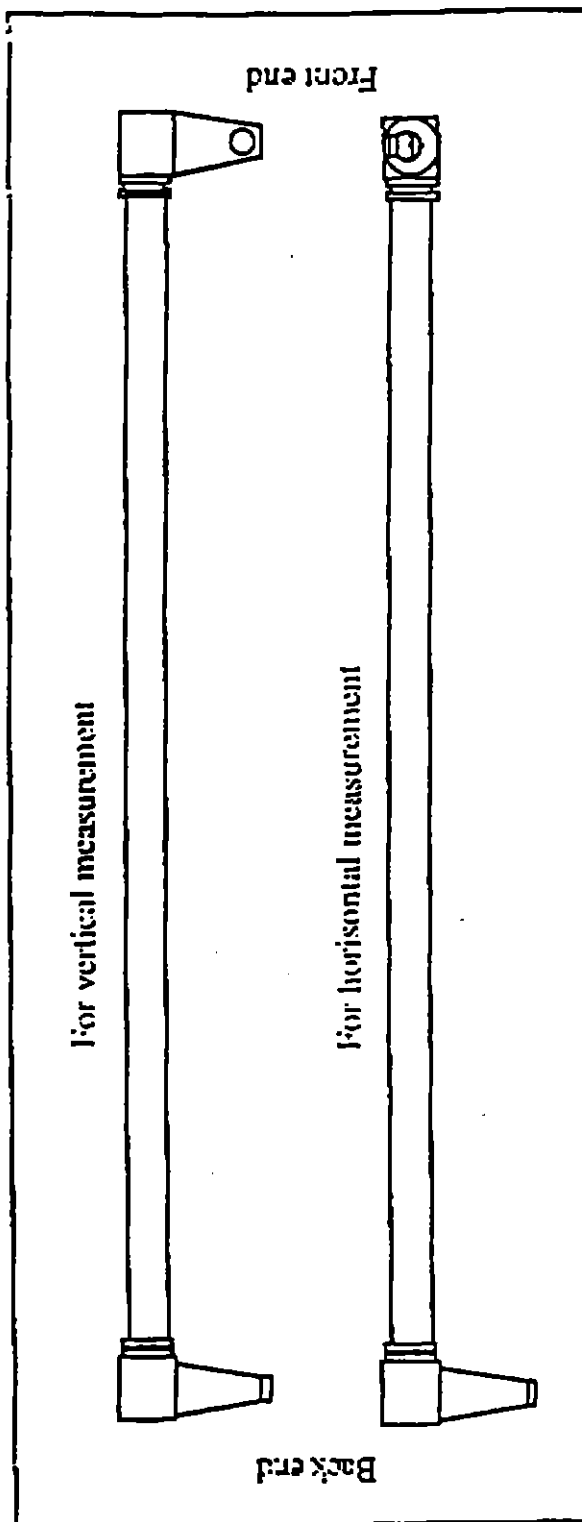


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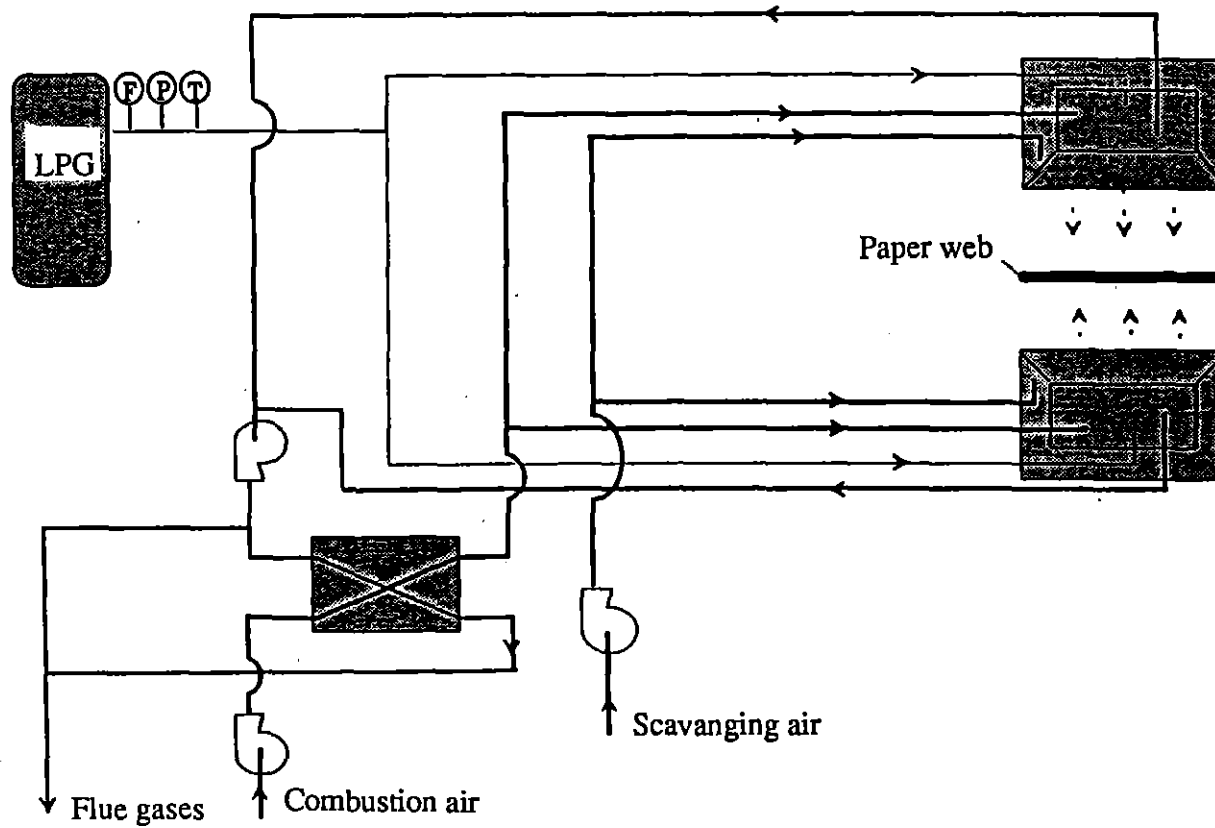
Available space in a Paper Machine



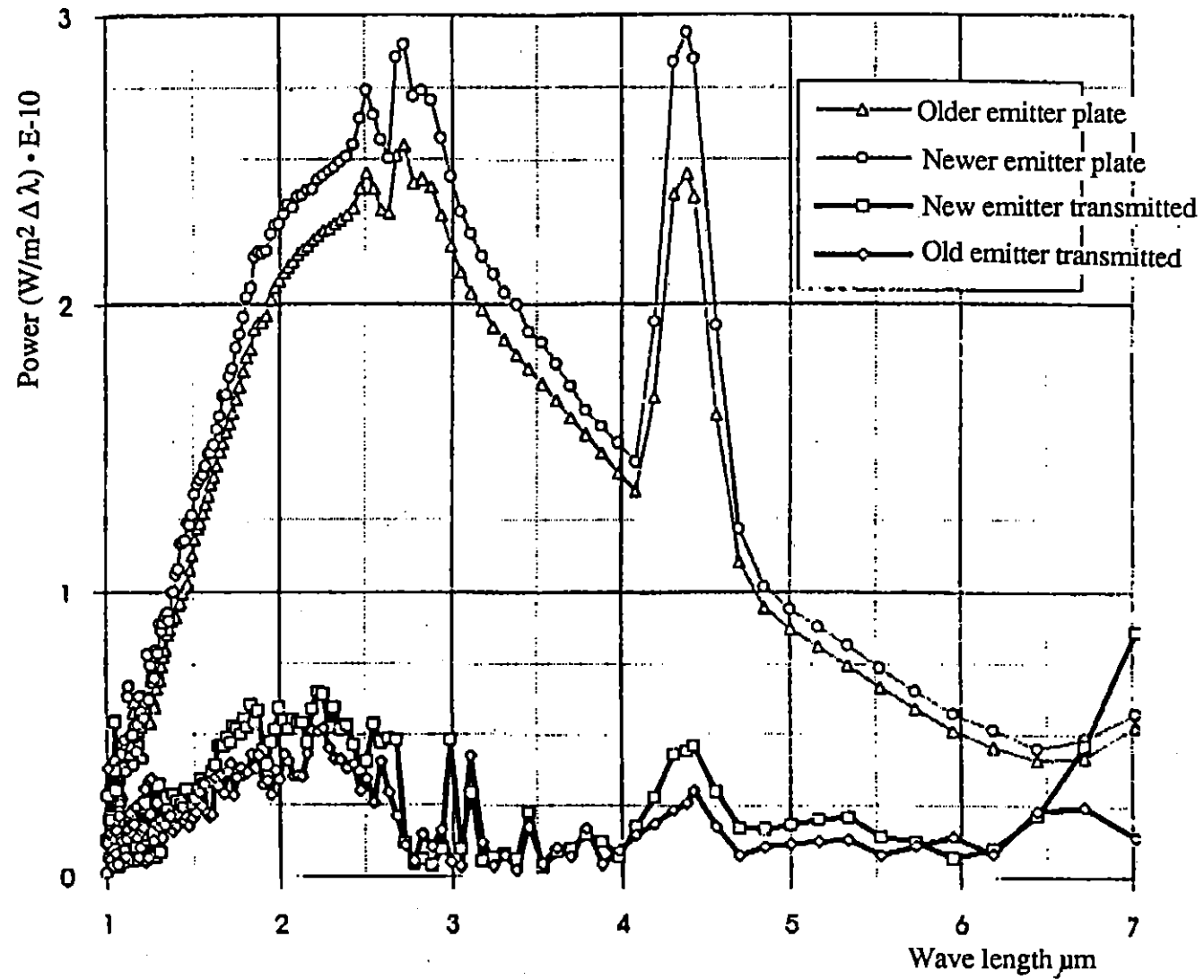
Light-Pipe for FTIR-instrument



Process Flow Sheet for IR-dryer



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Figure 5

	<u>Four Rows</u>	<u>Two rows</u>
Base Paper Weight before IR (g/m ²)	99-100	72-73
Moisture content (%)	7-8	7-8
Total energy efficiency CTP (%)	28-30	28-30
Total calculated energy eff. (%)	31	28

Gas Fired Air Heaters

Beginning in the summer of 1993 Arlöv Sugar factory (SSA) rebuilt their six production lines for sugar cubes. Each line contains a belt dryer in which the cubes are dried in hot process air with a temperature of 160°C. Before the rebuilding the process air was heated by high pressure steam but during 1993 the steam heaters were changed to compact gas fired heaters, one for each line. The reason for changing from steam to gas is that the Sugar Factory has chosen only to produce low pressure steam which pressure is not high enough to heat the air.

In figure 1 there is a process flow sheet for one of the six equally designed production lines. The sugar cubes are transported on a perforated steel belt through a tunnel dryer in which the hot process air is distributed over the cubes. The moisture content of the sugar at the inlet of the dryer is only a few percent and the amount of water evaporated in the dryer is small. The process air is then withdrawn from the tunnel through two outlets, one at each end of the tunnel. The two outlet ducts then join before a filter and a fan which increase the air pressure before it enters the air heater. Most of the air is recirculated. Only the amount that leaks out at the ends of the tunnel is replaced. The temperature drop of the circulating process air is mostly due to heat losses in ducts and fan.

A prototype of a compact gas fired heater from Bronswerk in Holland was tested during the spring in 1993. The heater is developed by GASTEC and equipped with a high-velocity burner from Eclipse. The input power (figure 2) of the prototype was 100 kW. The test results were of that kind that the Sugar Factory decided to install six units.

In the autumn of 1993 several of them showed severe damage with broken and even melted tubes. The SSA decided to replace one heater with a conventional heater from Eclipse (figure 3). This unit, RHT-100, is fired with a low velocity burner, Ratiomatic RM 50.

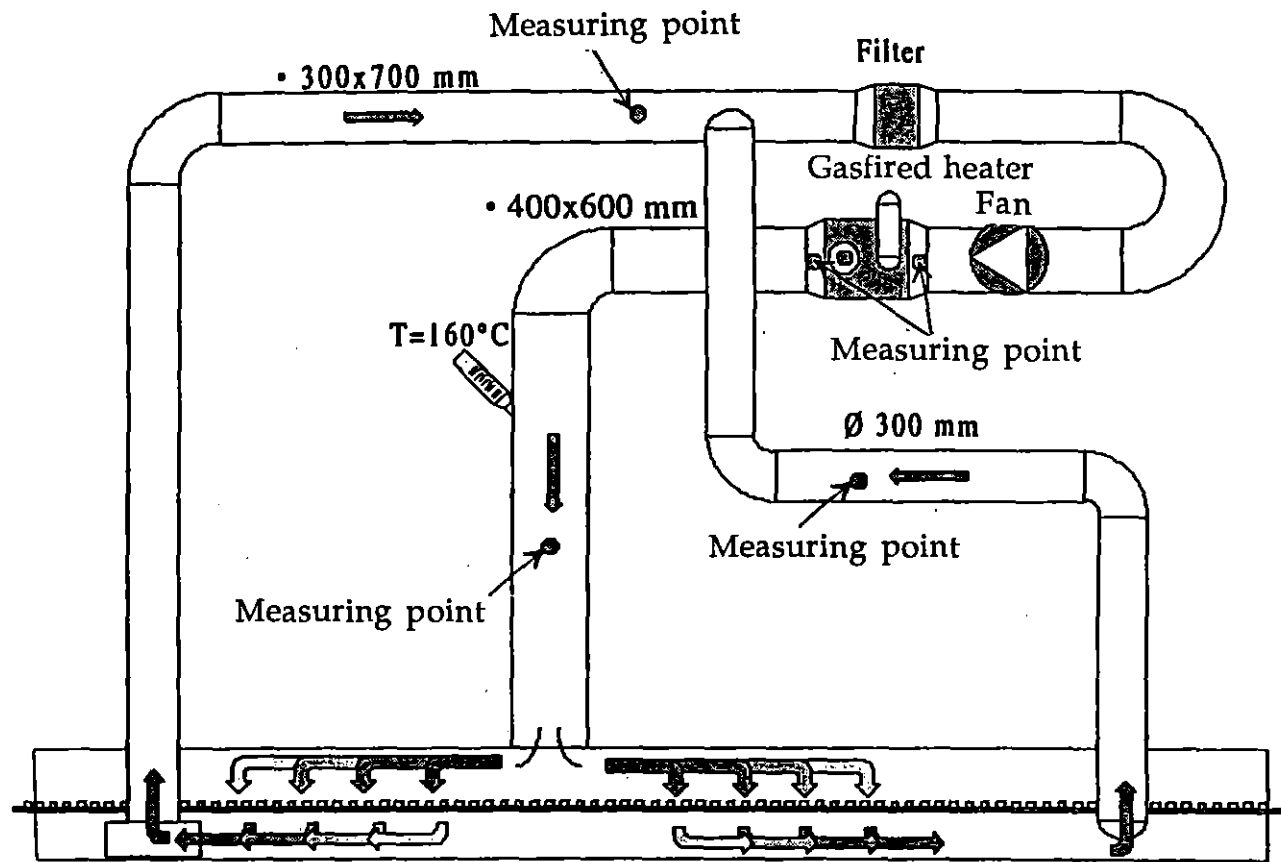
The design principles of the two heaters are different. The unit from Bronswerk is very compact with finned tubes and a high heat transfer rate both on the inside and the outside of the tubes. On the inside due to the high velocity burner, and on the outside due to the fins and also a high pressure drop. The flow of process air and combustion gases are counter current which means that the wall temperature in the firing tube is rather high and very different from the temperature of the last tube passage which have caused the problems. The design of the back turning chamber has not been able to cope with the difference in expansion of the tubes. The insulation inside the chamber has broken and the hot combustion gases have hit the steel wall.

