Final Technical Report

Low Weight Electric Bus with Multiple Energy Supply

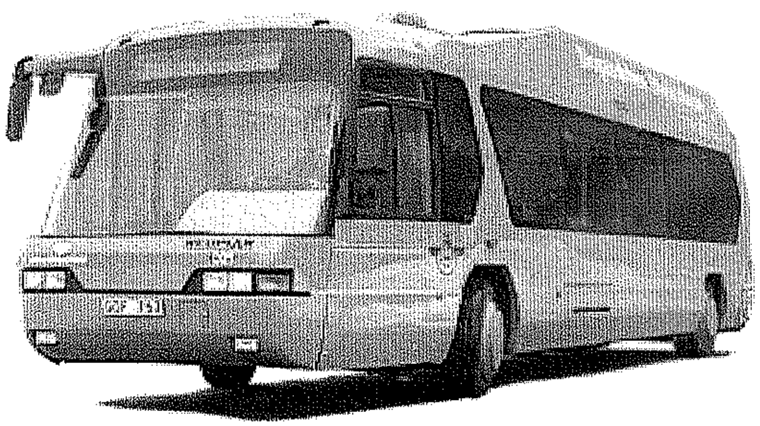
TR 228- 95 SE/DE/IT

AB Uppsalabuss
Skånetrafiken
Gottlob Auwärter GmbH Neoplan
SAD - Transporto Locale s.p.a.

European Commission
Directorate-General for Energy

Thermie II

2000.12.30



Summary

The serial hybrid concept and the use of electric wheel motors is found to be an attractive design which gives many advantages. The flexibility in the design, which an electric system offers is not fully explored though.The vehicles tested in this project are to be considered as prototypes. Hence the present design is by no means optimized from the aspect of manufacturing, service and maintenance.

The performance of the control system is perhaps the most important and critical individual component to ensure a reliable operation of the hybrid vehicle.

The performance of the vehicle, in terms of acceleration, is set by the electric drive motors. They do have enough torque to comply with the required acceleration. In a heavier bus more torque is required though. The maximum speed of 70 km/h is acceptable for city operation.

To make it possible to repair and manage the vehicles when in use much attention must be paid to documentation and trouble shooting routines.The training of the staff is crucial. The staff must have knowledge to understand and handle the systems in question

The hybrid bus has shown us a way to reduce emissions, exhausts as well as noise, from the public transport vehicles. At the same time we are able to lower the fuel comsumption substantially.

The higher fuel efficiency is reached in two ways. A smaller engine is used than needed for a normal bus, but the engine has to be chosen very carefully. If the engine is to big it will run with a too low load and the emissions will be high. If the engine is too small, the performance of the bus will be inadequate.

A citybus is almost always either accelerating or braking. Our tests have shown that most of the fuel savings and emission reduction is due to the regeneration of the brake power.

The hybrid bus is a necessary step prior to the introduction of the fuel cell bus. And so is the methane gas powered bus. These two types of buses contain the technology needed in a fuel cell bus. Both are today totally unknown within the organizations of the bus operators, but for the fuel cell bus to become a success, a driving and maintenance experience has to be created. This step is preferrably taken with the help of hybrid buses until the fuel cell bus is on the market.

At present there is no market for hybrid vehicles though. The manufacturers are uncertain about both technology and customer interest. The customers are certainly interested but more important for them are matters like price and reliability and there is always suspicion to new technologies even though the advantages are understood.

To make a market for a new drive system like the hybrid system both manufacturer and customer must have confidence in each other. There is a need for some kind of long term agreement based on long term planning for reaching future goals regarding both efficiency and environmental protection.

Final Technical Report

For the Project:

Low Weight Electric Bus with Multiple Energy Supply

TR 228- 95 SE/DE/IT

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1. PROJECT DETAILS

Final Technical Report

Project Reference Number: TR 228/95 SE/DE/IT
Title of Project: Low Weight Electric Bus with Multiple Energy Supply

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2. AIM AND GENERAL DESCRIPTION

2.1 Aim of the project

This Project aims at showing a city busdesign for the beginning of next century including an environmentallyl friendly technique.

The aim is expressed as follows: **"without noticeable negative impact on the environment".**

The Project gives an opportunity to develop environmentally friendly prototype buses together with a bus manufacturer. Buses that further on may come into serial production.

In the planned project a new type of bus with the following properties shall be demonstrated:

—Average energy savings and reduction of CO_2-emission of 30 % compared to present-day city buses.
—Zero emission operation in limited restriction areas
—Average reduction of the pollution to approximately a half compared to conventional buses.
—Comfortable, quiet low floor buses
—Economically attractive as a series product

2.2 Description of the sites

Part of project	Country	Region	Location
Engineering/design	Germany	Baden-Würtemberg	Stuttgart
Manufacturing	Germany	Saxonia	Plauen
Assembly/Installation			
Execution/commissioning	Germany	Saxonia	Plauen
Monitoring	Sweden		Uppsala/Malmö
Monitoring	Italy	South Tyrol	Bolzano
Evaluation	Sweden		Uppsala/Malmö
Technical Administration	Germany	Baden-Würtemberg	Stuttgart
Financial Administration	Sweden		Uppsala

2.2.1 Uppsala

Uppsala city is one of Sweden's fastest growing municipalities. Uppsala, together with Stockholm and the Mälar Valley, is the country's largest labour market making up one-third of the population of Sweden.

The population is young and well educated, much due to the students at Uppsala´s two universities – Uppsala university and the Swedish University of Agricultural Sciences (SLU).

Integration and multi-cultural resources have enriched social life and contributed to increased growing power in Uppsala. This makes Uppsala a many-faceted meeting place with over 100 different nationalities. Uppsala, the County capital, has a population of about 190,000 and is Sweden's fourth largest city.

Uppsala has good prerequisites for a flourishing industry with it's strategic location, in the middle of Sweden's most successful region with the Baltic countries as its nearest neighbours. Business life has a strong international orientation. The two universities contribute to a unique hot-bed for enterprises within several fast growing areas.

Uppsala is the *centre of excellence* of the food industry, with custom made pharmaceutical products, biotechnology, and bio information technology at the highest level. Development is taking place at a very fast pace and Uppsala is among the world leaders in this field.

With close proximity to Stockholm and the rest of the world - via Arlanda airport - Uppsala has a favourable geographic location and an advantageous setting for business.

Uppsala University, founded in 1477, was the first university of Scandinavia. SLU, founded 500 years later, has it's main academic activities centered in Uppsala. With 40,000 students and 7,000 doctoral candidates the region is a vibrant centre of knowledge.

Fig. 1. The cradle of the land of Sweden. It was here at Old Uppsala the Swedish Kingdom started to take shape. Under the mounds rest three kings. The church was erected in the 12th century. Som people claim it rests on the remains of the old heathen temple.

Uppsala is located a little closer to the world than the rest of Sweden thanks to Arlanda airport, which is today the fourth largest airport in Europe according to air traffic statistics. The Arlanda train takes 20 minutes from Uppsala Central Station to the air port gates.

Commuter train services between Uppsala and Stockholm is the most extensive in the country. Gothenburg is only four hours away thanks to the fast X2000 train.

Vigorous development of IT communication is underway in Uppsala. Several private and government corporations are constructing networks that can be linked together with broadband nets connecting households, enterprises and government agencies.

As a part of the Baltic region, Uppsala is looking forward to a great future growth.

2.2.2 Malmö

Malmö is Sweden's third largest city and the commercial centre of southern Sweden. Population: 255,000 inhabitants. The old city of Malmö is surrounded by a system of canals criss-crossed by bridges. Two nations one region. The Øresund Fixed Link, a combination of bridge and tunnel for both cars and trains, links the Copenhagen region with Scania. The Øresund region is one of the most dynamic regions in Europe, with a range of leading international companies working within medical science, biotechnology, food technology, information technology and the media. When resources on both sides of the Øresund are pooled into Europe's first transnational region, this new focus will emerge even more clearly.

The Øresund region enjoys Scandinavia's best resources for research and development, and ranks 5th in Europe. Also, there are no less than 110,000 students attending higher education at four universities - Copenhagen, Roskilde, Lund and Malmö - as the dominating centres.

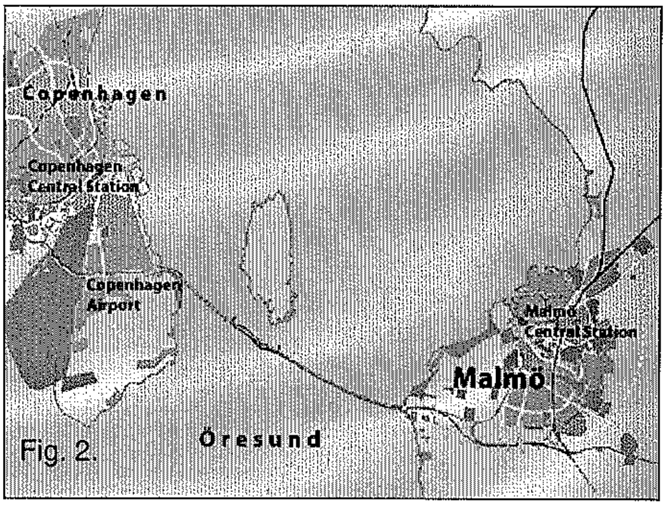

Fig. 2.

The Øresund region is a natural gateway to northern Europe and the Baltic, forming a potential market of more than 100 million people.

The Øresund region is a natural gateway to northern Europe and the Baltic, which forms a potential market of more than 100 million people.

Sweden's membership in the EU, the development in Eastern Europe, the Øreresund Fixed Link and the new Malmö University all contribute to create excellent conditions for the development of trade and industry in Malmö.There are 9,000 companies in Malmö, of which 1,100 deal in wholesale. 800 companies are in the manufacturing industry. 74 % have less than ten employees. These include many

Fig. 3.

rapidly growing knowledge-intensive companies.

The region has many food and packaging-related companies. The region is also known as Medicon Valley. More than 60 % of theScandinavian pharmaceutical industry is based here.

70 % of the Swedish export pass through Scania! Here goods are exchanged between Scandinavia, mainland Europe and the Baltic. Heavy goods are shipped between Malmö and Travemünde in Germany.

Air, sea and land communications in Malmö and the surrounding region are the best developed in Scandinavia. It takes less than one hour by air to Stockholm, Amsterdam, Hamburg or Berlin. London can be reached in two hours. Sturup, the local airport is just 30 minutes away. Copenhagen Airport Kastrup is reached just as quickly.

Malmö is the only city in the world where all public transport city buses are powered by environmentally friendly natural gas.

2.2.3 Bolzano

The Province of Bolzano is situated in Northern Italy in the heart of the Alps bordering to Austria in the north and Switzerland in the west. It covers an area of 7,400 km² and it is divided into 116 municipalities. It has a population amounting to approximately 457,000.

Traditionally a commercial town Bolzano's location made it an important meeting-place for Italian and German traders very early on. The first recorded market took place in 1202. The market´s growing importance led to the development of a widely appreciated, autonomous court in 1634. Bolzano's importance as a place for the exchange of goods rose with the growing traffic on the Brenner pass.

The main economic sectors today are:

-Tourism: approximately 250,000 beds, 4 million arrivals, 23 million visitors and a turnover of approximately EUR 1.3 billion.

-Agriculture: fruit (apples) and wine on the hills and valleys, dairy produce in the mountainous areas.

-Handicrafts: woodwork and furniture production.

-Small and medium-sized industries

Almost every town in the province concentrates on tourism.

The capitol of the province is Bolzano, a city of 100,000 inhabitants located along the

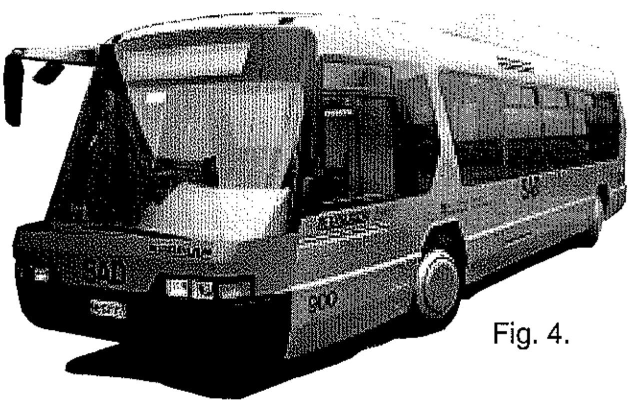

Fig. 4.

Brenner axis, the most important junction between Northern and Southern Europe passing through the Alps. Thanks to its strategic location, the economy of the city is mainly based on a flourishing commerce.

In province three languages are spoken: Italian, German and Ladin.

Public Transportation

Like all mountainous regions, Bolzano has a widespread territorial configuration that must be serviced by public transportation means. Already towards the end of the eighties the Integrated Transportation Service was introduced. It comprises all the road and rail public transportation services, both urban and extra-urban, which are organized from a single timetable and an integrated fare system. These services are provided by 27 operators: Ferrovie dello Stato S.p.A., the Italian railways, managing all the railway transportation, the SAD managing approximately 70% of the extra-urban services, the ACT, the transportation company managing mainly the urban transportation services in Bolzano and the town of Merano as well as the extra-urban connections between Bolzano and Merano and between Bolzano and Laives; ALM bus together with another 23 licensed companies have merged into a service consortium providing extra-urban transportation services.

The main pillars of the public transportation system are the railways and the scheduled bus services providing extremely frequent connections (with connections every half hour in most of the valleys). More remote valleys are serviced at a lower frequency, but still on a regular timetable. The entire network covers approximately 2.200 km.

Brief Outline of the Bolzano Province Public Transportation Services, 1998.

Service Provider	Passengers	Passenger km.
FS – Ferrovie dello Stato	2,235,114	82,492,647
ALM	1,537,177	8,947,630
ACT	12,760,420	43,069,626
SAD	9,008,797	118,293,245
Consortium	5,285,547	42,498,897
Total	**30,827,055**	**295,302,045**

3. CONSTRUCTION, INSTALLATION AND COMMISSIONING
3.1 Contractors, Subcontractors and Suppliers
Contractor
Gottlob Auwärter GmbH Neoplan

For over 60 years, NEOPLAN has focussed on the development of omnibuses. During this time, a streamlined and committed management team has worked hand in hand with the Auwärter family to keep the company heading in the right direction.

This joint cooperation between the Auwärter family and the management team, the resolute development of new technology and the extremely high productivity of all employees have made NEOPLAN what it is today: a globally successful enterprise. The company has about 2000 employees,and makes about 2000 buses per year.

Subcontractors to Gottlob Auwärter GmbH Neoplan:

• MM Magnet Motor GmbH
Petersbrunner Strasse 2
D-82319 Starnberg
Germany
Dr Werner Weck
Tfn: +49 8151 2621 91
Fax: +49 8151 12 478

Magnet-Motor is a company for the development and promotion of new technologies in the field of electric drives and energy technology.

The sucess of the company is based especially upon the devolopment and production of highly compact electric machines with permanent magnets, which are smaller and lighter than comparable conventional electric machines. On this technical basis, together with power electronics and processor control systems, also developed by MM, innovative propulsion systems for vehicles, such as low-floor buses, are carried out. MM delivers innovative propulsion technology for various vehicle and industrial applications.

The company has about 100 employees, 40 of them physicists and engineers and 40 technicians and qualified workers.

• Varta Batterie
NBT GmbH
Am Leinufer 51
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Germany
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NBT is a 100% Varta subsidiary founded in 1999. Its business is development and marketing of advanced battery systems for vehicle applications. They have 60 employees, working on basic electrochemistry, materials development, electronics, project management, pilot production and marketing. The development staff of NBT/VARTA have a long experience in different battery technologies. A main part of the work today is concentrated on Nickel/Metal hydride and Lithium-Ion batteries. Varta has actively been engaged in NiMH-work for 12 years. The successful development of a continuous improvement of round and button type NiMH-cells led to a highly successful product range on the market. This success wonVARTA the German National Innovation Award in 1993. A further number of successful improvements of the existing products will allow VARTA to increase its market share world-wide.

VARTA's core business is the development and production of all types of electrochemical energy storing devices, i.e. primary and secondary batteries. The overall turnover is about 1.1 billion ECU. VARTA is the leading European battery manufacturer.

Approximately six years ago VARTA started activities to develop the NiMH system also for traction applications. They were word wide the first company to present an electrically driven passenger car powered by a NiMH-battery in 1992. To the project NBT/VARTA will contribute with its full experience in the field of energy storing systems. In particular they will contribute to:

- Material characterisation
- Electrochemical testing
- Optimising electrodes for high drain
- Electrode production technology
- Modelling of cell and battery physical properties
- Cell manufacturing and testing
- Development and testing of battery management system
- Installation of interfaces, battery handling

Contractor, Coordinator

AB Uppsalabuss Public Transport Corporation

AB Uppsalabuss, Box 12, SE-751 03 Uppsala, Sweden
Phone +4618273700, Fax +4618101694, www.uppsalabuss.se

AB Uppsalabuss´s task is to plan, develop, inform, market and buy in city traffic. The operator Gamla Uppsala Buss AB runs the bus services and is directly responsible for safety matters for drivers and workshop personell.

The AB Uppsalabuss business concept is outlined as follows:
Uppsalabuss shall offer its customers reliable, comfortable and good value travelling by a well adjusted and environmentally friendly traffic system.

According to the business concept the environment friendly driving technique strategy is:

1. to investigate further steps with regard to available diesel engines
2. to ensure all diesel fuel used is of class 1
3. to continuously introduce biogas powered vehicles
4. to investigate possibilities for a further development of electrically powered buses, electric hybrid buses and rail bound traffic
5. to follow projects developing and demonstrating hydrogen gas powered buses

The over-all environmental objective is to make public transport attractive and environmental friendly in order not to strain to the environment.

In 1996 six biogas buses carried out normal traffic service in Uppsala. A year later another twelve were in operation. The biogas fuel plant is expected to produce enough fuel for 40 - 50 buses. In the year 2000 there are 20 biogas powered buses in operation, two hybrid elictric buses and six battery buses. Turnover:ca SEK 120 million. Number of employees: 21. Total traffic length: ca 170 km. Number of service buses in traffic: 150. Vehicle km/year 7.168.970.

Contractor Skånetrafiken, the Skåne County Public Transport Authority (former Länstrafiken Malmöhus)
is responsible for the public transport services in the Skåne county in southern Sweden.The aim is to offer the more than 150 000 daily customers a quick and safe journey in modern vehicles. Reliability and customer demands are paramount. Skånetrafiken operates ca 70 million bus and train journeys throughout the region per year and comprises a yearly turnover of just about SEK 1 billion.

The traffic is subjected to the standard EU public procurement directives.

The headquarter is located in Hässleholm.

The province of Skåne has a surface area of ca 11 000 sq. km with a population density similar to that of Central Europe numbering to about a million people (99 inhabitants/ sq.km). The main regional city, Malmö, has a population of about 250 000 people.

Ecotrans Teknik AB
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Ecotrans Teknik AB is a privatly owned consulting agency, specializing in environmentally friendly programmes for PSVs and traffic engineering.

Ecotrans Teknik AB:s business is to research, develop and find solutions to environmentally friendly forms of vehicles for public transport.

Ecotrans Teknik AB acts as technical advisors to Skånetrafiken in all matters concerning public transport vehicles.

Engineer Ingvar Blückert, responsible for the project work in Malmö, proposes and accounts for the chosen technical solutions to the project co-ordinator.

Engineer Ingemar Carlson, formulates all written information, trains and instructs drivers and workshop personell both in Uppsala and Malmö. Works out manuals for the use and service of the vehicles and for measuring possible towing and fire incidents. Compiles information on the Internet and is webmaster for www.ecotransteknik.se

Gamla Uppsalabuss AB, Uppsala
Gamla Uppsala Buss AB, Box 167, SE-751 04 Uppsala, Sweden
Phone +4618273800, Fax +4618147774
Technician Mikael Colm, is responsible for information and training of the staff at Gamla Uppsalabuss AB, the Uppsala bus operator.
Technician Mikael Söderström, is responsible for maintenance and repair.

Linjebuss Sverige AB, Malmö

Linjebuss Sverige AB, Box 3054, SE-200 22 Malmö, Sweden
Phone +46406696272, Fax +46406696280, www.lb.se

Linjebuss Sverige AB, the bus operator company operates public transport on contract to 12 out of Sweden´s 21 County Transport Corporations. Linjebuss is one of Sweden´s leading bus entrepreneurs with a turnover of SEK 1.5 million. The company has 3 900 employees and 1.800 vehichles. Owner is a CGEA Transport AB with operations in a number of European countries.

Engineer Olle Lundin; is responsible to the bus operator in Malmö for planning and management in connection with the start of the traffic. Helps the project in finding technical solutions for the city buses in Uppsala and Malmö.

Chief Instructor Kerstin Ohvander; suggests the frame for driver´s training and performs training programs for drivers and technical staff related to the project buses.

HC Duvander Utbildning

Hans Duvander; translates necessary documents from English/Swedish and vice versa.

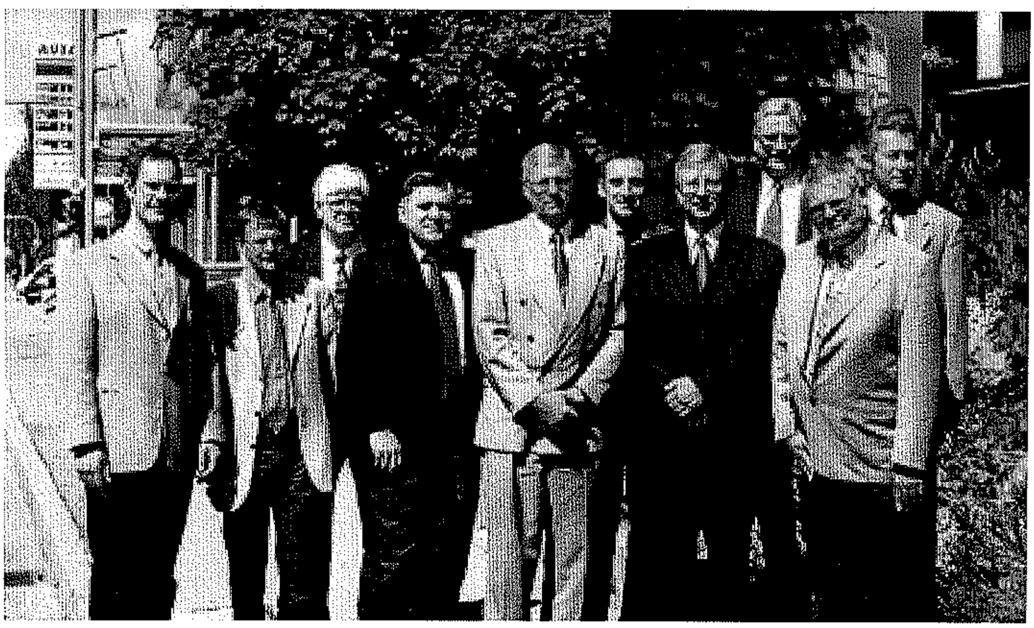


Fig. 5.
The Project Group, from the left::
Michael Sommer, Magnet Motor
Helmuth Moroder, SAD
Ingemar Carlson, Ecotrans Teknik
Karlheinz David, Gottlob Auwärter
Christer Hedefalk, Uppsalabuss
Rudi Kuchta, Gottlob Auwärter
Peter Eklund,Uppsalabuss
Ingvar Blückert, Ecotrans Teknik
Wolfgang Bullert, Svenska Neoplan
Eckart Buder, Varta