The Eclipse heater is of a co-current type with no fins on the tubes. This means that the temperature of the tube walls are more equal. There has been no mechanical problem with this heater.

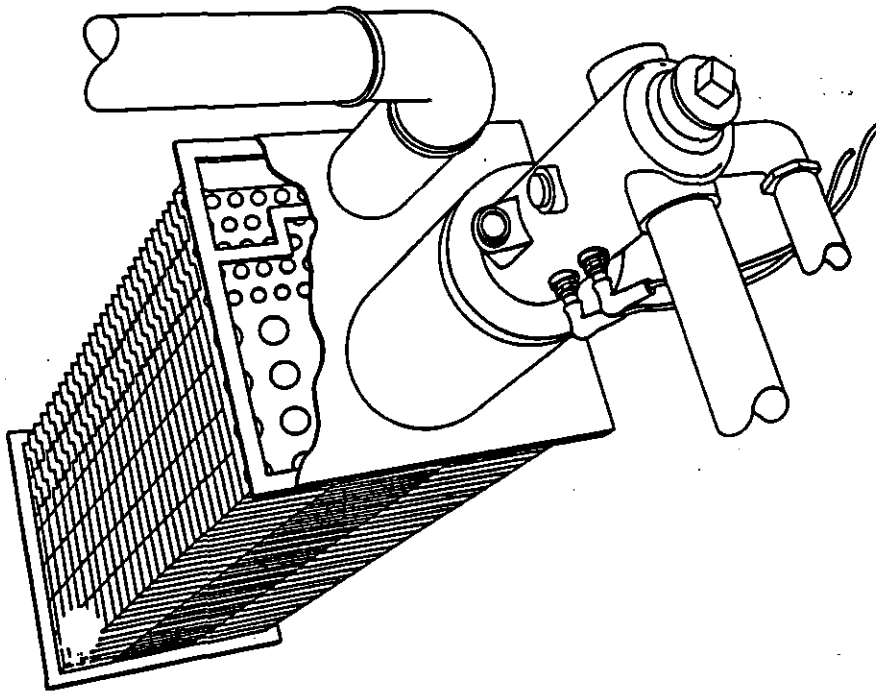
Bronswerk has changed the mechanical design of their heater to supply the firing tube with a separate expansion bellow, which will take up the thermal expansion of the tube. The back turning chamber is still free to move on it's guides and to take up the expansion of the following tube passages. One of the Bronswerk heaters has been rebuilt according to this different design and is now tested at the sugar factory.

When the Sugar factory installed the Eclipse heater it gave us a chance to compare the two types under equal circumstances. We have had a consultant to carry out measurements and making comparing heat balances for the two heaters. The results of these are shown in figure 4. As can be seen in the table both heaters produce the same outlet temperature, 160°C. The air flow in line 6, the one with the Bronswerk heater, is lower, 3.6 ton/h compared to 4.6 ton/h in line 5. This is due to a higher pressure drop in line 6, both over the heater and over the steel belt. In line 6 is used a non perforated steel belt. The energy efficiency of the Bronswerk heater is about 11 percent higher than the efficiency of the Eclipse heater.

The investment cost is comparabel for the two heaters. The difference in energy cost for a unit of 100 kW is small even if there is an 11% difference in efficiency. What is more important is the compactness of the Bronswerk heater which allows it to be installed even in a narrow space. The dimension of the Bronswerk unit is: 800 x 450 x 450 mm compared to 1,270 x 1,300 x 700 mm for the Eclipse heater. The flow gas temperature 130°C versus 350°C. This means that the cost for the flue gas installation will be lower for Bronswerk.

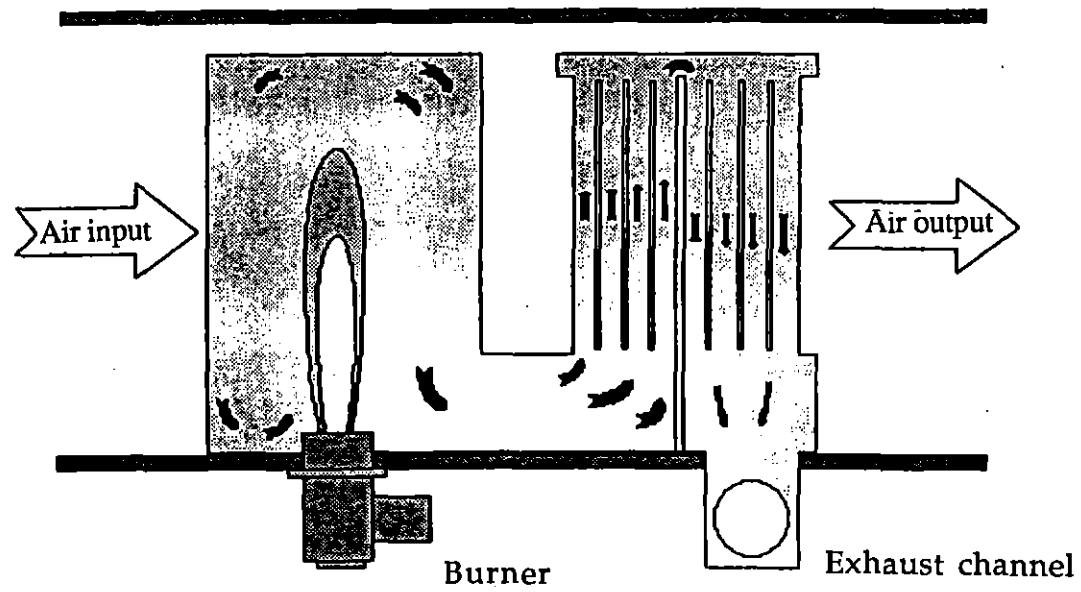


Process flow sheet for sugar cube's dryer



Compact Gas-Fired Air Heater

Swedish Centre of Gas Technology



Process flow sheet Eclipse RHT-100 Indirect Air Heater

	Air ton/h	Temp °C	Δp_{heater} mbar	Input P kW	η %
Line 5 - Eclipse RHT 100	4,55	160	0,1	79,1	84,7
Line 6 - CGAH Bronswerk	3,56	160	2,4	63,9	93,9

Nordic Pot Furnace Project

Background

Within the Nordic Pot Furnace Project which took place from 1990 to 1993, a new concept for gas-fired pot furnaces for glass melting was developed. The Glass Research Institute in Växjö (Glafo) was responsible for technical expertise as well as for project leadership. Additional collaboration was provided by the Institute for Heat and Furnace Technology at Kungliga Tekniska Högskolan, KTH (the Royal Institute of Technology), and by the Department for Control and Maintenance Engineering at the University of Lund.

The project was financed by the Nordic gas industry as well as by the hand made glass industry in the Nordic countries and by NUTEK (the Swedish National Board for Industrial and Technical Development).

Goals and Objectives

The objective was to develop a concept that would provide greater cost efficiency for the manufacture of glass products.

The specific goals for the project were:

- to improve glass quality so that the amount of produced first class glass increased by 2-3%
- to reduce energy consumption by 40% with (and 10% without) the installation of a recuperator
- to reduce NO_x-emissions by at least 50% of the existing level or to attain less than 200 mg NO_x/MJ_{fuel} (the future norm for TA-Luft)

A gas-fired furnace in Skruf's Glassworks was used as a reference for the tests. Measurements were taken there of energy consumption as well as of NO_x-emissions. The burner type in that furnace was the reference burner for the tests.

Organization of the Project

The project consisted of four parts:

I. Preliminary studies and a literature search

This part of the project was done by Glafo. A search of the literature was carried out and a simple model was constructed at Glafo to simulate heat transfer to a pot holding molten glass.

II. Tests using a water model at the Department of Heat and Furnace Technology at KTH in Stockholm

The tests were carried out by using a water model of a pot furnace and its burners. By simulation of different burner locations and combinations of burners as well as locations of exhaust outlets, it was possible to determine the optimal conditions for heat flow in the furnace.

III. Pilot furnace tests at the Gas Laboratory at the Department of Control and Maintenance Engineering at the University of Lund

The objective of the pilot furnace tests was to choose various burner types to be used in positions selected with the help of the water model tests. Selection of these burners required measurement of fuel consumption, NO_x-emissions and temperature distribution in the furnace wall and pot.

The pilot furnace, installed at the gaslab of DTI, was a full scale pot furnace with the pot replaced by a pot simulator, as DTI wasn't able to handle molten glass in their lab.

Various burners of conventional and low-NO_x-type were investigated as well as a Flat Flame Burner located in the roof of the furnace directly above the pot. In all, ten test series were carried out with different burner combinations.

To improve glass quality, uniform heat distribution in the furnace is desirable, especially so as to provide the lower portions of the pot with heat. This is attained through a two-burner alternative with one burner placed in the furnace wall even with the bottom of the pot and another burner above the pot. The effect was most pronounced in the combination with the Flat Flame Burner: virtually no temperature gradient existed between the upper and the lower parts of the furnace. It is important, however, to set the lower burner's maximum output at a level that ensures that neither the pot nor the furnace will be damaged.

IV. A field experiment with a pilot furnace at the Kosta Glassworks

The pilot furnace from DTI was installed at Kosta Glasswork The furnace was equipped with a new vault, a glass chamber and an exhaust duct as well as a recuperator. During the FE, LPG was the fuel.

Two different burner combinations were tested:

2. A conventional furnace burner above the pot edge (not of low-NO_x-type) as well as a low-NO_x-burner in the lower portion of the furnace.

Unfortunately testing of the low-NO_x-burners in both positions was impossible because control of the primary and secondary air could not be carried out within the framework of the project.

The goal of increasing glass quality by 2-3% was met. Excellent glass quality was attained, especially with the Flat Flame Burner in the roof.

Energy requirements remained at the same level or decreased somewhat as compared to corresponding oil-fired furnaces. A well-insulated and well-regulated gas furnace competes very well with other energy sources such as oil and electricity in terms of cost of operation.

It was not possible to reach TA-Luft norms for NO_x-emission. Future work to attain lower emissions should be concentrated in the areas of developing burners and lowering the nitrogen content of the raw materials.

Enclosures

Nordic Pot Furnace Project:

A new concept for a gas-fired pot furnace for glass-melting developed through a cooperative effort of:

- Glass Research Institute
- Nordic gas industry
- University of Lund
- Royal Institute of Technology, Stockholm (KTH)
- NUTEK (the Swedish National Board for Industrial and Technical Development)

Swedish Centre of Gas Technology

Nordic Pot Furnace Project

Specific goals:

- to improve glass quality so that the number of firsts increased by 2-3%
- to reduce energy consumption by 40% with recuperator and 10% without
- to reduce NO_x -emission by at least 50% of existing level or to attain less than 200 $\text{mg}/\text{NO}_x/\text{MJ}$ (future norm for TA-Luft)

Nordic Pot Furnace Project:

Project phases:

- I Preliminary studies and literature search
- II Tests using a water model at KTH
- III Pilot furnace tests at DTI
- IV A field experiment at Kosta Glassworks

Swedish Centre of Gas Technology

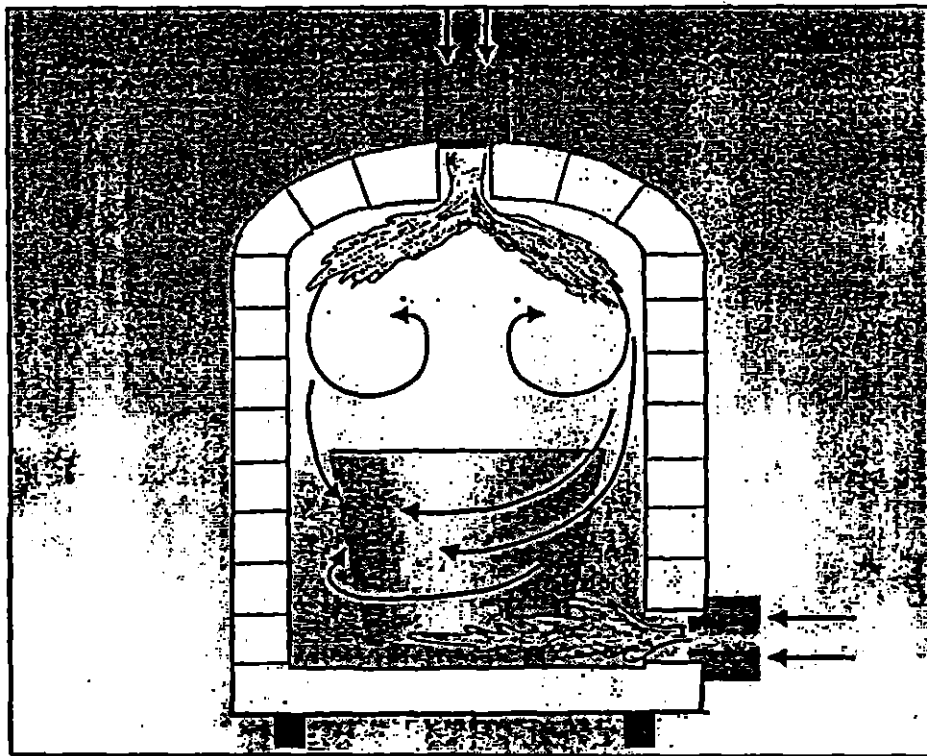


Figure 2: Flow pattern with a tangential burner in combination with a flat flame burner