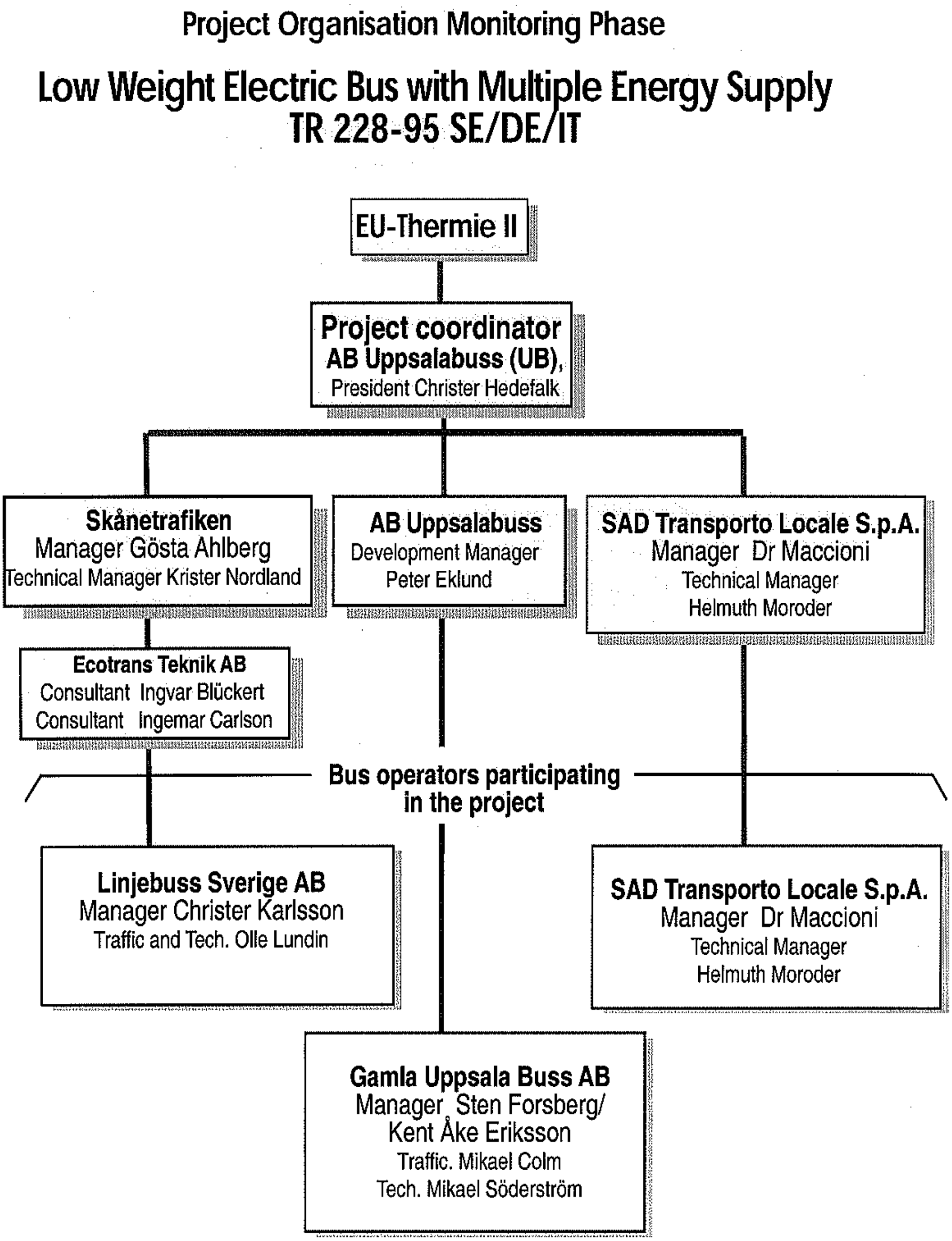
Raufoss Industrier, Raufoss Norge.
Raufoss Composites AS was established on 1st July 1997.Raufoss CNG systems have a high grade of commonality between the different truck and bus variants. Raufoss CNG systems use a lightweight Type 3 CNG-cylinder as standard. Other cylinders available on request. RAC is a subsidiary of the Raufoss Group, and has approx. 50 employees. Technical Manager Per Heggem, responsible for design, manufacture of the complete gas storage equipment up to the high pressure regulator. Also responsible for all contact with the authorities as TüV and "Svenska Arbetarskyddsstyrelsen" in questions concerning the approval of the high pressure gas systems.

Contractor SAD Trasporto locale S.p.A.

SAD is the largest extra-urban transportation company in the Bolzano Province. It has a staff of 340 employees, out of which 280 are bus drivers, and a fleet of 240 buses. It provides public transportation services amounting to a total of 18,500 km/year.

SAD is also responsible for an inter-company information service (SII) on behalf of the provincial authorities – the Transportation Dept. This service provides development and implementation of the timetables and the integrated fare system, collects passenger statistics and manages and distributes the revenues to the 27 companies involved in the venture on a monthly basis.

3.2 Project Management



3.3 MODIFICATIONS

The reason for participating in the project according to Skånetrafiken and AB Uppsalabuss is as follows:

Future demands

The requirements, technically as well as passenger quality wise, of a future city bus and consequently the way the traffic is organised has to be described in detail by the public transport community. The vehicle manufacturers will follow the entered course, which is mainly it look after the production efficiency and business economic interests. With the help of the grant from the European Commission the Participants will be able to influence future development.

Environmental city zones

Environmental city zones will be established in many densely built-up areas and the emission standards in these zones will gradually be made more stringent during the coming years. With the proposed development of a new type of bus, the public transport community will for a long time be able to keep a high environmentally friendly profile and with good margins fill future more stringent emission standards.

Decisions

The management of Skånetrafiken has decided to enter the project only under the conditions, "that the two buses in the city of Malmö are equipped with combustion engines with Methane gas fuel systems". Having started a grand scheme, for environmental reasons, Skånetrafiken is very reluctant to go back to a diesel fuelled futuristic prototype. Instead it wants the Malmö city traffic to be converted into methane gas propulsion. In the year 2001 all of the citybuses in Malmö will be powered by natural gas.

AB Uppsalabuss has decided that the buses to Uppsala also should be equipped with an engine for the same type of fuel.

SAD motivations for the Participation

The SAD and the provincial authorities have been working for some time now at reducing the impact of public transportation services on the environment and have made great investments to modernize the bus fleet that currently has an average age of 6 years. The tortuousness and steepness of most of the regional service routes require the use of diesel-powered vehicles.

The widespread environmental awareness of both the local inhabitants and tourists has led many local authorities to close off the historical centers of many towns to private traffic and in most cases also to public transportation. This causes many problems for the users of the public transportation system because they are often forced to use bus stops far away from the town center. Many local authorities are in favor of granting access to public transportation means provided that these are silent and do not pollute.

In the light of this situation participation in the research and development project to create a hybrid diesel-electric bus within the framework of the Thermie II programme of the European Union was met with great interest, despite the awareness that it involved substantial investments on the part of the SAD both in financial terms and in terms of human resources.

3.4 DESCRIPTION OF THE INSTALLATIONS

3.4.1 The Bus

The LOW FLOOR BUS, Neoplan Metroliner MIC 8012 GE for Urban Service without steps at entry and exit doors.

The bus is a monocoque cell completely manufactured from glass and carbon fibers. At the end of 1998 five vehicles were completed for the project.

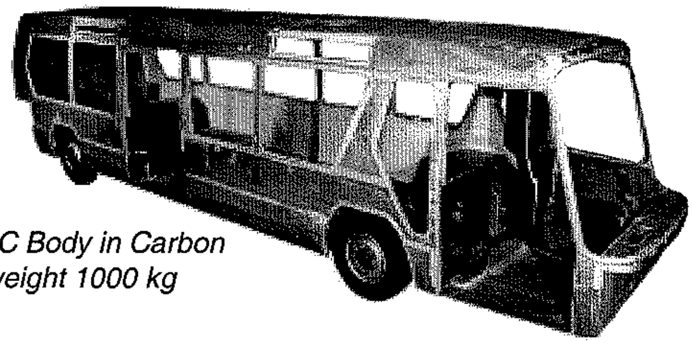


Fig. 6. MIC Body in Carbon Design, weight 1000 kg

To make the vehicles light and corrosion free, the bodies were made of glass- and carbon fibre composite material. The result is a body 30% lighter than that of a normal bus.

With regard to the protection of the environment this manufacturing concept has provided a fuel reduction by 30% which means that the exhaust emissions are reduced by 50%. A recycling and/or an energy recovery concept has been set up, too.

After the final design was decided the bus manufacturing could establish an expected energy saving of 30% and an exhaust emission reduction of up to 50% compared with today´s standard bus.

The electric drive system plays an important role in the future city bus drive technique due to environmental friendly emissions and energy savings.

The Electric Drive System

The electric motor technology for propulsion is old and has been applied in a number of vehicle applications. Electric motors have a much higher torque density than combustion engines which means the electric propulsion system takes less space and therefore can be mounted in the wheel (wheel-hub motors). Furthermore the electric motor has a much longer lifespan than combustion engines, they need no change of oil and generate no emissions. Added to that they are able to generate energy when braking. From a propulsion point of view the electric motor is without a doubt a more suitable device than any combustion engine.

The problem attached to electrically powered vehicles is due to the energy pack which has to accompany the vehicle in order to reach a reasonable distance covered. The alternatives at hand are mainly of an electrochemical storage type, (the battery), of an electro-magnetic kind (the fly wheel) and of an electro-statically stored energy kind (the supercondensator). No bus equipped with this type of energy supply will ever come close to the energy content a pure diesel bus can carry. An important trend here is the fuel cell which provides a kind of "in-between-technology", an intermediate link between liquid and gaseous fuels which instantaneously is converted to electric energy. On a long term basis the fuel cell based vehicle might well outnumber the conventional combustion engine with regard to vehicle propulsion.

One way of solving the energy-storing problem of an electrically powered vehicle is to place a combustion powered generator onboard the vehicle to assist the electro-chemical energy storages. From a mileage-point-of-view such a vehicle has the same advantage as the high-energy fuel combustion engine powered vehicle.

From an emission-point-of-view this type of vehicle has a disadvantage similar to the vehicle powered by a combustion engine. There is however a small but never-the-less important difference; the combustion engine doesn´t need to produce the instantaneous power needed for running the vehicle. Instead its working -point can be chosen to keep the battery long-term charge within reasonable limits.

The battery provides the difference between the combustion engine produced power and that of the vehicle movement and other systems consumed. This difference can be both negative, when the battery is discharging, and positive, when the battery is charging.

The possibility of choosing the working point in a electric hybrid hybrid bus is easier than in a combustion driven vehicles which means that certain characteris-tics in the vehicle can be optimized. The energy consumption is such a field, the emissions another. The electrically powered vehicle characteristics with quiet emission free running, which the hybrid powered vehicle also achieves with a shut off hybrid unit, are particularly interesting in city centres which makes the bus an especially interesting application for the hybrid technology.

General

The basic elements of the Magnet-Motor drive systems are the MM electric motors mounted directly on individual wheels, thus constituting a compact rear wheel drive unit.

Together with the accompanying MM power electronics system, the MM inde-pendent wheel drive motors are the basis for all electric hybrid variations. They can be combined with all electric power sources and acceptors. The easiest types of combination are either by using a diesel engine or gas engine plus generator unit (diesel-electric or gas engine electric drive), a chemical battery (electric bus) or by using the trolley bus system.

All the MM components used in such a system can operate both in "source" and "acceptor" mode, which means that they can operate both in "gen-erator" and "motor" mode, or in other words, in charge or discharge mode.

The most important factor is that the combination is realized exclusively within the electric medium. Intelligent power and processor electronic units provide the power and control management be-

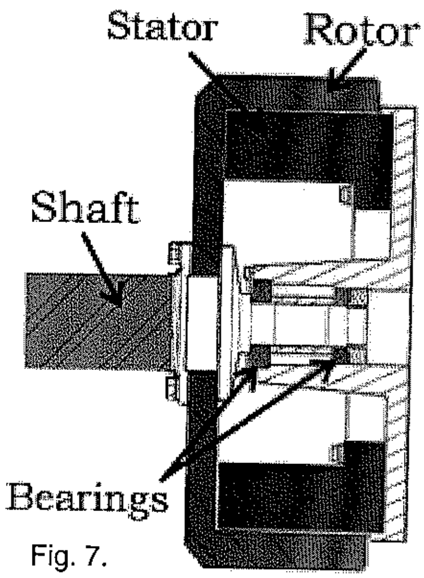


Fig. 7.

tween the individual components of the system, depending on the operating conditions and the commands coming from the driver.

At the moment there is a total of about 60 buses with MM electric propulsion systems running at the customers which represent approximately 300,000 working hours.

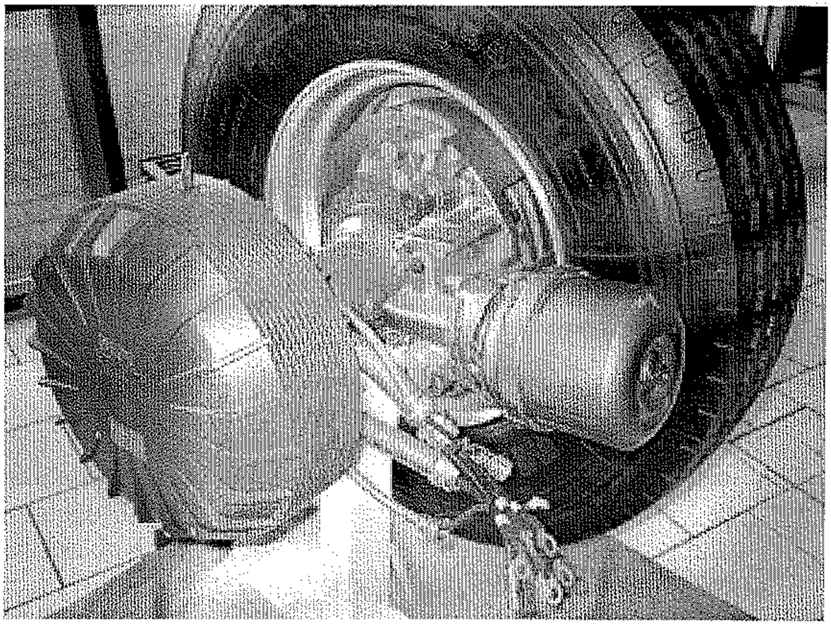


Fig. 8. The MM propulsion motor in the bus assembly.

The following present the MM components used in the bus applications as well as a short introduction in the operating strategy and modes of operation of the bus drive systems.

The simple design of the MM motor with just one rotating component and large air gap makes it easy to integrate it in the special drive axle designs.

The MM generators are motors operated in the reverse direction, like motors during the braking operation. Having the same internal design as the MM motors all the features and characteristics of the motors as shown above are also true for MM generators. Due to their small size and the high torque ability they can be installed directly to the diesel- engine flange without any gear step in between.

The Power Electronics System

The MSS (Multiple Current Control) power electronics system of MM is an extremely compact power inverter system to control the MM motors and generators.

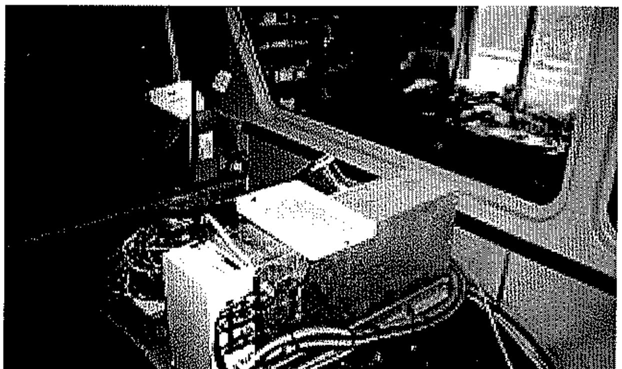


Fig. 9.

Each MM motor and generator is electrically connected to a set of the MSS. It supplies the machines with electric current with the correct amplitude and the required shape at the optimised timing.

The system uses the newest IGBT (Insulated Gate Bipolar Transistor) power components. The inverters are substructured as independent single phase current inverters in four quadrant design. Each of them is connected with its respective group of stator coils.

The IGBT modules and all other components producing losses are mounted on liquid-cooled plates, thus permitting a very compact design. It is therefore possible to install these components between the facing back rests of the seats in a low-floor bus, for instance. As a result, no additional mounting space is needed for the power electronics, an important factor particularly in low-floor buses.

Another important technical feature of the MM electronic components are the very high sampling rates. With these, you can generate current wave shapes with high frequencies, which are advantageous as to noise minimizing and system efficiency. Furthermore it is the task of the MSS to internally monitor and control the electric machines. For example the MSS is automatically reduced by sensors controlling the current amplitude in the case of overheating the stator coils inside the electric motor.

The MM Management and Control System

In order to set the innovative MM drive system working not only electric and electronic components but an electronic managing control system for the interaction of the components is needed. This unit adapts the characteristics of the components to each other and to the external interfaces, e.g. the driver's control panel or the diesel/gas engine control elements. The MM managing and control system also includes the interface hardware and the power managing software to realize the operating strategy and the various operation modes of the vehicle as well as the diagnosis of all system elements. Special features which can be realized directly are for instance ABS and Anti- Slip-Control of the individual wheels.

The communication between the MM components and the MM managing and control unit is performed by light fibre glass wires. This technique is very reliable and insensitive to interferences.

Operating Strategy and Operation

The rotation speed of the internal combustion engine does not have to be adapted to the required speed of the wheels via a conventional stick shift or automatic transmission gear. The engine can therefore always run at the speed of its optimum efficiency and at a minimum of emissions at a required output power. The result is twofold: A reduction of both fuel consumption and emissions. The other advantages are obvious: Wear on the diesel or gas engine is reduced considerably, with power interruptions and shift jolts typical for stick shifts or torque converters disappearing completely.

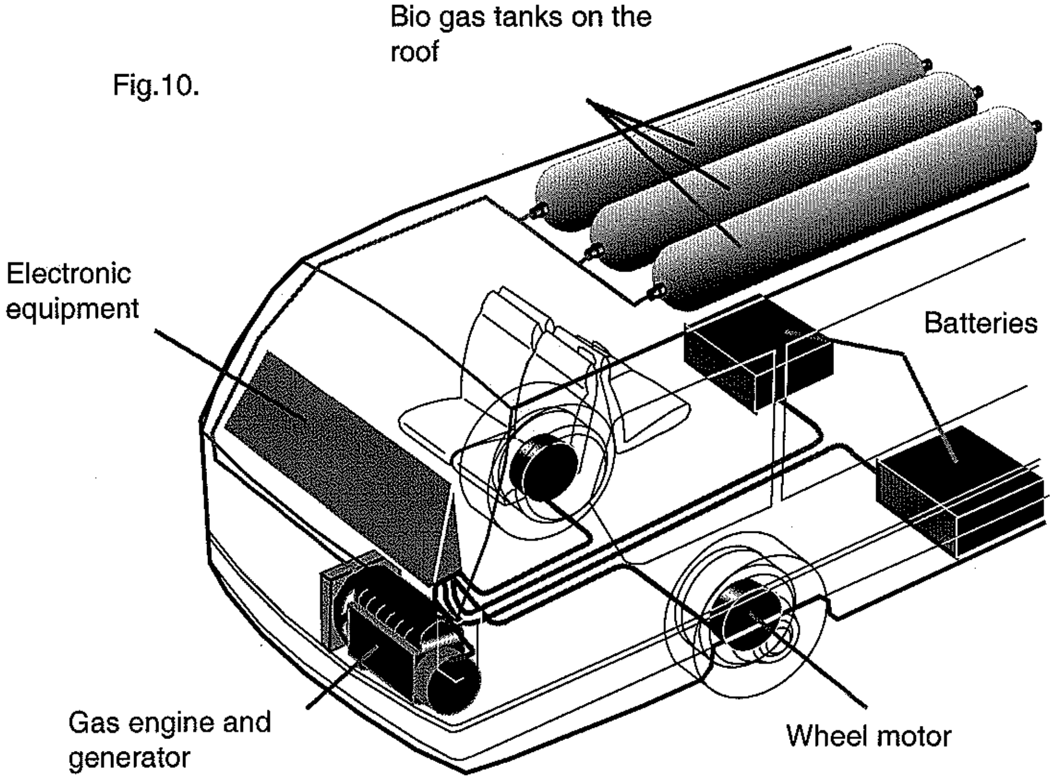
The quasi-stationary operation of the internal combustion engine causes a further reduction of emissions, particularly those of particulate matter.

The engine no longer has to be adapted to the varying load conditions of regular service en route, but is designed to deliver considerably less power and is run within its optimum consumption and emission range for longer periods of time than during pure diesel-electric or gas motor-electric operation.

The braking energy, normally converted to heat, is efficiently used for generating electric energy. During the braking phase, the motors run as generators and feed energy into the batteries. The braking energy charges the batteries. When the vehicle accelerates the batteries feed the stored energy back into the drive motors. To obtain synergy effects the power of the batteries and the MM generator work together during this phase.

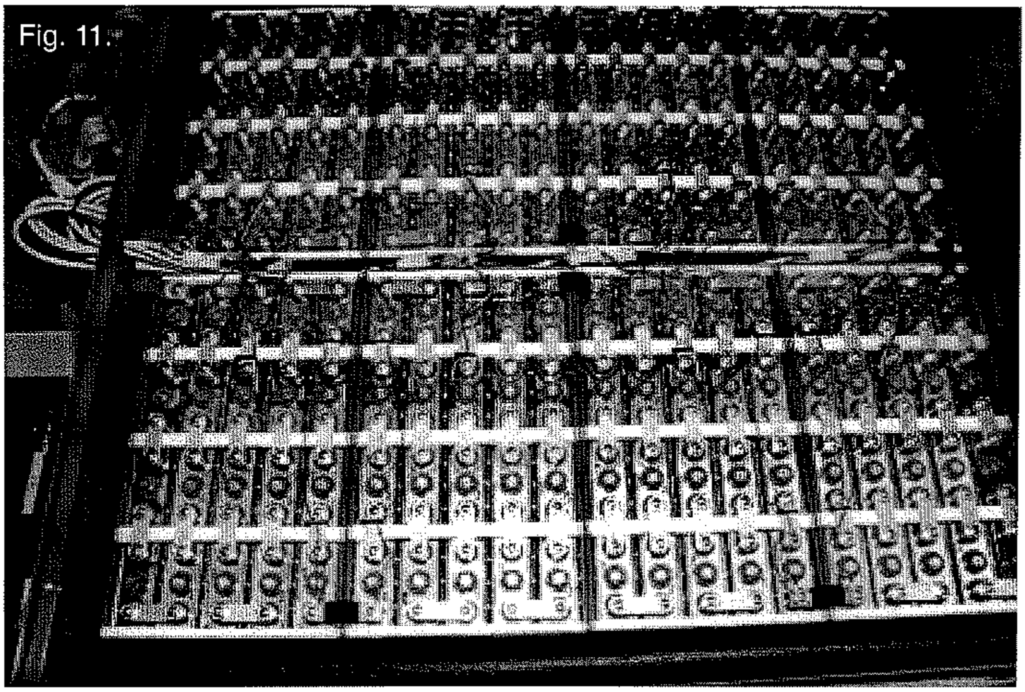
A further feature of the MM battery drive system is the possibility of pure electric propulsion within short or intermittent restriction zones. This type of propulsion means that the internal combustion engine is turned off and that the batteries provide power for a completely emissionfree and noiseless running.

Fig.10.



3.4.2 The Nickel- Metal Hydride Battery System

The VARTA NiMH cells are rechargeable, sealed, maintenance free and specially designed for application as traction batteries for electric vehicles.



The NiMH Battery System

Being very complex, a brief description of the basic chemical processes and properties of NiMH-cells are included in the following. The basic working principle of NiMH and NiCd batteries is almost identical, however in the case of the NiMH technology cadmium is replaced by a hydrogen storing metal alloy. The positive electrode mainly consists of Nickelhydroxide.
The chemical process of charging / discharging is schematically illustrated in the following figure:

Negative Electrode: $MH + OH^- \rightleftarrows M + H_2O + e^-$

Positive Elektrode: $NiOOH + H_2O + e^- \rightleftarrows Ni(OH)_2 + OH^-$

$$\mathbf{MH + NiOOH \rightleftarrows M + Ni(OH)_2}$$

The composition of the alloy is designed to yield the following specific properties:

- Large hydrogen storage capability resulting in high discharge capacity
- Pressureless storage of hydrogen within the specified operating temperature range
- High rate capability for charging and discharging
- High oxidation resistance for long lasting performance

Because of the employment of the hydrogen storage alloy the NiMH cell have a higher energy density than NiCd cells.
In sealed maintenance free cells it is necessary to overdimension the negative electrode compared to the positive which determines the useable cell capacity.

Charging reserve: Towards the end of charging, oxygen which is generated at the positive electrode must be consumed to avoid pressure build-up.

Discharging reserve: Prevent degradation (corrosion) of the negative electrode at the end of discharging process.

The NiMH Cell

The main components of a NiMH cell are:

- *positive electrode* - Nickelhydroxide as active material
  - additives (Cobaltoxid, binder, ..)
  - substrate Ni-Foam
- *negative electrode* - hydrogen storage metal alloy
  - additives like binder, carbon etc.
  - substrate (mesh or expanded metal)
- *separator* - nonwoven material having excellent electrical insulation characteristics retaining a suitable amount of electrolyte for ion transport.
- *electrolyte* - dilute alkaline solution (mainly KOH)
- *cell can* - metal case
- *safety valve* - resealable valve
  opening pressure: about 3bar abs.
- *terminals with sealing system*

Varta´s NiMH Cells for Electric Vehicle Application

In the NiMH field Varta is developing three different product lines for NiMH cells and batteries for electric as well as hybrid vehicles. Varta distinguishes between high energy and high power cells. Under development are ultra high power cells.

High Energy Cells

The high energy cells (NP80, NP150) in prismatic form are designed for traction batteries in pure electric vehicles. Today, the specific energy of these cells reaches values of up to 80Wh/kg. The corresponding energy densities are at levels around 200Wh/l.

The battery in such a vehicle must have a relatively high electric energy content in order to get a sufficient mileage. Thus the requirements regarding the load capability are not so high.

Due to generation of waste heat during continuous discharge the discharge current should be limited.

High Power Cells

High power cells (NP40, NP60) are specially designed for hybrid vehicle traction batteries. Due to high power demands the hybrid vehicle needs cells with high load capability and excellent rapid charging characteristics during the electric driving mode and for the fast recharging phase of these batteries. Today´s cells with power datas of 240W/kg and 650W/l can be achieved by continuous discharging.