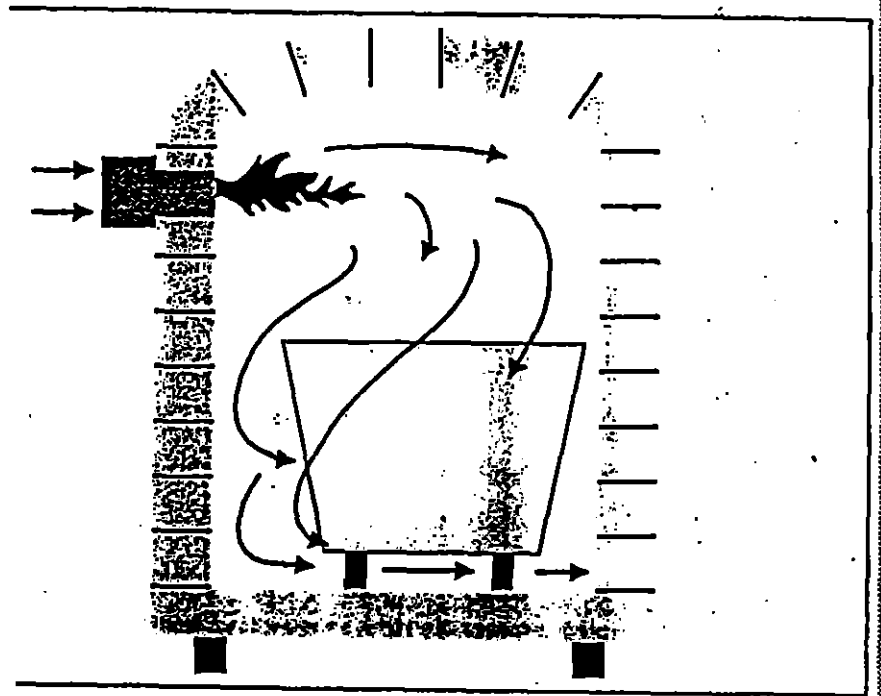
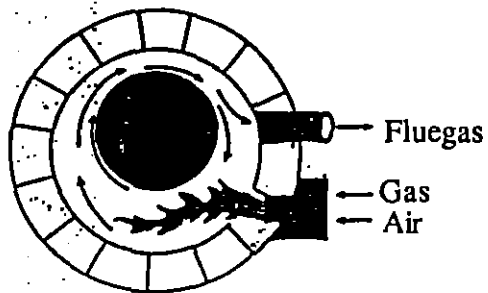


Figure 1: A flow pattern in the reference furnace



The furnace in cross-section

Nordic Pot Furnace Project:

Results:

- With a combination of a low-NO_x-burner in the lower portion of the furnace and a Flat-Flame burner in the roof excellent glass quality was attained.
- The goals of increasing glass quality by 2-3% were met.
- Energy requirements remained at the same level or decreased somewhat as compared to corresponding oil-fired furnaces.
- It was not possible to reach TA-Luft norms for NO_x-emissions





Hydrogen – a Gas Fuel for the Future Energy System?

Ola Gröndalen
Sydkraft Konsult AB

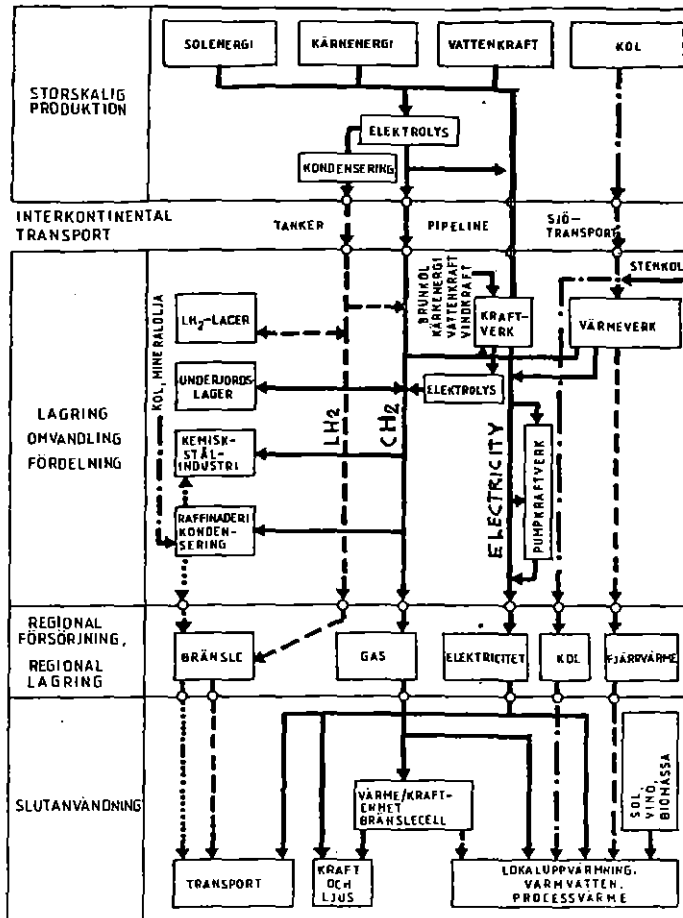


Hydrogen - a gas fuel for the future energy system?

A paper for Nordic Gas Technology R&D Workshop April 20, 1994

By

Ola Gröndalen, Sydkraft Konsult



A future hydrogen/electricity system. Based on material by Winter and Nitsch.

Content

1. Why discussing hydrogen?
2. Hydrogen related to energy use, a brief overview.
3. Aspects on hydrogen as a major future energy carrier together with electricity
4. The production, storage and distribution of hydrogen
5. The cost of hydrogen and other fuels including external costs.
6. Hydrogen transport
7. Hydrogen storage
8. The use of hydrogen
9. Factors influencing the move to hydrogen
10. Conclusions
11. References
12. Appendix

1. Why discussing hydrogen?

Energy systems based on solar/hydrogen/electricity basically meets fundamental criteria of sustainable development. The energy system of the world today based on mainly fossile fuels violates the basic criteria of sustainability. The most important violation is that the available fossile fuel cannot be used without a rapid change of the atmosphere. In addition the resources of easily accessible and cheap fossile fuels are limited. Both oil and natural gas are calculated having only some 40-50 years of use as major energy sources from now. (This has been the case for a long period as more resources have been discovered than the use). Introduction of new systems for energy supply, transport and distribution historically has taken a very long time from the first start to a large scale utilization in the size of order 50 years. It is no doubt that existing energy sources will be dominant for the next decades into the 2000's, but a move to clean and safe energy sources and systems is needed to support and substitute the existing system. In the debate hydrogen often is referred to as a fuel for the future. Hydrogen can only be regarded as a safe future fuel if the production of hydrogen is based on sustainable principles. Hydrogen based on fossile fuels which is today's major source does not meet criteria of sustainability. Hydrogen and electricity are both no primary energy sources, but energy carriers or energy currency with interesting complementary properties. The major complementary properties of hydrogen and electricity can be characterized:

- *Hydrogen can be stored; electricity cannot
- *Hydrogen transport is by moving material; electricity transport requires no material transport.
- *Hydrogen can be a feedstock for chemical or other purpose; electricity cannot
- *Electricity can be used for information handling; hydrogen not
- *Exchange between hydrogen and electricity is possible both ways with relatively low losses and small environmental impact.

The principles of sustainable development are related to

- * The principle of material
- * The principle of compatibility with the natural system
- * The principle of protecting the natural system and biodiversity

Fig 1 shows that a hydrogen based energy system meets the requirements of the first two principles and as will be discussed later also to a great part also has the potential of meeting the requirement of the third principle. Therefore hydrogen is discussed as one of the important alternative energy carriers for the future.

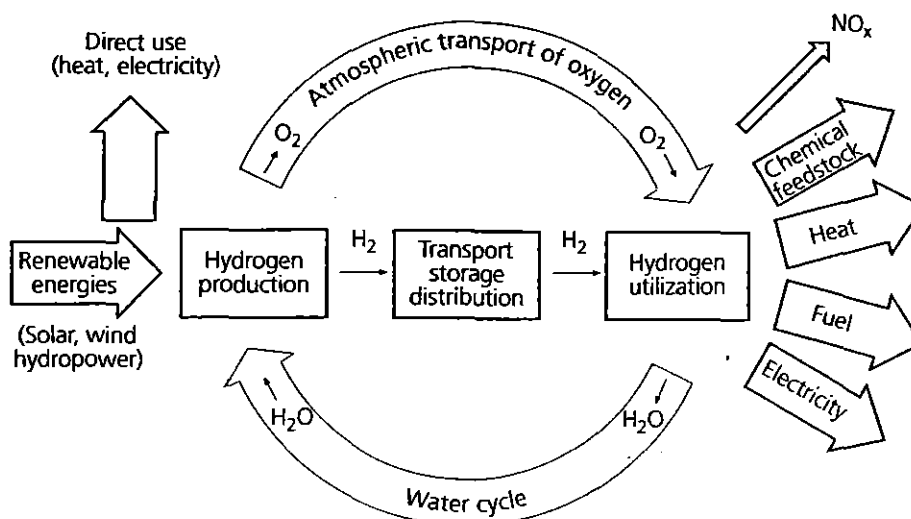


Fig 1 The hydrogen cycle based on renewable energy (solar, hydroelectricity, wind) Source:

2. Hydrogen related to energy - a brief overview.

The existence of hydrogen is known back to the 1500's when the Swiss doctor Paracelsus discovered its existence and started studying the properties. In 1766 hydrogen as an element was identified. (Cavendish, England). Hydrogen was used for balloons at the end of the 1700's and was used in air ships from the late 1800's. The dramatic accident 1937 with the airship Hindenburg ended this development. Hydrogen-rich gases were in use for heating and lighting from the end of the 1700's and gas distribution was started in Sweden around 1850. The first car driven by a hydrogen engine was made by Renard (France) 1917 and the largest had a power of 100 hp. Hydrogen together with oxygen is the major propulsion fuel for spacecrafts at the present time. In Russia tests with a civil aeroplane was made 1988.

Hydrogen today has wide industrial applications. The global H_2 - production is approximately 42Mt per year of which 76 % is based on natural gas, 23 % on oil and the rest on electrolysis of water. Approximately 80 % of the produced hydrogen is used in the chemical industry and approximately 20% for energy products, mainly hydration of fossil fuels. In Sweden ca 130 000t hydrogen is produced per year.

In the global society hydrogen has an increasing part of the energy content in fuel on an average. This may indicate a long term trend in the direction of a hydrogen domination (H_2).

Hydrogen is produced by steam reforming of natural gas, gasification of oil or coal and electrolysis of water. The main reasons why hydrogen today is not a major energy carrier is the complicated production process, the safety aspects in all stages during production, storage, distribution and use and the low cost level of other fuel. The production cost of hydrogen by means of steam reforming of natural gas depends to 70-90% of the raw material. The electricity cost is some 50-75% of the hydrogen cost when producing hydrogen by electrolysis of water. (2)

When producing hydrogen from natural gas or naphtha approximately 2 units of energy is needed for 1 unit of energy in the hydrogen. When producing hydrogen from fossil fuels, carbon dioxide, carbon monoxide, methane and sulphur etc. is released.

Hydrogen is used in large thermal power plants as the coolant for the alternators. Most power companies have positive experience for many decades of this application.

The cost of hydrogen production depends on the volume of the production. The German company, Caloric 1989 worked out a diagram, fig 2, of the costs of the production of 99,99% pure hydrogen at 17 bar pressure by three different routes (4).

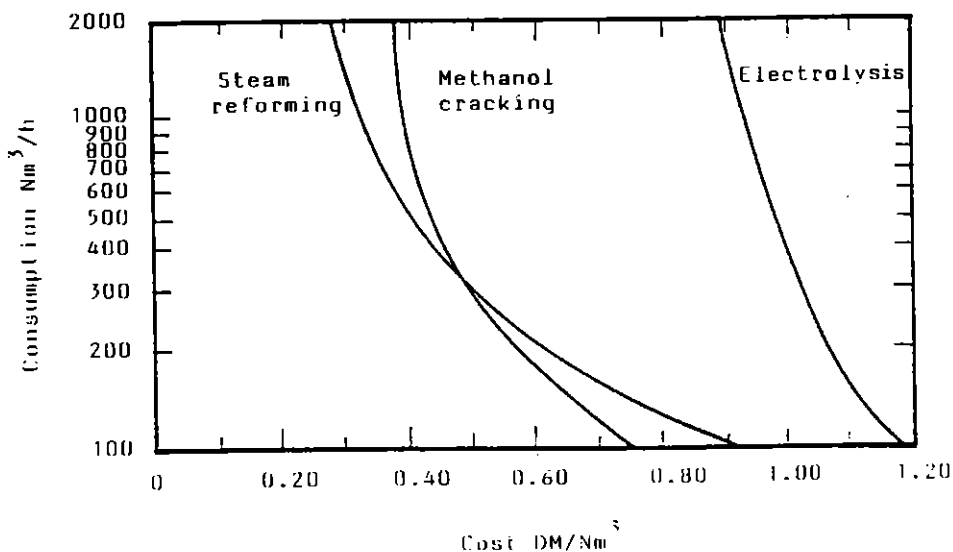


Fig 2. Production cost of hydrogen by steam reforming, methanol cracking and electrolysis of water. Source (4)

3. Aspects on hydrogen as a future fuel and energy carrier.

Basically it must be remembered that hydrogen is not a primary energy source. The production of hydrogen therefore must be based on other resources. Historically fossil fuel reforming or to a small degree the use of electricity for the dissociation of water has been applied.