Ultra High Power Cells
These cells are presently under development and are designed especially for very high power demands. The battery assembled to these cells is used in a hybrid vehicle together with a relatively small electric energy storing unit. The battery will mainly be used for serving the extra power required for acceleration and hill climbing.

Battery Design
The Varta NiMH battery technology is based on a module concept. The single module consist of 20 NiMH cells connected in series. They are equipped with an air cooling system (see Section 4).

In order to avoid swelling of the cells the modules are mechanic stabilized.

Thermal Management
Although the NiMH batteries can operate in different temperature conditions the thermal managing unit insures good performance in case of very low or high temperatures and will reduce the negative effects of high temperature on battery life.
Due to generation of waste heat the NiMH battery has a cooling system employed. The waste heat is generated by:
- Exothermic conversion of the H-storing alloy to the hydride phase (charging).
- Oxygen recombination at the negative electrode; the oyxgen is generated in a secondary reaction at the positive electrode after exceeding the 80%. SOC level (charging).
- Ohmic losses (charging and discharging).

Very important forgood battery long life performance is the homogenous temperature distribution in the battery. The main reason for this is that the charge efficiency depends on temperature.
The requirement of a small temperature gradient in the battery was taken into account by designing the module and the battery tray.

In the present air cooling system the battery is equipped with a top ventilator which sucks out air from the module (see battery drawings). The air inlet is at the bottom of the module. To avoid thermal short circuiting, the incoming and outcoming air streams must be seperated.
The air in- and outlets must always be free to make sure a maximum airflow is available for battery cooling.

The air stream per module has to be >50m³/h. The cooling system is controlled by the battery management system (BMS).

The ventilators are switched on at a certain battery temperatures. In case of charging fans start working during the whole charging process.

After charging the cooling system will stay activated for a some time. Operating the battery (charging as well as discharging) without the BMS control is not allowed.

Battery Management System

For longterm reliable operation of the NiMH EV battery a battery management system (BMS) is needed to control all the battery operation states.

The functions of the BMS are:

- ***module monitoring:***
  - voltage
  - temperature
  - current
- ***charge / discharge control:***
  - enable/disable charging and discharging
  - giving limits of voltage, current, temperature
  - compensation of self discharge
  - balance of charge in- and output (SOC)
  - charge equilisation
- ***state of charge (SOC) indication***
- ***activating the cooling system***
- ***ailure detection / safety functions***:
  - avoiding overcharge
  - avoiding overdischarge and cell reversal
  - protection against overheating
  - high impedance
  - short circuits
  - defect insulation
  - error handling
- ***user information***
  - dashboard
  - external computer
- ***interface to:***
  - motor controller
  - charger
  - dashboard

Battery Design

A battery is composed of many single cells. The cells are assembled into modules. These modules are placed in a battery tray. The battery of the vehicle is made of two battery trays.

Module

A module contains 20 cells. The poles of the single cells are connected by massive metal plates. The modules as a part of the battery has a voltage of 25V.

Construction

20 cells are placed in a metal case. The casing limits the swelling of the cells. Plastic components insulate the cells from each other to guarantee a minimum airstream between the cells. Plastic components fix the cells to the floor to prevent the cells from dislodging.

The bottom module metal sheet is made into webs. On the webs a plastic plate with holes is placed. The cells stand in the module on the plastic plate. The module case is covered at the top by a cover. In the middle of the cover an extractor fan is mounted.

Ventilation
Cooling takes place by extracting air through the cell space, by a centrally installed fan. Air enters at the sides of the module and passes between the bottom of the case and the cells. From here it reaches the cells in the upper compartment. From there the air is extracted by the fan.

Battery
The battery is composed of two battery trays, connected by cable. In a battery tray several modules are summed up to a group. The poles of the individual modules are inter-connected. The battery consists of 14 modules with a voltage of 350 V.

Electric components, necessary for operating the battery, like the battery management system (BMS), contactor and controllers are built into the tray.

Battery Construction
The modules stand in an metal tray. Because of the necessary air ventilation the tray is set on webs. These give the tray additional stability so that it can be transported by a lifter. The modules are fastened over profile bars and drawing bars in the tray. The profile bars support the module case to prevent cells from swelling. The modules are insulated by plastic plates. The battery tray is fastened tot he web via bolts to the vehicle.

Ventilation of the Battery
Ventilation is produced by the module fan. Air enters through the web slots at the bottom of the tray. From there it passes the lower chamber of the module and distributes itself under the cells.

The air passing the cells is extracted by the fan into the pressure room above the module. It´s important, that the air inlet and the pressure area are separated.

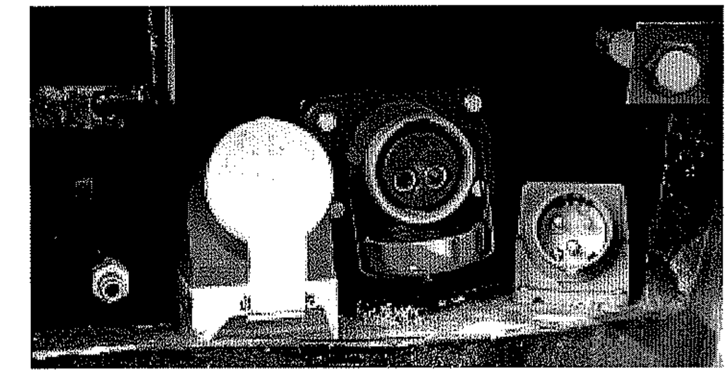


Fig. 12. Connectors for charging, heating and air during parking.

3.4.3. Gas System for the Bio Gas Hybrid.

The chosen methane gas storage system is designed in Sweden and approved by the Swedish authorities it has also been inspected and approved by TüV.

The storage tanks, light weight aluminium/glass fiber/carbon fiber composite tanks, are made by Raufoss Composite AS, Norway. The three tanks have each a volume of 203 liters and a working pressure of 200 bars.

The gas system components are made by the Swedish firm Gaveco AB, the system design is of their origin too. All components are made of very high quality stainless steel and the whole system has the same high safety factor as the tanks.

All tanks and the roof mounted parts of the gas system are delivered as a module and placed directly on the roof of the bus.

The system has several safety arrangements;

- The tube from the filling connector to the roof mounted tanks has a check valve close to the tanks which prevents the gas from leaving the tanks if the filling connector or tubing is damaged.
- A solenoide valve close to the tank arrangement is opens only if the ignition key is in the on-position.
- All tanks have manual shut off valves.
- All tanks have two termal safety valves, one at each end, which opens if the tank is exposed to too high temperatures - to prevent too high a tank pressure.
- The outlet tubing from the tanks to the engine room has a leakage indicator which by means of a differential pressure tubing down to the engine room senses the presence of a leakage and closes the solenoide valve.
- The gas system in the engine room is shut off unless the engine is rotating.
- The low pressure system has a maximum pressure relief valve to prevent damages if the pressure gets to high, after the high pressure regulator in the engine room, which reduces the pressure in the tanks to the 10 bars the engine requires.

Gas System Bio Gas Hybrid

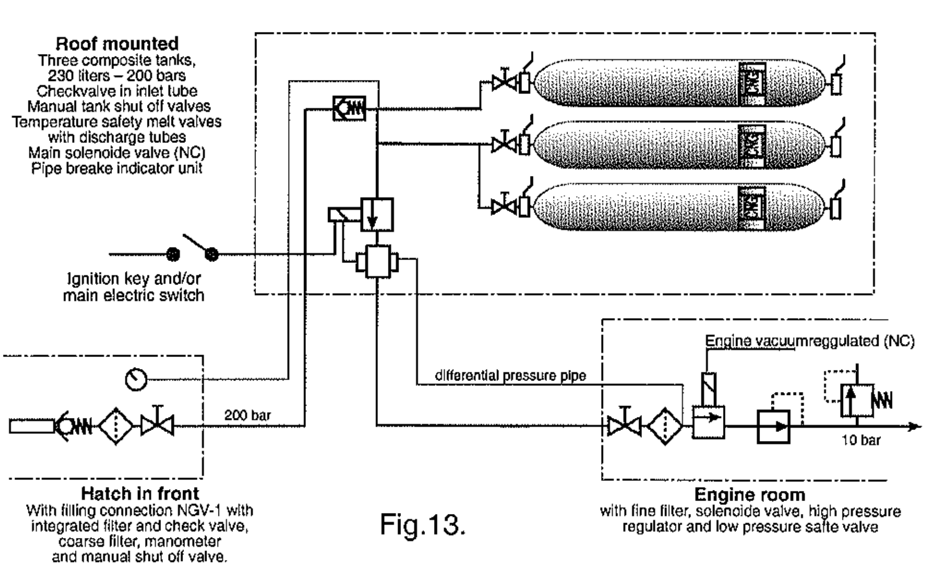


Fig.13.

3.4.4 CUMMINS B5.9G HEAVY-DUTY ENGINE

The B5.9G is the first heavy-duty natural gasengine to complete certification for the 1998 Environmental Protection Agency (EPA) Clean Fuel Fleet Vehicle (CFFV) Ultra-Low Emissions Vehicle (ULEV) and Low Emissions Vehicle (LEV) standards. This spark-ignited dedicated product features advanced electronic engine controls management, closed-loop air/fuel ratio control, lean-burn technology and integrated sub-systems.

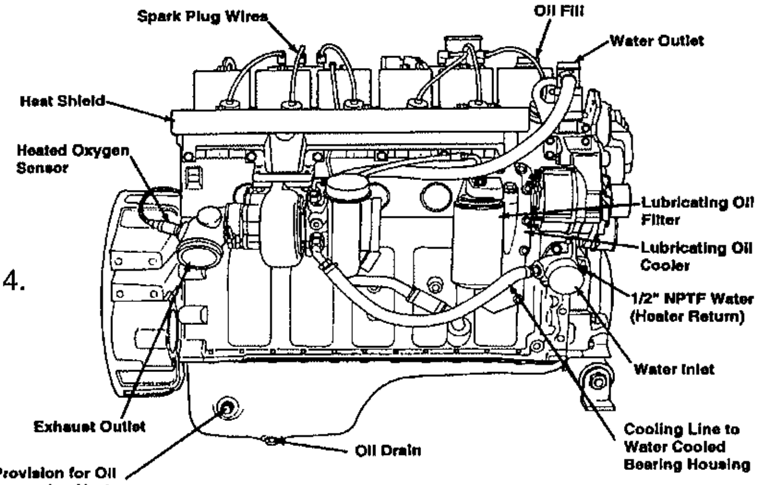
The B5.9G was the first heavy-duty six-liter engine to receive emissions certifications in 1995 from the EPA and the California Air Resources Board (CARB) at levels that meet both agencies' 1998 on-highway heavy-duty truck and bus emissions standards without the use of an exhaust oxidation catalyst. The B5.9G now meets the EPA CFFV LEV standard without a catalyst and the EPA CFFV ULEV standard with the addition of a catalyst.

This spark-ignited six-cylinder engine utilizes lean-burn technology to provide cooler combustion temperatures which result in lower levels of nitrous oxides and higher engine durability than a stoichiometric natural gas engine. The B5.9G combustion technology also increases the engine thermal efficiency to a peak of 37% versus a typical stoichiometric engine.

The ignition sub-system components for Cummins natural gas engines have been developed specifically for lean-burn conditions and the higher-energy ignition requirements. Like the B5.9 diesel, the B5.9G features a Cummins-built Holset turbocharger with exhaust wastegate to optimize torque capability and a one-piece crossflow cylinder head to provide maximum structural stiffness of the block/head assembly, combustion optimization and higher durability. The cast-aluminum three-ring piston with a rectangular top ring provides excellent sealing and long ring groove life.

Engine Model	Rated Horsepower hp @ rpm	Peak Torque lb-ft @ rpm	Governed Speed rpm
B5.9-195G	195 @ 2800	420 @ 1600	2800

Fig. 14.



3.4.5 Desciption of the Performance Monitoring System

The Vehicle Onboard System

The energy systems onboard the bus are threefold: Kinetic, electric and chemical. The measurements system on board the vehicle is used to acquire knowledge about the energy flow, vehicle behaviour, temperature and engine parameters like fuel consumption, speed and lambda.

The equipment would have to be compact and non-sensitive to vibration, dust etc which might influence results. The measuring system onboard the bus is built around a commercial data collection system from National Instruments called SCXI. To the "SCXI" system the LabView program is set up on a laptop computer, is connected with the program LabView". The analogue data acquisition is done by 16 bits resolution. This means that 0 - 10 V gets the resolution of 160 V, which is a high resolution It is very important that the channels are sampled at the same time so voltage and current do not to appear at different times.