Production of hydrogen can be illustrated by the steps of development to sustainable and clean energy from today's mainly fossil fuel based production.

Present	*Reformation of NG, oil and coal - > Hydrogen
	*Fossil based electricity, hydroelectricity and nuclear electricity - > Electrolysis of water - > Hydrogen
Future	*Biomass based hydrogen production
	*Solar electricity generation - > Electrolysis of water - > Hydrogen
	*Solar energy, direct conversion to hydrogen

The potential sources of hydrogen.

A very large potential for the production, transmission and distribution of a fuel like hydrogen exists along different routes. This potential is very unevenly distributed on the planet. Hydrogen from hydroelectric power has a large potential in theory of approx 56 EJ, but is limited to certain countries and only a fraction of the total potential can be utilized. Biomass seems to have a larger potential, but the required land area and competition with food production, forestry and other products from crops limits this option. It seems very unlikely that land will be dedicated to fuel production rather than food production in a world with a very rapid population increase. In Sweden with some surplus of land area at the present as seen from the needs of the own country, this option however may have a chance. As the development of future hydrogen seems to be an international task, special national solutions can be doubted. Wind power is another source of sustainable energy with a large theoretical potential. With an assumption of 10 % of the energy up to 1 km height being utilized, the energy content represents 1750 EJ. Only a very small fraction of this potential can be practically utilized. The gap between the theoretical and practical potential is very large for wind power. In Sweden 10-30 TWh annually of electrical output from wind power has been calculated being a future possibility with a reasonable economy. The future source of sustainable energy of the required potential and other properties is direct solar energy via solar cells or some thermal process. A Stirling engine in the focus of a solar is the most efficient process known. An efficiency of more than 25% can be reached. Solar cells at 1% at the earth's land area would supply more energy than today's total human use. The earth's deserts represent approximately 25 % of the earth's land area. The requirement of land area for PV electricity and hydrogen is only about 1/30 part of the area needed for biomass.

Hydrogen in comparison with key factors. Source: (4)

Global human energy use 1993 EJ	Projected energy use 2020 EJ (WEC 1993)	Hydrogen based on biomass, 10 % of land area for crops and forest, 15 t dry-mass per ha EJ	Total solar energy flux to the earth surface EJ	Total wind energy potential EJ	PV on 1 % of land area Hydrogen EJ
382	497-755	113	1 009 000	1196	580

The supply of water is today a critical issue in most countries of the world and particularly so in the countries with high solar radiation. This question also is actual for the different hydrogen options. The problem of water supply can be solved even if water should have to be produced in

desalination plants and transported hundreds of km to the solar hydrogen plant. The output would be reduced som 10 % for the water supply.

Land and water requirement for different alternatives of hydrogen production.

(Based on: Ogden & Nitsch, Renewable Energy 1993 and own material)

Electrolytic hydrogen from:	Land requirement		Water requirement
	ha/MWe peak	m ² /GJ(year)	l/GJ
PV	1,3	1,9	63
Stirling engine	1,2-1,6		63
Solar thermal	4	5,7	63
Wind	4,7-16	6,3-33	63
Hydroelectric	16-900	11-500	63*

* Not including the large hydroelectricity water supply

An evaluation clearly indicates the largest potential in hydrogen from conversion of solar electricity. The required land area is relatively small, there seems to be no competition with other human need as food. The development of the technique is in strong progress and the requirements of water supply can be met.

4. The production, storage and distribution of hydrogen

As the background of this paper is hydrogen in the perspective of sustainable development only solar based hydrogen is discussed.

4.1 The production of solar based hydrogen.

The different routes to solar hydrogen are illustrated in fig 3. There are options of which some don't need the way via electricity. No system are available for practical use for direct photochemical decomposition of water (1). Decomposition of hydrogen sulfide by thermolysis is one alternative with promising properties. Sulphur and hydrogen would be the end result. Thermocatalytic methods are also investigated as well as hybrid systems like the Yokohama Mark 5, 6 and the latest Mark 7 cycle. The cycles are only experimental and nothing is known about the problems related to corrosion or the long run economy. Experiments are also made with thermochemical/electrochemical and thermolytic/ electrochemical processes. In a feasibility study for a module of 344 GJ/year hydrogen production the efficiency was found to be 4,1 % and costs were found to be 46\$ per GJ or of the same order of level as solar PV and electrolysis of water (1). Hybrid photochemical/ thermochemical/electrochemical cycles are discussed and tested by different companies mainly in USA, Japan, Germany etc. The cost indications available (1) tells that conventional electrolysis is rather competitiv. Table 1 shows some typical parametrs.

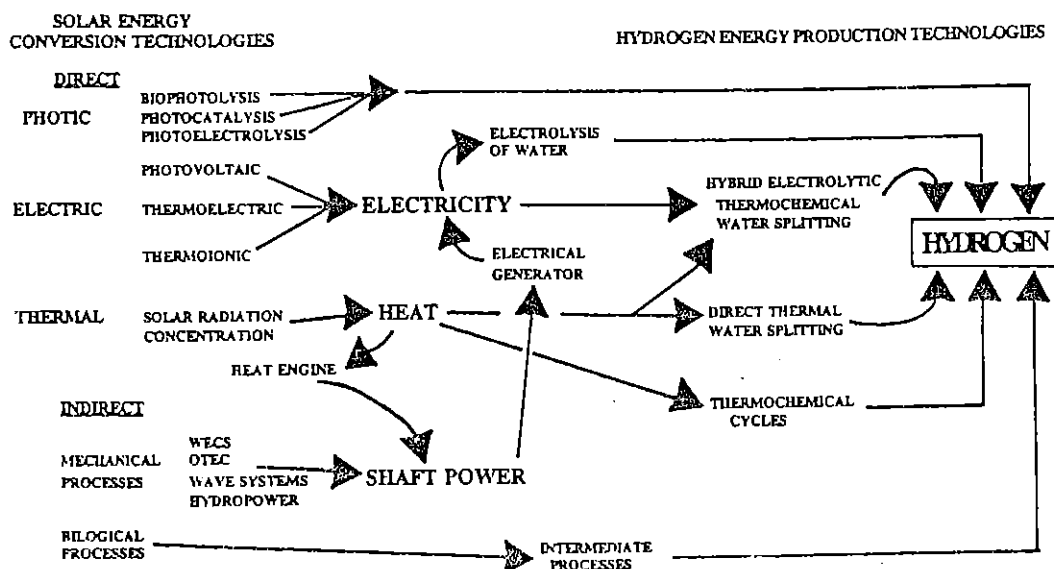


Fig 3. Routes to solar hydrogen. Source: (1)

Table 1. Energy efficiency, plant size and typical costs of hydrogen production. Source: (1)
(Capital charge=0,1)

Solar process	Energy efficiency	Plant size GJ hydrogen/year	\$ / GJ H ₂
Thermolysis	4,1	300	68
Hybrid thermolysis	5,4	600	46
General Atomic cycle	25,5	1,4x10 ⁶	62
Mark 13	21,5	10 ⁶	39
Christina	21,5	"	60
Mark-IIA	22	"	34
Mark-IIB	68,7	"	-
Thermo-electrolysis	18,9	"	48
PV- electrolysis	11	1(Modular)	57-125

4.2 Large scale hydrogen systems

Electricity and hydrogen is a working couple which complementary properties. Only hydrogen can be stored. The conversion between hydrogen and electricity is possible in both directions with some losses. The transmission in large quantities on an international scale can be made both with HVDC and hydrogen. Several studies have been made on that subject.

A very important factor of the economy of solar hydrogen is the efficiency of photovoltaic cells or the solar thermal process which can be utilized. Table 2 gives some indications of the development the last decade.

Table 2 Characteristic data for solar electric systems in Californian or North African conditions.

Plant	Year	Peak power MW	Collector area m ²	Electricity production kWh/ m ² collector	Electricity production kWh/ m ² land area	Electricity cost US \$/kWh *
SEGS 1	1984	14	82960	236	70	0,206
" 2	1985	30	165376	261	71	0,144
" 3	1986	30	203980	296	90	0,119
" 4	1987	30	203980	296	92	0,122
" 5	1988	30	233120	292	94	0,132
" 6	1988	30	188000	365		0,128
" 7	1988	30	183120	389		0,124
100 MW project central tower	1991	100	874200	380	91	0,11
Luz hybrid solar/NG project for dev. countries	1991	30	218000	276	75	0,17
PV at 6 % discount rate:						
Thin film	1990	Any size is possible				0,14-0,15
Polycrystalline	1990	"				0,12-0,19
Crystalline	1990	"				0,19-0,30
Projected past 2000						
PV at 6 % discount rate						
Thin film						0,018-0,038
Polycrystalline						0,057-0,106
Crystalline						0,057-0,106

The table shows a steady increase in efficiency and reduction of specific costs of solar electricity. The investment level in the early 1980's was approx. 15\$ per W peak. (The correspondence between area and power is based on an irradiation level of 1000W / m²). In 1990 the cost level was one decade lower and the projections point at further reductions and at the same time improved performance for the future.

Large scale production and transmission of solar based hydrogen and electricity to central Europe from Africa or Spain.

A German study of comparison between HVDC and hydrogen transmission was performed 1991 (13). The idea was a large scale transmission of HVDC electricity and hydrogen from Algeria. The study looked at only HVDC, only hydrogen and a combination of the two. The total energy quantity which should be supplied to the Ruhr district amounted to 281 TWh/year of which 56TWh as electricity and 225 TWh as hydrogen. The study showed that the combined system was most economical and the total losses the lowest. Depending on the price of solar energy from the solar plant, the costs in Germany were calculated as shown in table 3.

Table 3. Calculated costs of HVDC/Hydrogen transport and storage.
Combined transport of HVDC and hydrogen.
DM/kWh

	Price of solar energy DM/kWh		
	1,00	0,50	0,10
Investment costs	0,14	1,14	0,14
Energy cost	0,18	0,09	0,02
Transport cost	0,32	0,23	0,16
Total cost	1,32	0,73	0,26

In another study (3) PV hydrogen production of 200TWh annually from Algeria or Andalusia in Spain to Central Europe was evaluated. The energy flow in the transmission pipeline was calculated to 29,3 GW hydrogen in the start going down to approx. 27 GW at the delivery outlet. The equivalent utilization hours of the solar plants were 1800 for the plant in Spain and 2100 in Algeria and 3600 hours annually for solar thermal process with 4-5 hours of daily storage. From Spain the losses were 19 % and from Algeria 22 % with gaseous hydrogen. Storage and transmission accounts for 10% of the total losses. Land requirement was higher for the solar thermal alternative because of tracking heliostats giving a land use factor of 0,25. The same quantity of solar hydrogen produced in central Europe would require the double land area at a totally much higher cost. With 6% respectively 12 % discount rate the energy costs were calculated for two alternative techniques of solar cells. One advanced, post 2000 polycrystalline of 16 % efficiency costing 100\$ per m² manufactured in factories in the 100 MW range per year for each factory. The other was advanced thin- film technology. Another alternative was steam cycle (St)

Table 4. Calculated costs of solar hydrogen from Algeria alternatively Andalusia to Central Europe. Discount rate 6% or 12 %. Source: (3)
Gaseous hydrogen in Central Europe \$/GJ.

	PV1		Andalusia PV2		St		Algeria PV1		PV2		St	
	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%	6%	12%
*Electricity	26	37	13	22	26	39	20	32	11	17	21	31
*Electrolysis	8	12	7	10	8	9	8	10	6	9	6	9
*Storage and transmission	4	6	3	4	4	6	5	9	4	7	5	8
*Hydrogen in the producer country	34	49	20	32	33	49	28	42	18	27	27	40
*Hydrogen in Central Europe	38	55	23	36	37	55	33	51	22	34	33	48

50\$/GJ corresponds to 1,44 SEK / KWh of hydrogen.

The transport of hydrogen further to the Scandinavian countries would mean a further approximately 1000 km up to 60 degrees north resulting in an increase of the cost level by several %.

The calculations of liquid hydrogen gave somewhat higher costs in the range 36-75 \$/GJ depending on location, technology and discount rate.

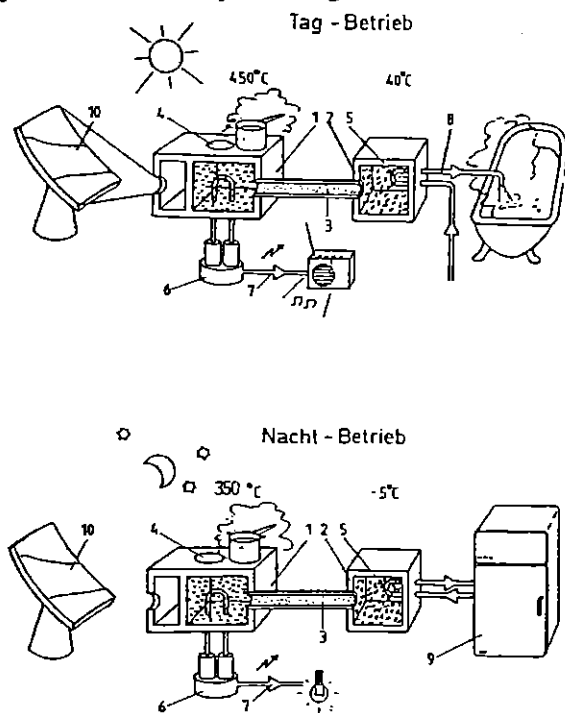
WRI 1989 published data of present and future solar PV electricity and hydrogen. At present stage the cost of hydrogen was calculated at 36 \$/GJ. With improvements in scale of manufacturing, modular efficiency increase, reduced material costs etc projections down to 8,4\$/GJ was given. This would be equivalent to SEK 0,24 per kWh.

It seems clear that the cost of long distance transmission does not dominate the cost. Production of hydrogen in a country with high insolation seems to be favorable. The cost of producing hydrogen in Germany was calculated to cost 40-50% more than import from Africa. If land area available should be evaluated this would be even more clear. Desert areas have no alternative value for foresting or agriculture and the areas are not a limiting factor. The consequences of the weather impact on solar systems in desert climate probably is a factor to be considered. The importance of international long term agreements and cooperation and peace must be undelined.

4,3 Small scale solar hydrogen

Small scale system for residential use and use for fuel in cars have been demonstrated also in Sweden. The problem today is the high cost level. Development for the use of hydrogen as a future fuel in cars is in progress by many manufacturers and at research institutes. One very interesting idea of development for solar- rich countries was published in H₂ Bericht nr 2 1991(9). Max-Planck Institute in Mülheim, Institut für Kernenergietechnik, Energiesystem at the University of Stuttgart and the German company Bomin Solar have developed a system for solar-rich countries. Hydrogen is the working and storage medium. The system is designed for cooking, cooling, and electricity. If system of this type could be produced at a reasonable price the market would be enormous.

The function of this system is based on a concentrating fix-focus mirror, a high temperature storage with catalytic magnesium-hydrid, a Stirling engine or fuel cell and a low temperature hydride-storage. The storage capacity in MgH₂ is high (up to 0,86 kWh/kg Mg) and the process nearly completely reversible. For the storage of one Mol MgH₂ 75 kJ is required. This energy is released during the dehydration. The day and night situation is shown in fig 4.



Das Schema des von Bomin-Solar vorgestellten Energiesystems bei Tag und bei Nacht. Die einzelnen Bauteile sind 1) Hochtemperaturspeicher, 2) Tieftemperaturspeicher, 3) H₂, 4) Kochplatte, 5) Wärmetauscher, 6) Stirling-Generator, 7) elektrische Energie, 8) Warmwasser, 9) Kühlschrank, 10) Spiegelkonzentrator.

Function.

During the day the sun heats the high-temperature storage and the Stirling engine receiver. The Stirling engine can produce electricity. From the high-temperature storage hydrogen is driven out to the low-temperature storage. In this storage ca 40°C is reached which can be used for warming of water. The high-temperature storage reaches 450 °C which is sufficient for cooking. During the night hydrogen flows back to the high-temperature storage from the low-temperature storage. The low-temperature storage is then cooled to levels suitable for the use for refrigeration. At the high-temperature side the Stirling engine or a fuel cell can generate electricity.

Fig 4. Small scale solar-hydrogen- electricity system. Source (9)

5. The competitiveness of hydrogen production including "externalities"

The conventional cost analysis of hydrogen now and future indicates in summary:

	Conventional steam reforming or methanol cracking \$/kWh	Solar hydrogen Estimate range \$/kWh
*Hydrogen production today	0.075-0,15	~0,75
*Hydrogen at site in Spain or Africa >year 2000		0,064-0,18
*Hydrogen to central Europe from Spain or Africa		0,08-0,2
*WRI projections 1989 Present technology		0,13
*WRI advanced future technology		0,03

The price level of gasoline in Sweden incl. taxes 1994 is ~0,1 \$/kWh

The price level of electricity incl taxes in Sweden 1994 is ~0,03-0,06 \$/kWh depending on conditions.

The USA are dominant in the world economy. Therefore an overview of the market prices and projections for the year 2000 for US conditions are given in table 9.

Table 5. US price level of fossile fuel 1990 and projected for the year 2000. \$ per kWh (thermal). Source: (5)

		1990	2000
Residential sector,	NG	0,020	0,025
	Fuel oil	0,024	0,032
Industrial sector	NG	0,012	0,016
	Fuel oil	0,016	0,028
	Coal	0,007	0,008
Electric utilities	NG	0,010	0,014
	Fuel oil	0,011	0,020
	Coal	0,005	0,007
Transportation	Gasoline	0,032	0,040
	Jet fuel	0,021	0,027

When comparing the level of cost of traditional fuel to the present and projected cost level of hydrogen the problem is apparent. Only the WRI futuristic projection is within the cost range of some of today's fuels. The power of competition on conventional commercial conditions for hydrogen versus conventional fuels therefore is impossible and will continue being so for a very long period. If all costs including external costs are incorporated the competitiveness of clean fuels improves substantially.

Incorporating the "Externalities"

What are the real or true economic costs of something we as humans do?

Traditionally the costs have been related to the situation at short term. For example in a system for electricity production the costs are constituted by capital costs, operational costs (mainly fuel) and

maintenance costs. The costs now and future of using a material of limited quantities and spreading it as molecules and visible waste causing different type of damage has traditionally not been included in the economic system. This situation is in a changing phase at the present time in Sweden as well as in most other western countries.

When applying the principle of incorporating the "Externalities", the importance of identifying the relevant parameters of costs and their magnitude is obvious. The science in this field is rather novel. Much work has already been done from different points of view, but a lot remains to be done. The results from different evaluations some times differ substantially.

In principle two cost categories have to be included in addition to the conventional cost analysis.

- The environmental and social cost
- The resource cost

The environmental and social cost.

These costs also are named external costs or "Externalities".

The external cost of emissions due to energy utilization is an important part of the true economic cost as seen from the national and international society in the long run.

Local and regional effects.

- Health effects
- Damage and corrosion on constructions and buildings
- Damage on the natural system, plants, animals, water, fishes, forests etc.

Global effects

- Consequences of "Global Change". Global warming from enhanced greenhouse effect leading to climate change, rising sea, more violent storms etc.
- Depletion of stratospheric ozone. The international society have decided on stringent regulations for the phase out of some CFC's, halons etc. according to the Montreal protocol and the later London agreement. More stringent time schedules is supposed to follow as the indications of "ozone holes" in the polar regions continue to increase. The indications 1993 from the Antarctic regions are the most severe ever measured.

Research is going on in this complicated area and different estimates have been made of the size of external costs in by researchers in several countries. Studies are being performed jointly by USA DOE and the European Community, by RCG/Hageler Bailly for New York and EPRI, at many universities and institutions in the USA and Europe.

The research has resulted in the use of taxes or fees on CFCs and halons, on carbondioxide and other emissions like SO_x and NO_x. In the USA the utilities and the regulatory commissions have led the way in establishing and incorporating environmental "Externalities".

Twelve states have calculated environmental externalities values which are used for the utility resource selection and twenty six states have taken some actions to incorporate the external environmental externalities. The effect of the quantified externalities is very strong, especially for coal fired plants in some states and more than doubling the electricity price. An example of the result from the evaluation from different methods is given in table 6. It should be noticed that the calculations are used for the establishment of plants, but not for the operation of the plants.

Table 6. Summary of Externality values in US cent per generated kWh.

Source: (6)

	Existing power plants		New power plants		
	Unscrubbed coal	Scrubbed coal	CC	AFBC	IGCC
Pace University	10,3	4,0	0,77	2,6	2,1
Massachusetts DPU	7,7	5,2	1,4	3,6	3,0
California Energy Commission	30,3	10,9	0,6	5,9	3,8
In- State					
New York PSC	2,5	1,3	0,3	0,7	0,5
Nevada PSC	7,9	5,3	1,4	3,7	3,0

The costs are calculated by use of external costs for different emission types. In table 7 an example again from USA shows the ingredients in the calculation and the figures used. The differences are in several cases very large.

Table 7 Comparison of externalities in the USA by emission type.

US 1989-1990 \$ per kg.

	Pace Ext. values	Calif. Energy Commission Out of state values	Massachusetts values	New York PSC values	Nevada PSC	Average
SO ₂	4,47	1,19	1,65	0,90	1,72	1,98
NO _x	1,81	3,22	7,16	1,96	7,49	4,32
VOC's	-	0,35	5,83	-	1,29	2,06
CO	-	-	0,95	-	1,01	0,98
Particulate	2,62	0,95	4,41	0,57	4,60	2,64
CO ₂	0,013	0,0077	0,024	0,002	0,024	0,014
CH ₄	-	-	0,24	-	0,24	0,24
N ₂ O	-	-	4,36	-	4,56	4,46

In Germany research has been performed and the results are showing significant variation. Particularly the evaluation of the external cost of nuclear power shows large differences. An example is given from an publication in VDI Bericht 927 Nov 1991 and is related to German conditions. In table 8 the monetized external costs are shown.

Table 8. External costs of alternative electricity production methods. US cents per kWh electricity.

	Dr Hochmeyer 1982 cost level	Prof. Voz 1988 cost level
Coal total	1,8-5,3	0,68-0,71
Nuclear (Uranium)	6,11-15,1	0,32-0,38
Solar	+3,7- +10,6	0,35-0,84

The figures of dr Hochmeyer have been based on statistics in which the Chernobyl accident 1986 is dominating. With the assumption that nuclear plants are built to western standards the figures would be at least one or two decades lower.

In a report 1991 Veziroglu and Barbir published external costs of Fossil fuels.

The result was in 1990 US\$:

Total estimated cost for :	Coal	0,035
" " " "	Oil	0,037 (Incl. military protection)
" " " "	NG	0,020

The resource cost.

The resource cost is thought to reflect the costs in the future of depleting resources to day and to increase the costs to future generations.

If for instance natural gas is burned to day and will be depleted for the next generation the true cost part for substitute has to be added.

This cost level can be the cost of burning coal if that is supposed beeing possible from resouce and environmental point of view. If not it might be the level of cost for future solar energy. This has to be monetized back to the present value. The argument against this principle is that technical development is not reflected. Such development may for example make the alternative cheaper in the future. The resource cost can be calculated as a present value analysis. (7)

From the material it is obvious that the figures are uncertain and have to be related to the actual environment and used with great care. The principle of applying the external cost is however important and is to day being introduced in many countries, sometimes as camouflaged fiscal taxes.

The incorporation of external costs would substancially increase the competetivness of sustainable alternatives as solar energy and hydrogen with an earlier introduction than with today's economic methods. It must be remembered that such a system on an international scale does not exist. The international society has more demanding and acute issues to deal with like war, hunger etc.

The conclusions on the production of hydrogen in a sustainable perspective:

- * Solar based supply of hydrogen and/or electricity is possible in all scales from microscale, solar- based supply for residences, industry etc. and very large scale quantities in an international and intercontinental scale.
- * The economy today related to existing fuls is not competitive. Introducing "externalities" would change the situation substantially and make clean energy sources competitive at an earlier stage.
- * More or less optimistic projections on future costs existes. Only large scale realistic projects will give the needed answers.

6 Hydrogen transport.

Hydrogen transport can be made in different forms. In pipelines, as liquid in cryo-tanks or in other chemical form as for instance ammonia or toluol. The quantity and the length of transport are two key parameters. Pipe-lines can be used for transport within a limited area as for instance a factory. Pipe-line transport can be used for long-distance transport of very large quantities of hydrogen in the same way as for natural gas. The energy content per mass unit is at the top for hydrogen, but the low density makes the volume more than three times larger than for natural gas at the same capacity. A comparison of different alternatives of long-distance energy transport table 9 gives some key relations.

Table 9. Energy transport and generation size. Source C. Marchetti 1988. Journal of Hydrogen Energy.

	Transportability km	Technical maximum km	Size of generation GW
Hot Water	~2	50	0,2
Electricity	100	1000	1
Hydrogen	1000	3000	100
Compressed air	2-3	10	0,001
Natural gas	1000	3000	100
Oil	10 000	10 000	2000*

* Possibel production from one field

The transport of hydrogen compared to natural gas for the transport at a distance of 2000 km is shown in fig 5.

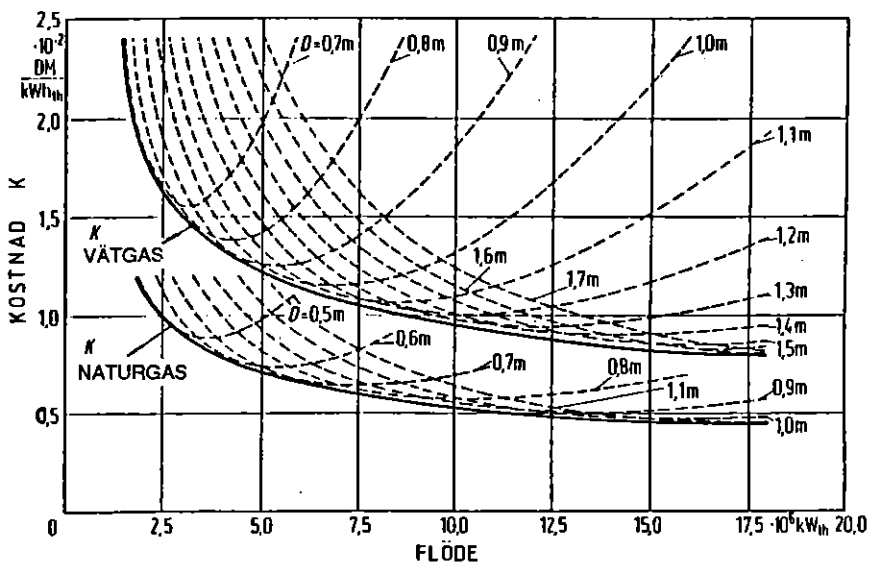


Fig 5. The cost of transport of hydrogen at a distance of 2000 km for natural gas and hydrogen as a function of flow and pipe- line diameter. Source: (10)

The transport from Southern Europe or Africa as discussed above would be within this range. According to the study by Ogden and Nitsch(3) the main data of the transmission pipe system would

be as indicated in table 10.

Table 10. Main data of hydrogen transmission system from Andalusia or Algeria.

Pipeline diameter	1,7m
Pipeline pressure	10 MPa
Hydrogen flow rate	29,6 GW or 8,3 M Nm ³ /h
Capacity factor (daily storage assumed)	6040 h/a
Usable storage volume	355GWh of hydrogen
Transmission distance	2000 km from Spain, 3300km from Algeria
Number of compressor stations	4 from Spain, 8 from Algeria
Mechanical compressor power MW	720 from Spain, 975 from Algeria
Transmission efficiency	9,5 % from Spain, 88,5 % from Algeria
Cost of pipeline per m	1900\$ (Incl 300 km of underwater pipeline)
Cost of compressor station per kWm	1100\$
Cost of underground storage per kWh hydrogen	2,4\$
Existing depleted NG field supposed utilized for storage	
Operation and maintenance	1,5 % of capital cost
Lifetime	30 years.