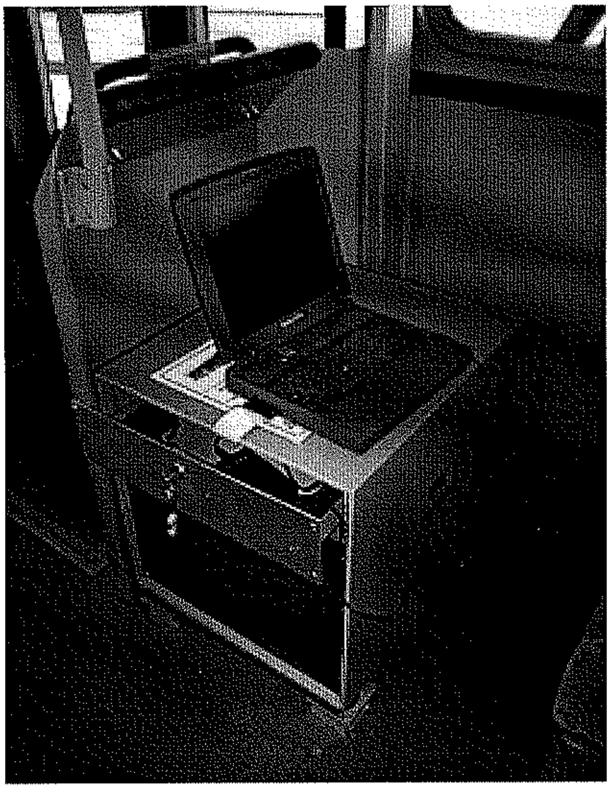


Fig. 15. The computer and measuring system.

All quantities are sampled at a rate of 5 Hz. The data is stored on a lap-top computer hard disk, normal day datas will amount to a total of 30 MB. Data transferred to the stationary computer is done by a "zip-drive".

When the ignition is turned off (during the night) the data acquisition system goes into a sleeping mode.

Data acquisition program

The program used for data acquisition is called LabView".

Sensors
All sensors were built into the bus after it was built. The sensors are listed below.

Sensor specification

Unit	Remark
Voltage (drivesystem)	To calculate the powerflow
Voltage (24 V system)	"
Current from generator	"
Current to DC/DC (drivsystem)	"
Current to motor 1 & 2	"
Current to brakeresistor	"
Current to DC/DC (24V system)	"
Current from generator (24V system)	"
Speed engine	Engine behaviour
Speed Vehicle	Vehicle behaviour
Lambda	Air/Fuel ratio
Mass gas	Fuel consumption
Pressure inlet	Corresponds to the torque
Dif. Pressure Catalyst	Check catalyst condition
Accelerator	Drivers activity
Throttle	Engine parameter
Temperature inlet	Engine condition
Temperature exshsed	"
Temperature before & after Cat.	Catalyst condition
Temperature Cooling	Engine condition
Temperature Outside	Condition
Temperature in the bus	"

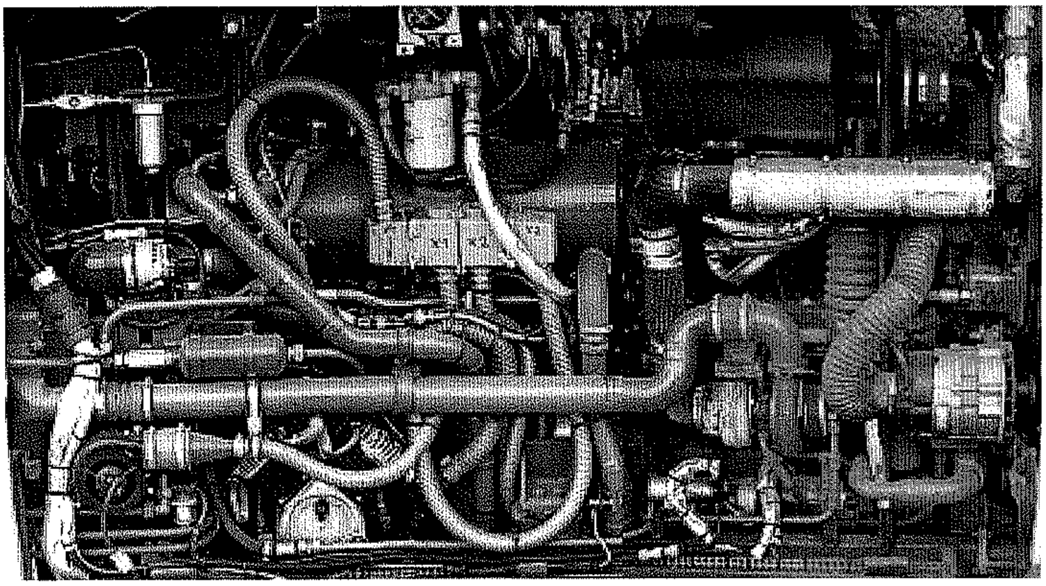
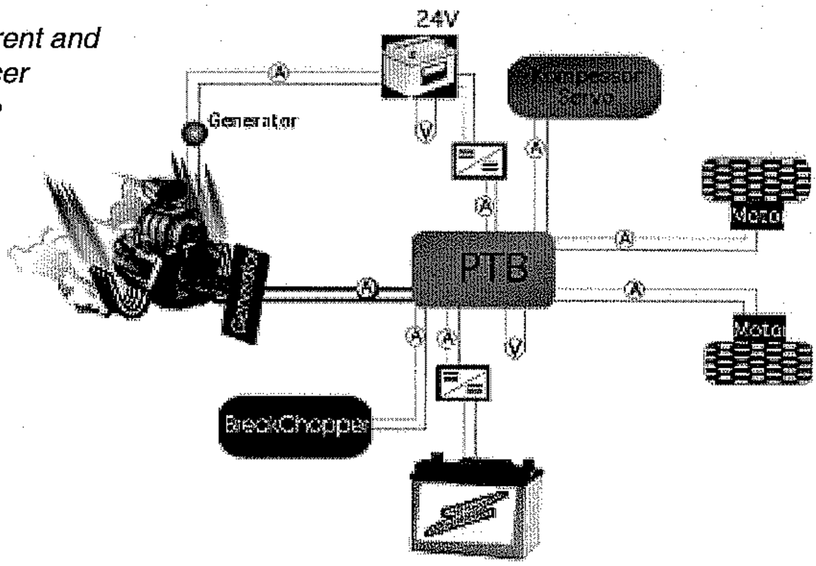


Fig. 16. The engine room

Fig. 17. The current and voltage transducer placement in the Neoplan bus.



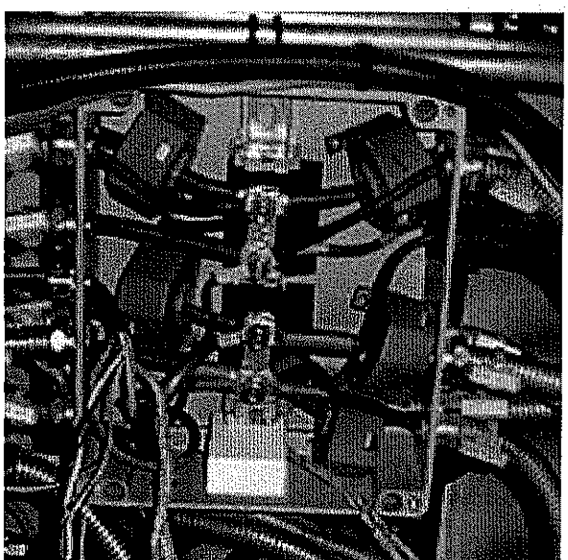


Fig. 18. The current transducers around the cables and voltage transducer at the bottom in the PTB box.

The current and voltage sensors measure the electrical power flow in the bus. Manufacturer of the sensors is LEM. The sensors are galvanically insulated from the respective system. The current sensors are built on the Hall effect principle where the current passes through the transducer only. The inaccuracy is%, this will make the voltage error of 500 V to V, and the current error of 100 A to A. See figure XX for a connection point with many current transducers and two voltage transducers.

Temperature measuring less than 150 degrees is made by PT-100 elements, which are resistive sensors. Temperature measuring above 150 degrees is done by temperature elements of type K. These high temperatures are measured in the engine exhaust gases mainly. The temperatures on both sides of the catalyst are measured to be able to see weather it is working or not.

The lambda-sond is mounted on the engine. It has an attached electronic equipment with a very fast responding time. The sensor has been installed at the exhaust outlet, to check the fuel/air ratio change. With a fast (high band width) lambda sond makes it possible to see changes even when the engine changes working points. The fuel/air ratio is important for the emissions from the engine. The lambda-sond comes from ETAS.

The fuel-flow sensor for the fuel consumption is made by Bronkhorst hi-tec. The sensor measures the mass flow of natural gas, the working range is between 0 - 36 kg/h. The measuring principle is thermal and is not sensitive to jolts, nor does it need a long straight pipe. The sensor gives a response time of under 1 second.

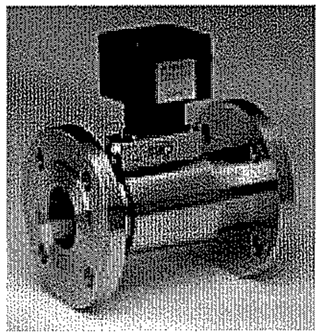


Fig. 19. The massflow sensor for methane

Pressures in different places are also measured. The differential pressure is measured over the catalytic converter. One of the reasons for this is that a fire started at the back in one of the buses. A stop in the exhaust pipe by the catalyst was suspected to be the cause of the accident.

Pressure in the intake is measured; it is interesting because this is directly coupled to the torque of the engine.

Other sensors installed in the bus are: Speed sensors, position sensors and GPS-sensors.

The speed sensors receives pulses from the bus system and are transferred into DC-voltage, which is used by the data acquisition system.

The position sensors are used to measure the position of the throttle and accelerator pedal of the driver.

The GPS unit was installed to log speed, position and variation of height; this sensor was too slow and could only be used for calibration of the speed sensor.

The Malmö cycle

The Malmö cycle is a randomly selected recording of the bus velocity going from the town centre to an exhibition site by the Øresund fixed linkbridge. See figure. It is not as demanding as the Braunschweig cycle. The maximum speed is 49.7 km/h, the average speed is 20.9 km/h and it is 10,5 km long. The maximum acceleration is 1.36 m/s2, thus significantly lower than the Braunschweig City Driving Cycle, partly reflecting that Malmö is a relatively flat city. It is important to note that when a HEV is specified, a standard driving cycle like the Braunschweig City Driving Cycle will impose too high demands on acceleration, resulting in an over powered vehicle that is less able to run near optimal operation with respect to fuel consumption, exhaust emissions etc.

Efficiency

The combustion engine efficiency and the generator efficiency are shown in the graph below. The added chemical energy is here shown together with the given off electrical energy.

The combined efficiency for both the combustion engine and the generator is good, specially at high power. At low power the efficiency is slightly lower.

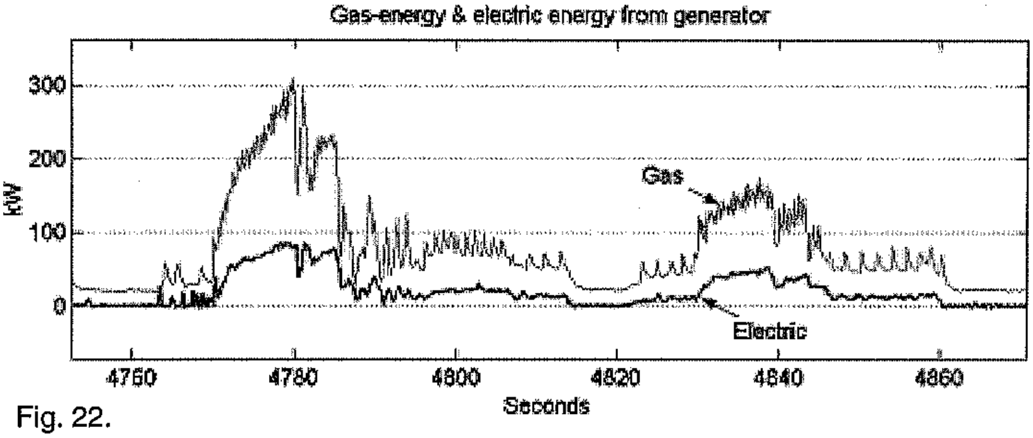


Fig. 22.