7. Hydrogen storage

Hydrogen can be stored in different form as hydrogen gas or liquid. Storage also is possible in metals or as part of chemical substances as methanol or ammonia. Storage is also possible in systems with hydroelectric resources as water. The storage can be made at the production site or other suitable location and also connected to the end use in a car, an aeroplane etc. The storage properties of hydrogen compared to some important fuels are shown in table 11. Although the energy content per mass unit is the highest for hydrogen the energy content per volume is low even for liquid hydrogen compared to most conventional fuels.

Table 11. Storage properties of hydrogen compared to important fuels.

	Storage temp K/ pressure kPa	Density kg/m ³	Volumetric energy MJ/liter		Mass energy MJ/kg	
			HHV	LHV	HHV	LHV
Gasoline	300/7,65 v.p.	720	34,5	32,3	45,9	43,0
LPG(6,9bar)	300/690	510	25,5	23,6	50,0	46,3
Methane CH ₄ (166bar)	300	111	6,16	5,51	55,5	50,0
Liquid CH ₄	109/102	470	26,2	23,6	55,5	50,0
Methanol CH ₃ OH	300/17v.p.	791	18,1	15,9	22,7	19,9
Ethanol C ₂ H ₅ OH	300/8v.p.	790	24,0	21,6	30,2	27,2
Hydrogen gas	300/17300	14	2,0	1,7	142,4	119,9
Liquid Hydrogen	20/102	71	9,95	8,4	142,4	119,9
Hydrogen Metal hydride						
Mg ₂ NiH _x	567/612	2560	11,6	9,8	142,4	119,9
FeTiH _x	310-535/3450	3420	13,8	11,6	142,4	119,9
Ammonia, liquid	300/100	600	12,9	11,2	21,5	18,6

Fig 6 illustrates the relations of the fuels in table 11.

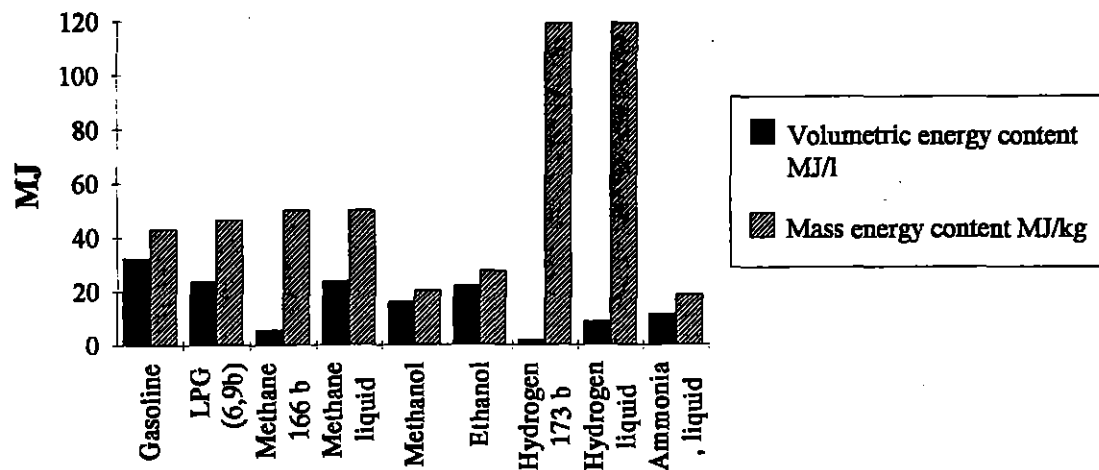


Fig 6. Volumetric and mass energy for hydrogen and other fuels.

The figures relates only to the fuel itself and in the case of hydrogen in metal hydrids including the metal. If the storage as a complete system were considered gaseous hydrogen requires heavy pressure tanks. The energy content for liquid hydrogen compared to compressed gas at 173 bar is more than four times higher. There are however losses for the evapoation energy of liquid hydrogen which requires efficient insulation of the cryo- tanks and functioning cooling apparatus. The storage method of hydrogen is related to the storage volume and time aspects.

Compressed hydrogen.

Hydrogen can be stored in tanks or underground storage. The density of hydrogen follows the ideal gas law at low pressures but the pressure is increased relatively more than the density at higher pressure.

Underground storage has sucessfully been operative at the salt mines near Teeside in England at a depth of 360 m and 5 Mpa pressure. 1 Gm³ of 95 % hydrogen is stored there. Other examples exists from France and Germany (8). Studies have been performed on storage in underground rock cavities. In one study water as sealant was proposed. The proposed storage had a volume 0,3M Nm³. Fig 7 indicates the idea of such storage. Other proposed underground storage is depleted oil or natural gas fields and salt mines.

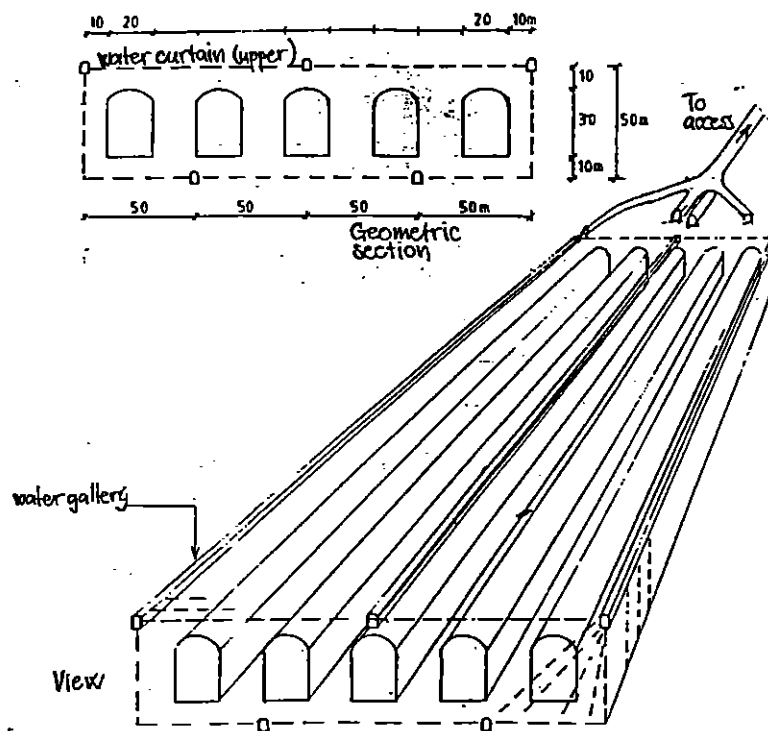


Fig 7 . Principle outline of an underground rock cavern for hydrogen storage. Source: (11)

Hydrogen in pressure vessels is another alternative for both large scale storage and storage connected to the use of hydrogen for instance in cars. This technique is in wide use all over the world. Research and demonstration projects for automobiles, buses, aeroplanes etc are in rapid progress.

Storage for the use as transportation fuel.

Development of hydrogen storage for transportation purpose is under way. Different metal hydrides and pressurised systems as well as liquid storage are being tested and indicates very high weight and costs for gaseous hydrogen and hydrogen in metal hydrides. According to (12) the data for a car of 500 km nominal range or 1500MJ of energy typical data would be:

	Fuel weight kg	Fuel volume l	Tank+ fuel weight kg
Liquid hydrogen	12,4	175	75
Hydrogen, 173 bar	12,4	886	1364
Hydrogen/ metal	16,5	172-204	837-863
Ammonia NH ₃	80,6	134	148
CH ₄ , liquid	29,9	64	95
Methanol	71,1	90	110
Ethanol	54	68	84
Gasoline	33,8	50	56

8. The use of hydrogen

The use of hydrogen can in the future expand the applications already in use and find application in many new areas. Examples are:

- * Chemical and petroleum industry. Is already in use.
- * Production of environmentally safe fuels for industrial use.
- * Space industry. Is already in wide use.
- * Fuel for aeroplanes.
- * Fuel for ground transport.
- * Fuel for domestic use for heating, cooling etc.
- * Fuel for electric power generation, specially peak power.

8.1 Some projects or activities.

Several projects are on-going and in progress. The objective is to gain experience of rather large scale application.

The Euro-Québeck project.

This Canadian- European project is based on cheap hydroelectricity in Québec and aims at practical demonstration at rather large scale of the production, storage over-sea transport of hydrogen in liquid form and the demonstration of the technology of the application in Central Europe. The project's original principle is shown in fig 8

The principle was to use the hydrogen from electrolysis of water together with toluole to produce metylcyclohexan which is a easily stored and transported product.

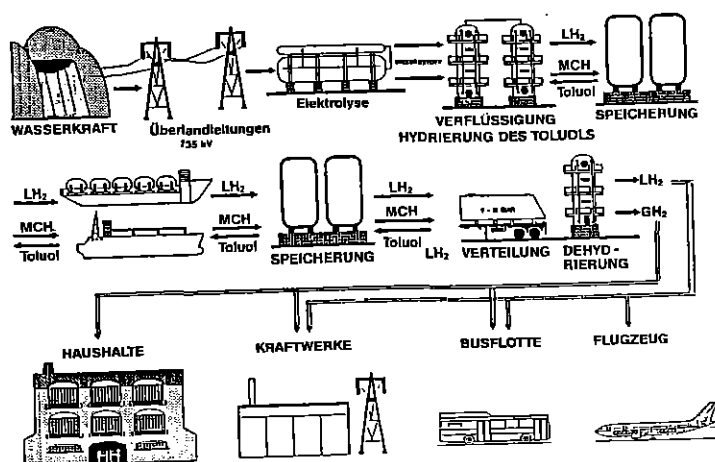


Fig 8. The original principle for the Euro- Québec- project. Source (9)

In the project announced later the transport will be made as pure LH_2 in cylindrical cryo-tanks of $3000m^3$ volume. The project runs in different phases and detailed planning is scheduled from end of 1993. The target is to have the system operative before the year 2000. Liquid hydrogen is calculated at 0,15 ECU/kWh in Europe. The efficiency of the electrolysis is 74% and annual operation of 8300h at full load has been calculated-

The basis of the project is 100 MW of hydro power from Quebec. Later other sources will be exploited. The production cost has been calculated and the distribution of costs are:

Electricity production	0,021 ECU
Electrolysis	0,025 "
Liquidification	0,046 "
Handling in Canada	0,015 "
Sea transport	0,022 "
Deloading and storage	0,019 "
Distribution	0,002 "

The use of hydrogen is projected for three buses, one boat, two district heating plants (one 70 kW and one 30kW), the direct reduction of iron ore and the development of an engine for Airbus. Development of fuel cells for bus operation is under way in Italy. Environmental aspects on using hydrogen in airplanes have come up. (The release of water vapour is 2,5 larger than for conventional fuels and this may be bad at high levels in the atmosphere).

A hydrogen and electricity system on an international scale connected to national and regional systems for the storage and use may in the future look like fig 9 indicates.

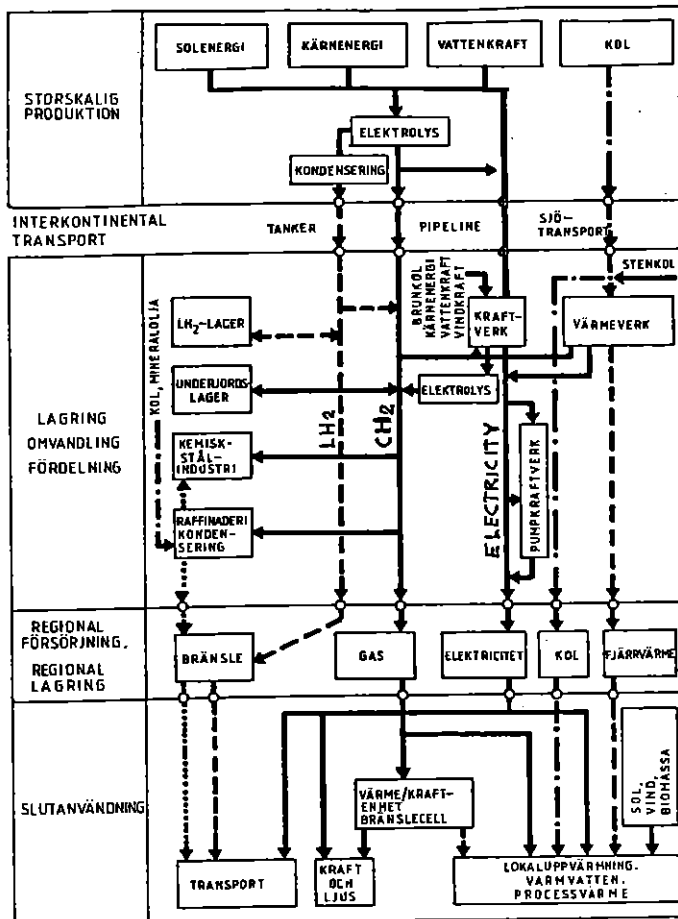


Fig 9.
A future hydrogen/electricity system. Based on material by Winter and Nitsch.

9. Factors influencing the move to hydrogen

Two major forces both related to sustainable development are in favour of hydrogen. The first, and probably the strongest, is related to environmental issues and the second is the resource aspect of fossil fuels. Another important factor is the development of a hydrogen system and the economy related to other options.

Environmental aspects.

The violation of the principles of the sustainability of today's energy system is quite obvious. The consequences are not yet understood to the degree that consensus exists on the actions to be taken. Of the environmental aspects of most importance, three is discussed.

Acidification

The use of a clean fuel like hydrogen would dramatically reduce the load of acid elements to the environment. There are other potential ways than pure hydrogen to improve this situation. Even carbon based energy is possible.

Enhanced greenhouse effect causing global temperature increase and climate change,

This is an unfinished issue. Although most researchers seem to agree on very strong actions to reduce the release of greenhouse gases, the basis is still only incomplete computer-models. The complexity of the real world is such that to wait for confirmed computer-models probably would mean waiting too long.

A solar-hydrogen-electricity system would be an option for a strategy to eliminate this problem.

Destruction of the stratospheric ozone layer.

The introduction of a hydrogen cycle seems to be completely free of any problems related to this issue. The use of fossil and biomass fuels are in different ways related to ozone depletion (for example N_2O). Is still an unfinished issue.

The depletion of existing fossil resources.

This is the second major force which in the long run will be of increasing power when the existing cheap resources are getting more scarce and expensive.

The development of a hydrogen system.

Different routes can be thought to energy systems with pure hydrogen in local expanding hydrogen based islands is one strategy under development. Another way is blending hydrogen into existing natural gas systems. Several issues related to this option exist related to material, capacity, customer installations, function and safety, etc.

The economy of hydrogen.

Today hydrogen as a general energy carrier cannot compete with the existing and well established system. Incorporating external costs would make sustainable strategies like solar based hydrogen competitive at an earlier stage than would be the case in the conventional economic system. The establishment of a functioning international system for external costs is a difficult task.

10. Conclusions

- * Solar hydrogen and electricity systems of both large scale and very small scale is technically possible. The resources are much larger than the human requirements of energy.
- * Solar hydrogen and electricity from unpopulated areas of the world's deserts would not be a competition to production of food for a growing human population.
- * Cheap solar hydrogen and electricity in solar- rich and developing counties would be of enormous value to eliminate forest destruction and land erosion.
- * A solar- hydrogen energy system cannot compete with existing systems based on conventional economic thinking. Incorporating external costs would make such introduction possible at an earlier stage.
- * Several technical problems exist related to material, safety, technology of storage etc.
- * The introduction of a solar hydrogen energy system would be the start to eliminate the major environmental problems of to day.
- * The introduction of a solar hydrogen system would be a way to long term sustainability for energy supply.
- *Blending of hydrogen into existing natural gas is one way of early introduction.
- * Research and practical demonstrations is needed based on realistic conditions and for a large number of different applications from the production of hydrogen, the transport and transmission of hydrogen, the interaction with electricity and liquid fules, blending with natural gas and the use of hydrogen for numerous applications.

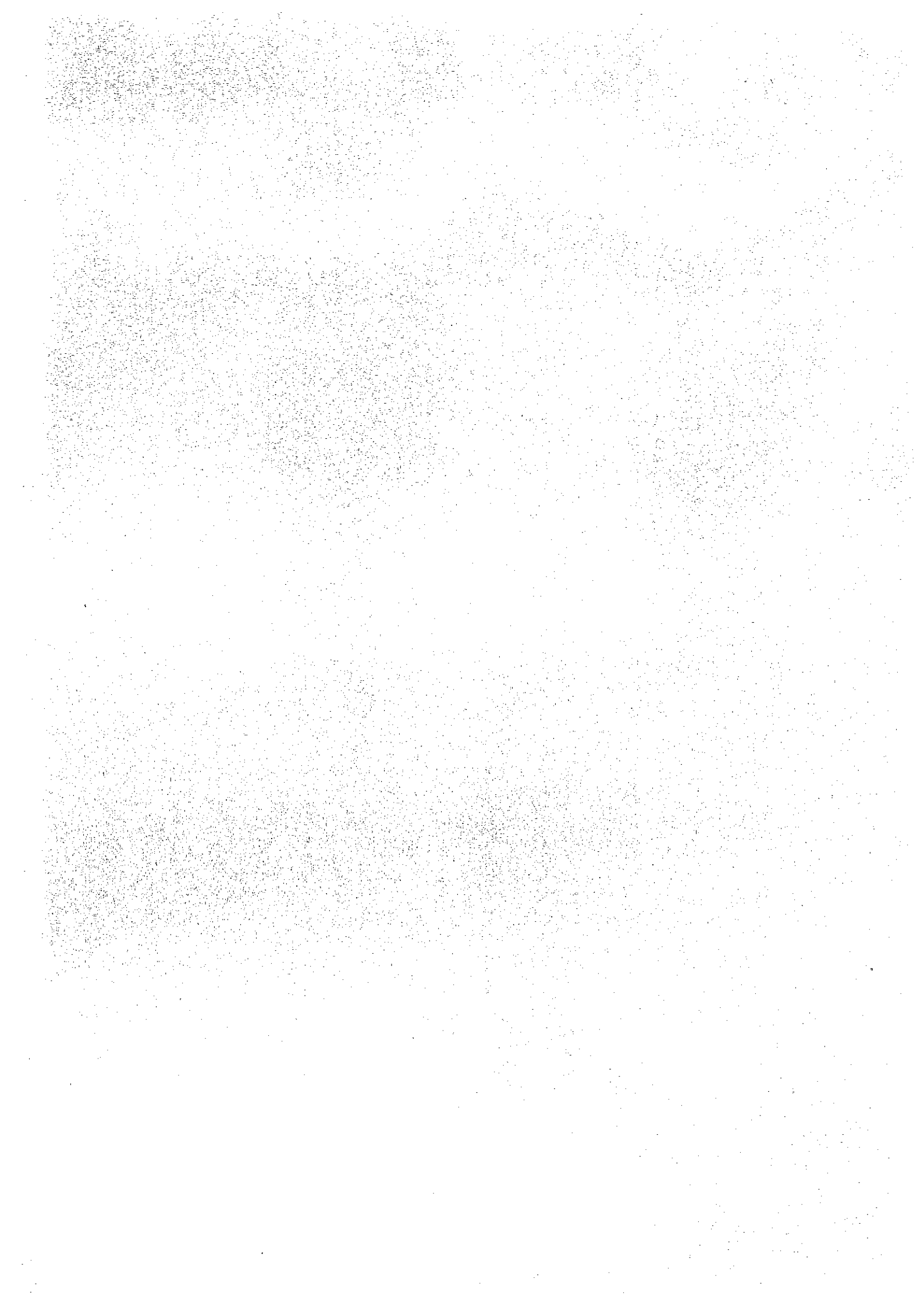
9. References:

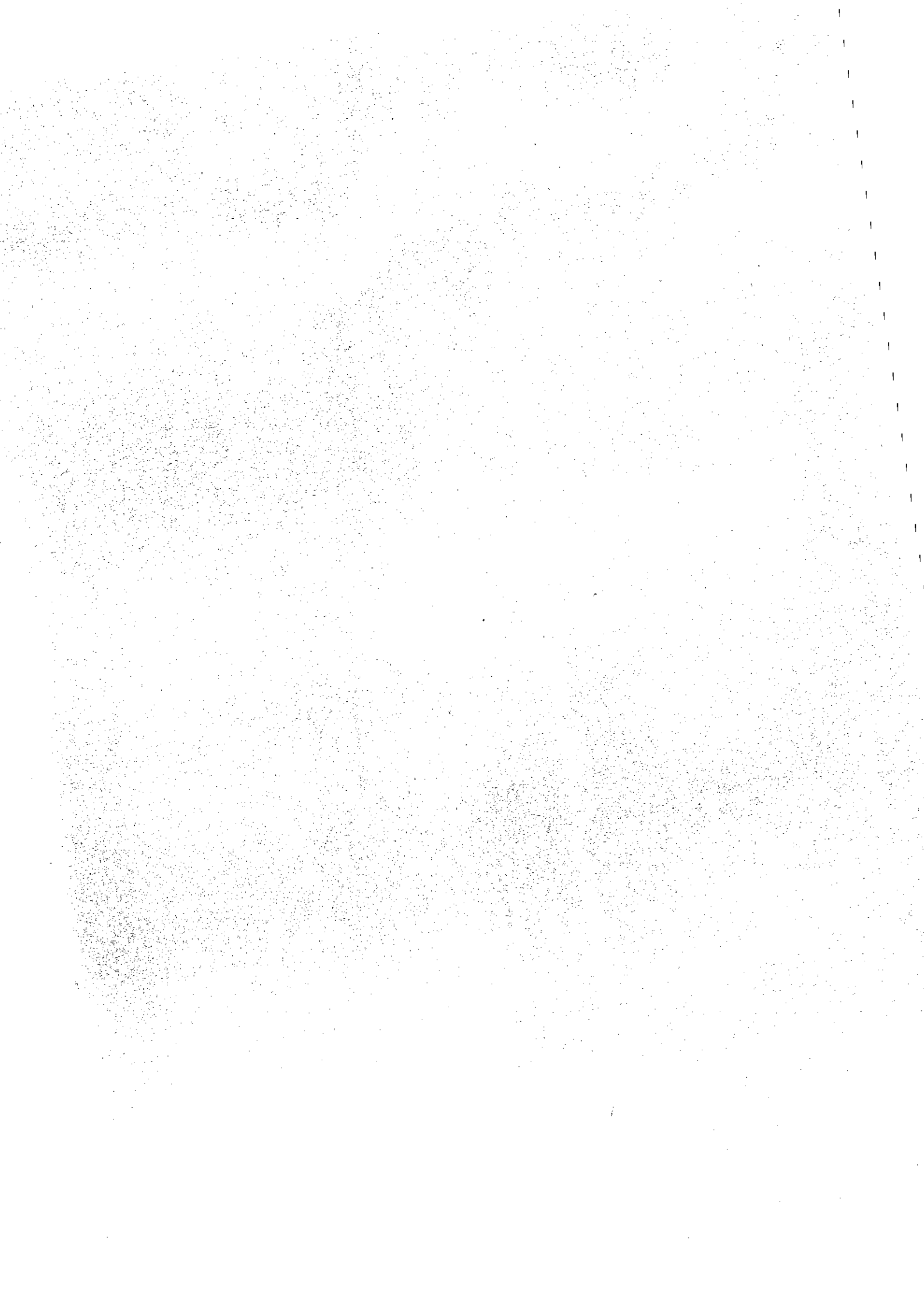
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10 Appendix

Some key data for hydrogen:

Density, gas at NtP	0,0838 kg/m ³
Density, liquid at NBT	70,8 kg/m ³
Melting temperature (0,1 MPa)	14,1 K
Boiling temperature (0,1 Mpa)	20,3 K
Critical temperature/pressure/density	33,25K / 1,296MPa / 0,03kg/l
Specific heat, cp, at NTP, gas	14,89 J /gK
Specific heat, cp, at NBT, liquid	9,69 J /gK
Stoichiometric mixture in air	29,52 % (Volume)
Evaporation entalphy	435,97kJ/kg
Heat of combustion, calorimetric	141,86 MJ/kg
Heat of combustion, effective	119,93 MJ/kg
Energy content effective, gas at 10 Mpa	33,5 kWh/kg, 300 kWh/m ³
Energy content, liquid	33,5 kWh/kg, 2400kWh/m ³
Flame temperature in air	2318 K
Flame temperature in oxygen	3000 K
Flame speed in air	2,75 m/s
Limits of ignition in air	4-75 % (volume)
Limits of ignition in oxygen	4-94 "
Limits of detonation in air	18-59 "
Speed of detonation in air	2,0 km/s
Temperature of self ignition	858 K
Ignition energy	20 μ J
Explosion energy	0,17 gTNT/kJ theoretical.
Diffusion velocity in air	2,0 m/s





Concluding Remarks

Jörgen Thunell

Swedish Center of Gas Technology (SGC)

Concluding Remarks

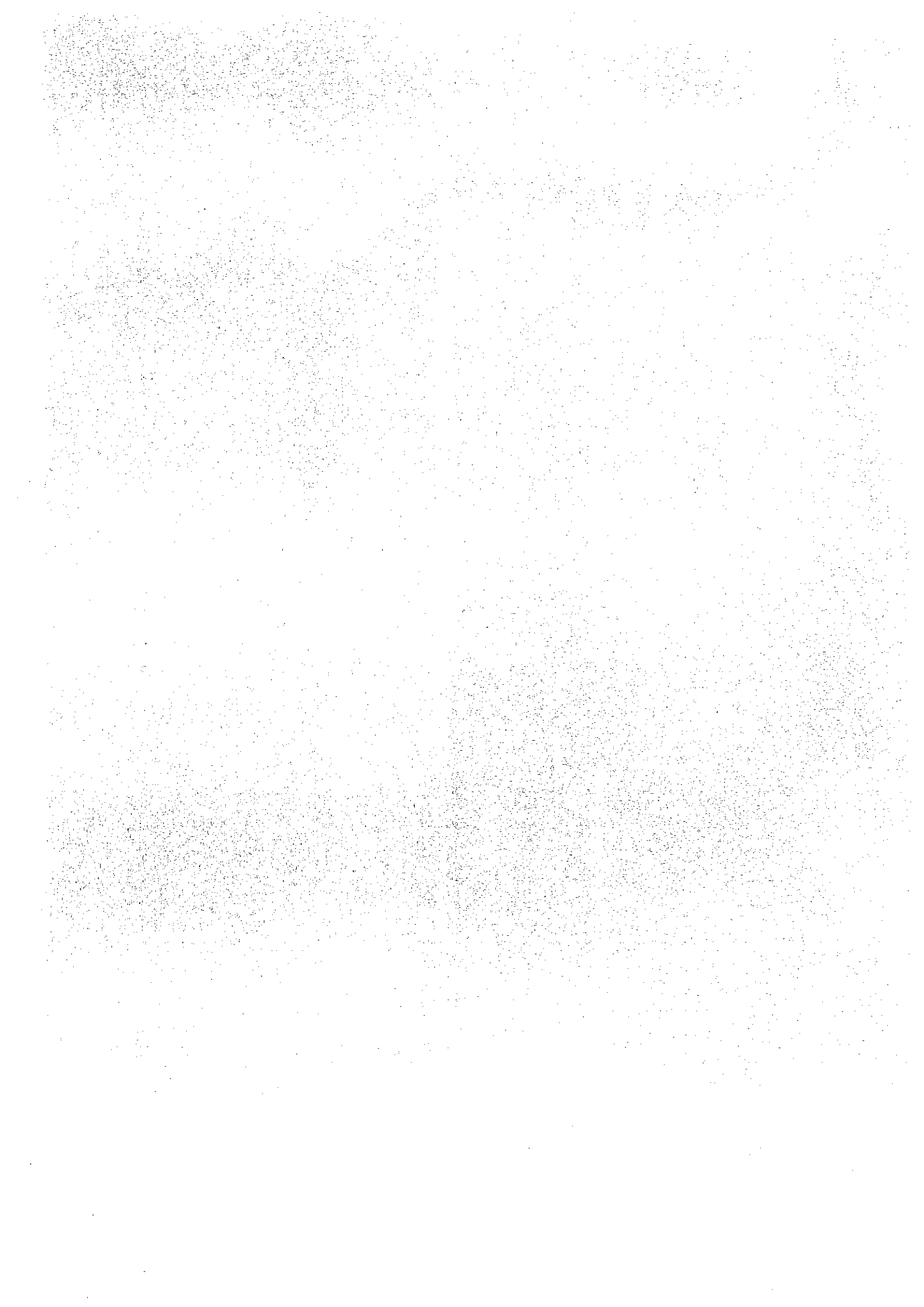
From the presentations we can notice that much activities are going on and are planned for in the Nordic countries in the field of gas technology R&D. I said in my introduction earlier today that every country has its own R&D profile and I think that statement has been confirmed by the speakers.