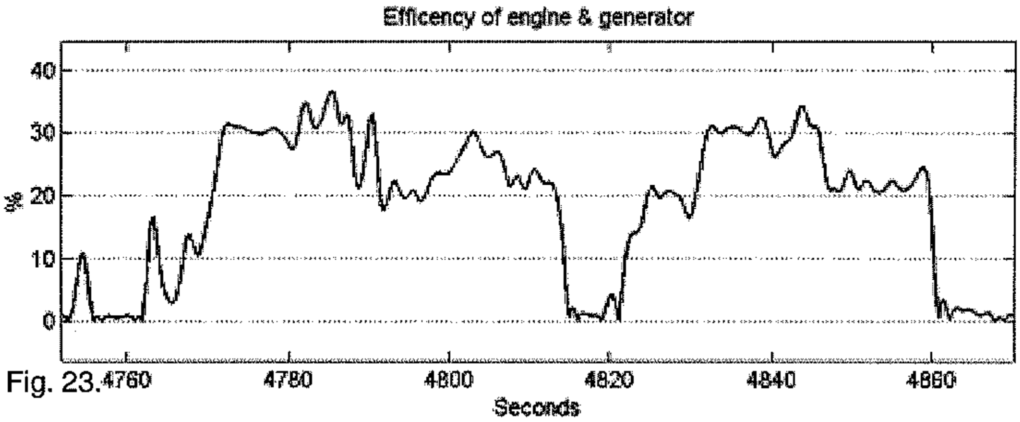


Fig. 23.

The Hybrid System

The main reason for using a combination of combustion engine/generator and electric propulsion, i.e. a hybrid propulsion system, is among others to disconnect the combustion engine power/engine speed from the propulsion and driver behaviour. This is shown in the figures below, where several different interface signals are shown.

The upper graph shows the connection between speed and the driver´s accelerator position. In practical daily use it shows that the driver uses three different commands for the propulsion, viz. acceleration, constant speed and no speed.

The lowere graph shows the hub motor power, the power from the generator and the power to the brake resistor.

A first hand study of this graph shows that the system´s energy regulation has a good potential for improvements. The battery pack charging degree is unnecessarily high at times, with the effect that the batteries doesn´t absorb the brake energy available and that the system instead steers this energy to the brake resistor.

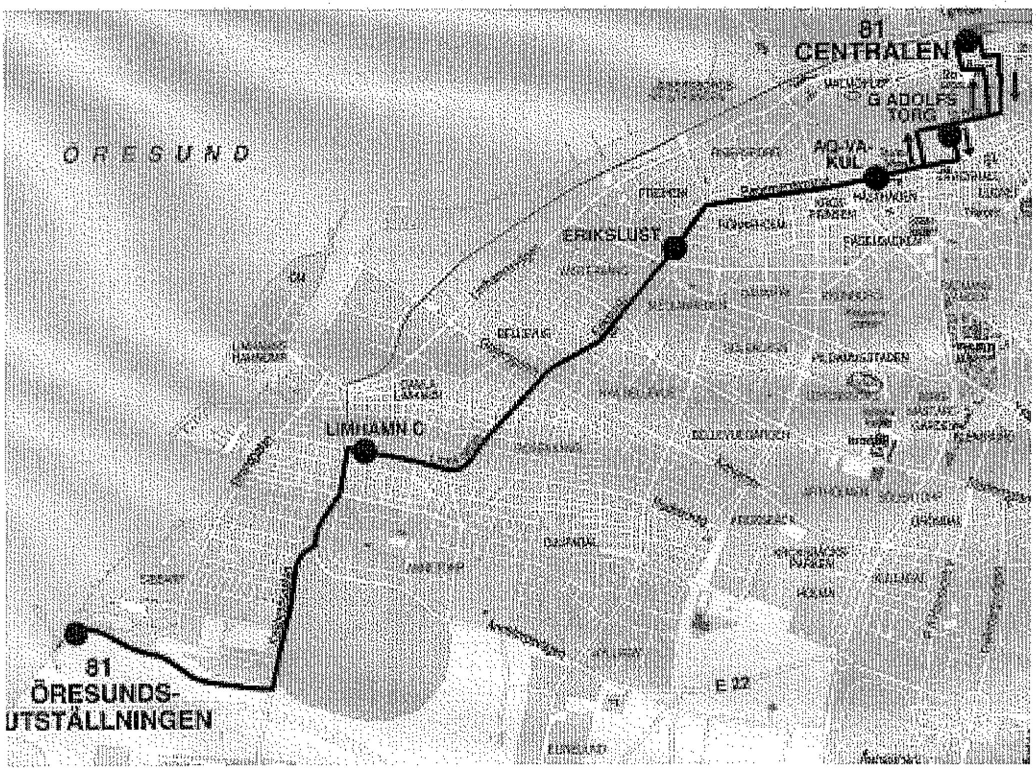

81
CENTRALEN
G ADOLFS
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Fig. 20.

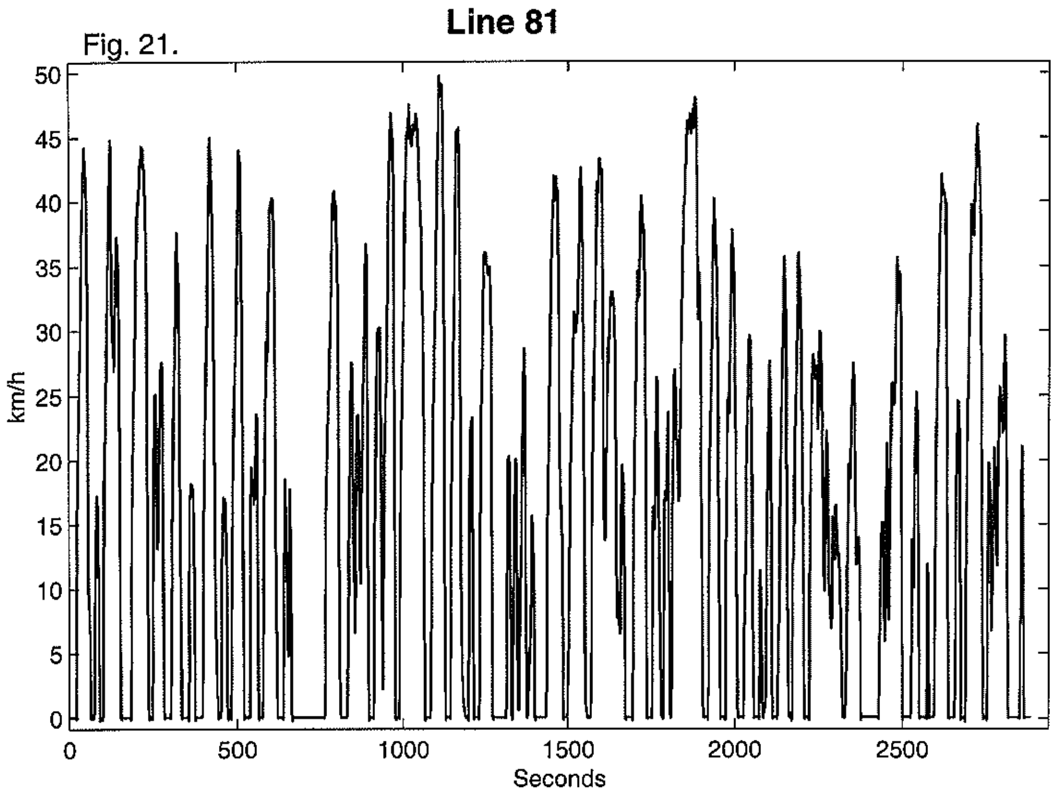
Line 81
km/h
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Fig. 21.

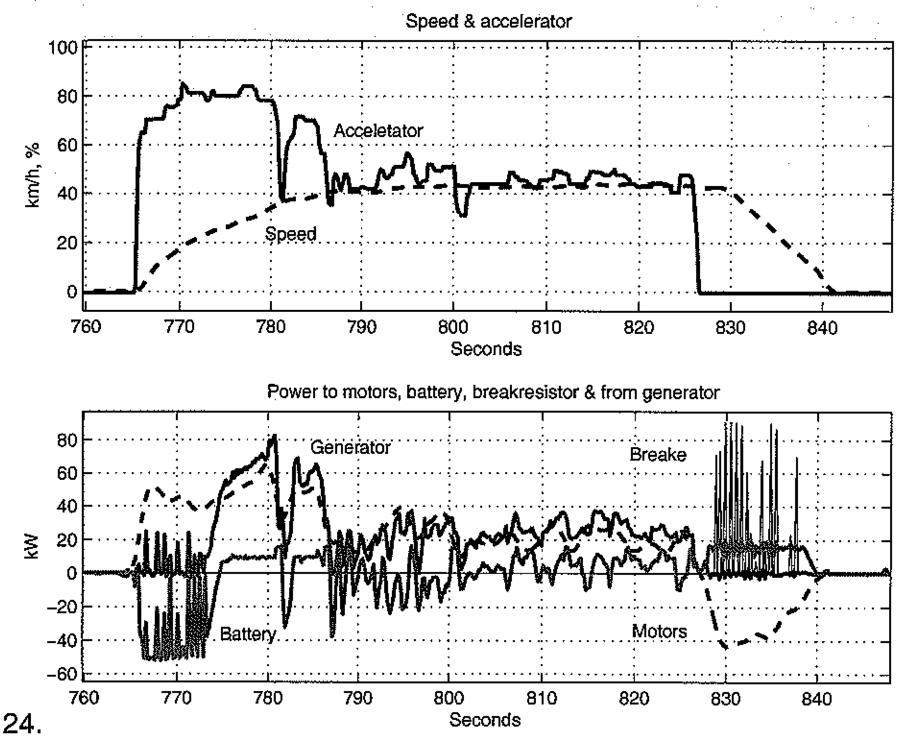


Fig. 24.

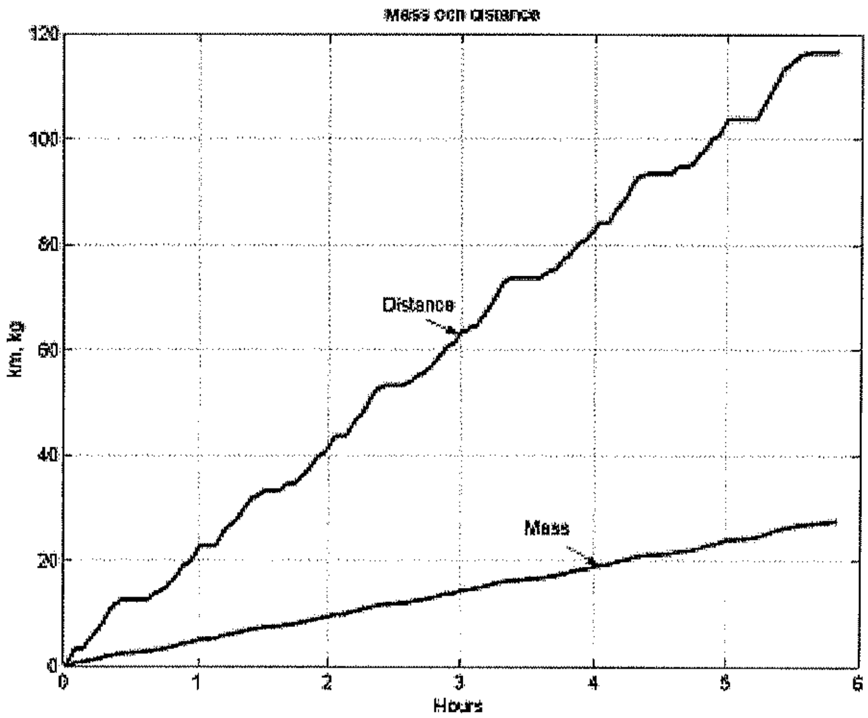


Fig. 25. Distance and fuel consumption during the Malmö cycle. The fuel consumption results in ca 2.35 kg per 10 km, a figure considerably lower than for an equivalent diesel bus.The difference is mainly due to the regeneration of the brake power.

4.OPERATION AND RESULTS

4.1 Bus fire in Malmö.

One of the biogas electric hybrid buses in Malmö, a Neoplan MIC 8012 GE, Malmö hybrid nr 1, was destroyed by fire during traffic operation on the 28th of June 1998. The cause of the fire is unknown.

The vehicle was approved for traffic operation on the 9th of June 1998 and was put in operation on the 25th of June. Before the fire it had only run some 650 km.

Course of events

Fig. 26.

The vehicle caught fire during traffic operation in the city of Malmö on the 28th of July for some unknown reason and was almost completely burnt out on the inside, it was also heavily damaged on the outside.

On the occasion there were three passengers onboard, all of whom could leave the vehicle without injuries.