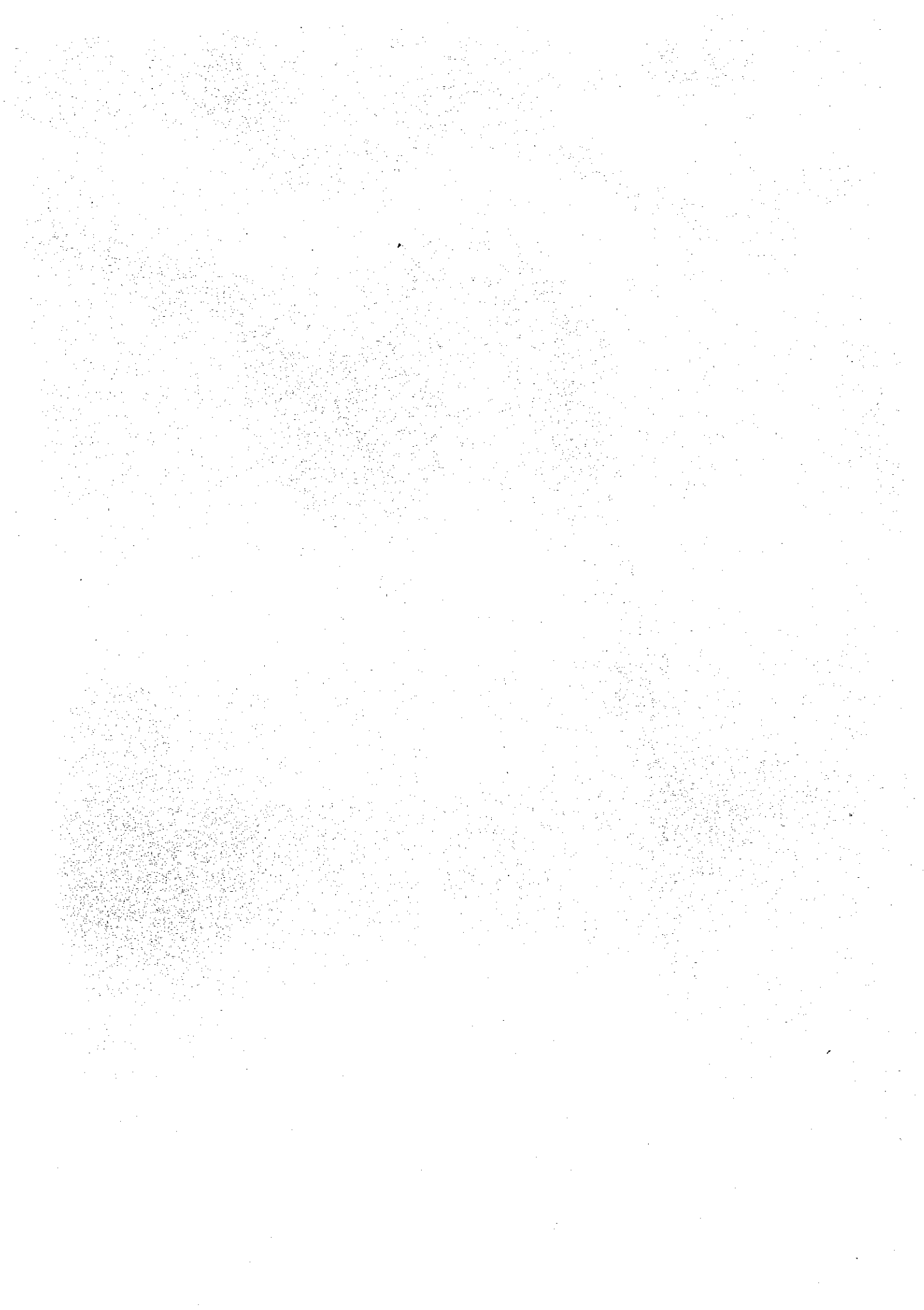
I hope the knowledge of what is going on both in the Nordic countries and in Germany and elsewhere will be useful in the guidance of new projects and new research activities. Companies or organisations can, by this knowledge, avoid doing the same things as others do and they can also go together in projects where there are common interests. As I have said earlier, I think the Nordic cooperation for the time being should be built up on a project basis rather than on an administrative basis.

Of course, somebody has to take the necessary initiatives. Without an administrative Nordic body, it is up to everyone to take an initiative. To promote this, I think it has to be more or less planned meetings between individuals, and between individual companies and individual organizations. Taking Sweden as an example, we have regularly meetings, once or twice a year between SGC and DGC to inform each other of what is going on. These meetings have up to now resulted in 4 projects with participation of both SGC and DGC. There have also been meetings between the former Swedish and Finnish NGC participants to discuss questions of common interest. I don't know if there are similar meetings between Norway and Finland, Norway and Denmark or Finland and Denmark.

Another body to initiate projects is perhaps the former NGC's industrial reference group whose aim was to evaluate R&D proposals within the area of industrial natural gas use but also to create proposals for new projects within that area. There is an interest to keep this group alive after the disappearance of NGC. Two meetings are planned for during 1994, one in the spring in Malmö and one in the autumn in Finland. I hope these meetings will be fruitful and that some common projects could come out of it.

Now I think we will close the Workshop and I do that by thanking all of you who have participated both as speakers and as listeners. I propose we give the speakers a warm applause for their contribution. I hope we will meet in Finland next year. Thank you.





94-08-12

RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
001	Systemoptimering vad avser ledningstryck	Apr 91	Stefan Grudén TUMAB	100
002	Mikrokraftvärmeverk för växthus. Utvärdering	Apr 91	Roy Ericsson Kjessler & Mannerstråle AB	100
004	Krav på material vid kringfyllnad av PE-gasledningar	Apr 91	Jan Molin VBB VIAK	50
005	Teknikstatus och marknadsläge för gasbaserad minikraftvärme	Apr 91	Per-Arne Persson SGC	150
006	Keramisk fiberbrännare - Utvärdering av en demo-anläggning	Jan 93	R Brodin, P Carlsson Sydkraft Konsult AB	100
007	Gas-IR teknik inom industrin. Användnings- områden, översiktlig marknadsanalys	Aug 91	Thomas Ehrstedt Sydkraft Konsult AB	100
008	Catalogue of gas technology RD&D projects in Sweden (På engelska)	Jul 91	Swedish Gas Technology Center	100
009	Läcksökning av gasledningar. Metoder och instrument	Dec 91	Charlotte Rehn Sydkraft Konsult AB	100
010	Konvertering av aluminiumsmältugnar. Förstudie	Sep 91	Ola Hall, Charlotte Rehn Sydkraft Konsult AB	100
011	Integrerad naturgasanvändning i tvätterier. Konvertering av torktumlare	Sep 91	Ola Hall Sydkraft Konsult AB	100
012	Odöranter och gasolkondensats påverkan på gasrörssystem av polyeten	Okt 91	Stefan Grudén, F. Varmedal TUMAB	100
013	Spektralfördelning och verkningsgrad för gaseldade IR-strålare	Okt 91	Michael Johansson Drifttekniska Institut. vid LTH	150
014	Modern gasteknik i galvaniseringsindustri	Nov 91	John Danelius Vattenfall Energisystem AB	100
015	Naturgasdrivna truckar	Dec 91	Åsa Marbe Sydkraft Konsult AB	100
016	Mätning av energiförbrukning och emissioner före o efter övergång till naturgas	Mar 92	Kjell Wanselius KW Energiprodukter AB	50
017	Analys och förslag till handlingsprogram för området industriell vätskevärmning	Dec 91	Rolf Christensen ÅF-Energikonsult Syd AB	100

94-08-12

RAPPORTFÖRTECKNING

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018	Skärning med acetylen och naturgas. En jämförelse.	Apr 92	Åsa Marbe Sydkraft Konsult AB	100
019	Läggning av gasledning med plöjteknik vid Glostorp, Malmö. Uppföljningsprojekt	Maj 92	Fallsvik J, Haglund H m fl SGI och Malmö Energi AB	100
020	Emissionsdestruktion. Analys och förslag till handlingsprogram	Jun 92	Thomas Ehrstedt Sydkraft Konsult AB	150
021	Ny läggningsteknik för PE-ledningar. Förstudie	Jun 92	Ove Ribberström Ove Ribberström Projektering AB	150
022	Katalog över gastekniska FUD-projekt i Sverige. Utgåva 4	Aug 92	Svenskt Gastekniskt Center AB	150
023	Läggning av gasledning med plöjteknik vid Lillhagen, Göteborg. Uppföljningsproj.	Aug 92	Nils Granstrand m fl Göteborg Energi AB	150
024	Stumsvetsning och elektromuffsvetsning av PE-ledningar. Kostnadsaspekter.	Aug 92	Stefan Grudén TUMAB	150
025	Papperstorkning med gas-IR. Sammanfattning av ett antal FUD-projekt	Sep 92	Per-Arne Persson Svenskt Gastekniskt Center	100
026	Koldioxidgödsling i växthus med hjälp av naturgas. Handbok och tillämpn.exempel	Aug 92	Stig Arne Molén m fl	150
027	Decentraliserad användning av gas för vätskevärmning. Två praktikfall	Okt 92	Rolf Christensen ÅF-Energikonsult	150
028	Stora gasledningar av PE. Teknisk och ekonomisk studie.	Okt 92	Lars-Erik Andersson, Åke Carlsson, Sydkraft Konsult AB	150
029	Catalogue of Gas Techn Research and Development Projects in Sweden (På engelska)	Sep 92	Swedish Gas Technology Center	150
030	Pulsationspanna. Utvärdering av en demo-anläggning	Nov 92	Per Carlsson, Åsa Marbe Sydkraft Konsult AB	150
031	Detektion av dräneringsrör. Testmätning med magnetisk gradiometri	Nov 92	Carl-Axel Triumf Triumf Geophysics AB	100
032	Systemverkn.grad efter konvertering av vattenburen elvärme t gasvärme i småhus	Jan 93	Jonas Forsman Vattenfall Energisystem AB	150
033	Energiuppföljning av gaseldad panncentral i kvarteret Malörten, Trelleborg	Jan 93	Theodor Blom Sydkraft AB	150

94-08-12

RAPPORTFÖRTECKNING

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034	Utvärdering av propanexponerade PEM-rör	Maj 93	Hans Leijström Studsvik AB	150
035	Hemmatankning av naturgasdriven personbil. Demonstrationsprojekt	Jun 93	Tove Ekeborg Vattenfall Energisystem	150
036	Gaseldade genomströmningsberedare för tappvarmvatten i småhus. Litteraturstudie	Jun 93	Jonas Forsman Vattenfall Energisystem	150
037	Verifiering av dimensioneringsmetoder för distributionsledningar. Litt studie.	Jun 93	Thomas Ehrstedt Sydkraft Konsult AB	150
038	NOx-reduktion genom reburning med naturgas. Full- skaleförsök vid SYSAV i Malmö	Aug 93	Jan Bergström Miljökonserterna	150
039	Pulserande förbränning för torkändamål	Sep 93	Sten Hermodsson Lunds Tekniska Högskola	150
040	Organisationer med koppling till gasteknisk utvecklingsverksamhet	Feb 94	Jörgen Thunell SGC	150
041	Fältsortering av fyllnadsmassor vid läggning av PE-rör med läggingsbox.	Nov 93	Göran Lustig Elektro Sandberg Kraft AB	150
042	Deponigasens påverkan på polyetenrör.	Nov 93	Thomas Ehrstedt Sydkraft Konsult AB	150
043	Gasanvändning inom plastindustrin, handlingsplan	Nov 93	Thomas Ehrstedt Sydkraft Konsult AB	150
044	PA 11 som material ledningar för gasdistribution.	Dec 93	Thomas Ehrstedt Sydkraft Konsult AB	150
045	Metoder att höja verkningsgraden vid avgaskondensering	Dec 93	Kjell Wanselius KW Enerkiprodukter AB	150
046	Gasanvändning i målerier	Dec 93	Charlotte Rehn et al Sydkraft Konsult AB	150
047	Rekuperativ aluminiumsmältugn. Utvärdering av degelugn på Värnamo Pressgjuteri.	Okt 93	Ola Hall Sydkraft Konsult AB	150
048	Konvertering av dieseldrivna reservkraftverk till gasdrift och kraftvärmeprod	Jan 94	Gunnar Sandström Sydkraft Konsult AB	150
049	Utvecklad teknik för gasinstallationer i småhus	Feb 94	P Kastensson, S Ivarsson Sydgas AB	150

94-08-12

RAPPORTFÖRTECKNING

SGC Nr	Rapportnamn	Rapport datum	Författare	Pris kr
050	Korrosion i flexibla rostfria insatsrör (Finns även i engelsk upplaga)	Dec 93	Ulf Nilsson m fl LTH	150
051	Nordiska Degelugsprojektet. Pilot- och fältförsök med gasanvändning.	Nov 93	Eva-Maria Svensson Glafo	150
052	Nordic Gas Technology R&D Workshop. April 20, 1994. Proceedings.(På engelska)	Jun 94	Jörgen Thunell, Editor Swedish Center of Gas Technolog	150



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