The fire seems to have started in the built-in exhaust channel that leads from the engine room to the roof. The driver first observed the fire from the outer right mirror. Spreading along the roof top the fire proceeded to the internal roofchannels on both sides of the bus all the way to the drivers seat.

Inspection

The outer rear wall was opened by cutting a strip of the plastic body into the channel where the exhaust tube runs to the roof. In the hidden vertical channel where the exhaust tube runs were signs of fire and it was established that the two shorter protection tubes around the exhaust tube which passes the lower wall and roof, had not prevented the fire from entering the passenger compartment.

At the lower part of the exhaust tube was a joint with a clamp fitted, which may have leaked and let hot gases come into contact with the composite body. This probably caused the exhaust gas fire which spread into the channels leading to the tube on the roof. At a distance of ca 800 mm, between the lower and upper protection tubings was only a textile heat protection cover that had been clamped on in several places. The textile heat protection cover was completely burned out.

On the roof, fire damages had reached the surrounding installations, as the cooling system, tubings and a roof window as well as the fuel tank covers.

Fig. 27. Rear end of the passenger compartment.

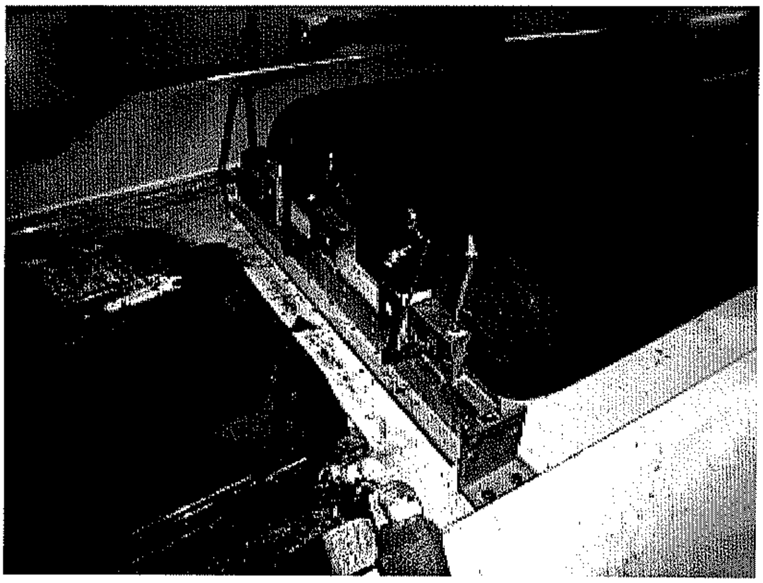
From the heat of the fire the center tank temperature safety valve released and emptied all the gas through the outlet tube, completely as designed.

The outlet gas caught fire and was re-extinguished again, causing a puffing noise. No further visible damages was seen on the gassystem and all the safety arrangements worked as planned.

A close analysis of the gas tanks was carried out by the Raufoss Composite A/S Company experts.

However, having been exposed to high temperatures and fire the tanks were not permitted for further use by the authorities.

Fig. 28. Roof window and gas tanks.



Inside the bus, the fire followed the roof and the closed roof channels with the result that the bus body composite melted and burned and the glassfibre hung clean from the roof.

All the electric components in the rear compartment and roof channels were exposed to high temperatures and either melted or burned.

The sandwich design in the roof was broken up when the lower- and middle layer disappeared. All electric cables were without insulation.

The engine room, floor and below floor mounted components seemed to have survived better, but at dismounting and testing it was necessary to establish the extent of damage and the possibility of reuse for every single component.

The propulsion batteries- in their special aluminium cases on the floor in the middle of the bus were exposed to high temperatures during the fire. They were sent to Varta, Hagen in Germany to be tested.

The batteries were not damaged, but as the BMS-electronic system had been exposed to high temperatures it had to be replaced.

This fire incident has shown us what could happen when a rather simple design fault is not corrected in time. It has shown us the importance of information and training not only of your own staff, but as in this case, the fire-brigade personnel. Different actions from the fire-brigade when they arrived to the scene could have reduced the damages considerably.

Different actions from the salvage corps when towing the bus away could also have reduced the damages.

4.2 Problems, Solutions, Successes SAD

During the trial period and the test drives some problems were encountered. Most of these were solved shortly after. Below you will find all the problems encountered and the solutions adopted.

Stiffness of the Vehicle: At speeds above 65 km/h steering becomes heavy and the whole vehicle vibrates. This depends on the particular system used to build the bus which causes the body to be particularly stiff. The bus was conceived for use in cities, where there is no need for higher speeds.

Noise: the bus is noisy more than expected both inside and outside. The noise is ascribable to the wheelmotors and in part also to the electrical pumps of the water circulation system.

Steering: the turning radius is not as wide as that of other buses. After a curve the steering wheel does not return on its own like that of other buses.

Electrical Pump of the Servo Steering Unit. At the beginning, while driving in H mode (hybrid) or B mode (battery), the pump of the servo steering unit would shut off after a few seconds it was not used. This could be dangerous in some circumstances.

This problem was solved by Magnet Motor by decreasing the voltage by 2 V to enable the regular functioning of the servo-steering pump.

Dangerousness when driving in reverse gear: When driving in reverse gear (already on roads with a gradient of 6%) the brake had to be used when driving. The engine brake that was supposed to recover energy was too weak as it was set at a power output of 60 KW.

This problem was solved by Magnet Motor by raising the braking power of the engine brake from 60 KW to 100 KW.

This measure also enables to recover more braking energy for the battery.

Battery Charging in L Mode: When driving in L mode (= battery charging) with a low power demand (e.g. on level roads) the battery would not be charged enough. It was seen that the battery charging was dependent on the diesel engine output, i.e. the greater the output of the diesel engine, the more the energy charged into battery. However, this was a problem: the battery is supposed to be charged if it is necessary independently from the diesel engine output needed for driving. In addition, it was seen that, while driving in L mode with a charged battery, a part of the battery's energy was supplied. However, this energy had to be diverted to the resistors on the roof.

This problem was solved by Magnet Motor by duly modifying the control program: now the bus is programmed to maintain a constant energy supply to battery while driving in L mode irrespective of the engine output.

Low Air Autonomy: The air supply was too low. After no time at all the air pressure would drop and the relevant signal would light up on the dashboard.

The problem was solved: the four-way valve was changed and the pressure in the air tank was increased to 1.5 Bar (just like in other buses).

Faulty activation of the diesel engine when driving in H mode: When exceeding a certain speed (24 km/h) the diesel motor is activated automatically. At times, however, the rpm was too low and the bus would continue to run with the battery. In order to increase the rpm the gas pedal had to be pressed all the way 2 or 3 times.

This situation was considered as normal by the technicians of Neoplan; it depends namely on the detection and response time.

Control BMS: It happened frequently that in the case of hard shocks (e.g. pot holes) the BMS would signal the "drive failure" error and the diesel engine would be turned on. When the key was turned off and then on again, the error would disappear. Probably the BMS EPROM's were too sensible to shocks. In addition, also a new error appeared: the battery charging display did not visualize the actual situation. Although the battery status was shown to be at 90%, the diesel engine would be started after a few kilometers – when driving in B mode.

This error was eliminated with two measures: the whole control unit was padded with plastic, while the Varta Company provided a new EPROM for the BMS control unit. After these changes the error message has not appeared anymore. The problem with the battery charging status display was solved with Varta by entering the actual battery status again via the software.

Lower performance during long voyages: Once the bus had been driving for a long period of time, it would often happen that the drive engines would provide lower power without signaling any error. After the vehicle had stopped for a some time, it would start to work normally again.

This problem was caused by a defect in the water-cooling of the diesel engine. The error was eliminated according to the directions provided by the Neoplan technicians by building a new water cooling air fan, which enabled the air to be blown in the opposite direction, i.e. from the outside towards the inside.

New concept for the use of the battery: Once the test drives were completed successfully, the Magnet Motor technicians presented a new proposal for a more lasting use of the drive battery. While driving, for example in L mode, the battery would be charged up to a maximum of 75% of the charging capacity in order to avoid overloading the battery and to leave enough storage capacity for braking energy. In addition, the battery charge would never be left to fall below 25% of the charge capacity so as to avoid reaching low levels of charge and to ensure the optimal efficiency of the battery. This proposal was accepted. Also the EPROMs by Magnet Motor were changed and installed. After this change the bus normally uses 50% of the battery's energy charge capacity, i.e. between 25% and 75%. This should increase the life of the battery and ensure its optimal efficiency. Only battery charging at the bus depot with an external connection can bring the charge level to 100%.

4.3 Operating History and Results – SAD

Once the SAD-Nahverkehr A.G. decided to take part in this project, a group of technicians was called to take care of the construction, introduction and maintenance of this vehicle. This group is composed by Mr. Helmuth Moroder – project manager, Walter Boito – workshop foreman, Gian Battista Milan – mechanic, Renzo Polato - electrician, Massimo Cestarolo - mechanic, Martin De Gasperi – electrician, Fabio Giovannucci – mechanic.

During the bus construction phase the team moved to the workshop of the Neoplan firm in Plaunen, where the bus was built. There they attended a two-day training course. On this occasion also some of the execution details were discussed and coordinated.

The bus was consigned in Bolzano on October 2, 1998. In this case too the team attended another training course held by the technicians of Neoplan, Magnet Motor and Varta. These two training courses and the supplied documents enabled the SAD technicians to get quickly acquainted with this new bus.

On November 15, 1998 the bus was presented to the press in Bolzano. The press, the radio and TV all give wide coverage to the event.

The bus, however, still required the approval of the Italian motorization authorities before its putting into service. This was possible only once all the necessary documents were received from the Neoplan firm. The bus could finally be put into service on August 31, 1999.

In the meantime the first test drives were made. During these tests some problems and defects came to the surface. Almost all these problems, as mentioned already in paragraph 3.3, were eliminated.

During the first week of October 1999 the bus was presented at the Bolzano trade fair. For this occasion a brochure in two languages with all the most important information on this bus was issued.

Test Drives

1st course of the test drives: the SAD line servicing Bolzano – Appiano – Caldaro – S. Antonio – S. Nicolò and back was chosen as the bus would be used on this line in the future for passenger service. The choice fell on this line for several reasons:

• The bus leaves from Bolzano and can be charged during the night at the depot where it can also receive maintenance;

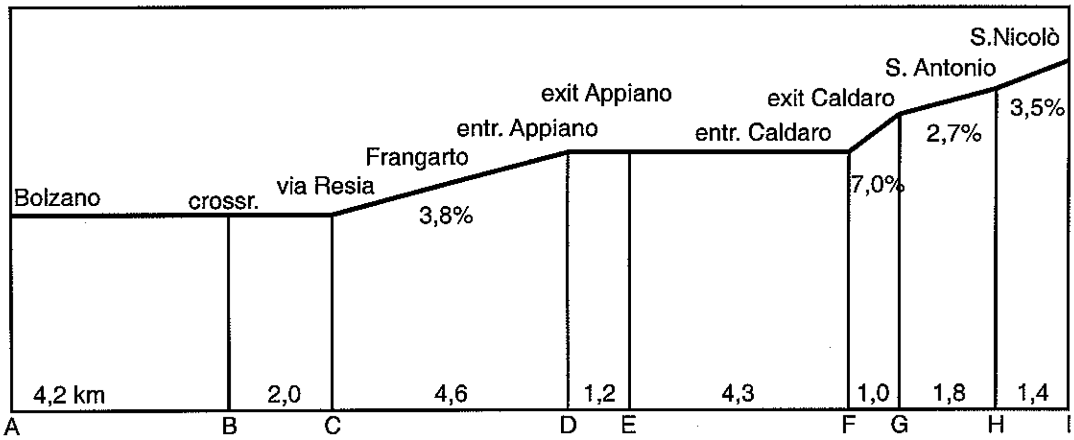
• The terminal is only 20 km away from Bolzano. In case of emergency the bus can be quickly reached from the depot;

• The line also has some sloping stretches. This makes it interesting because the bus can be tested to verify its performance driving uphill and the charging of the battery while driving downhill.

• The towns serviced by this line currently have traffic limitations so it was all the more important to drive through them without polluting.

During the test drives the battery charge status was monitored and registered in tabular form.

Fig. 29. Schematic Profile of Test Course 1



Test Drive Results of November 20, 1998

Outward Journey

Position	Distance in km	Drive Mode	Battery Charge Status in %
A	4.2	B	98
B	2.0	L	77.6
C	4.6	L	
D	1.2	B	90
E	4.3	L	86.4
F	1.0	B	91.5
G	1.8	L	85
H	1.4	L	79
I			84

Return

Position	Distance in km	Drive Mode	Battery Charge Status in %
I	1.4	B	84
H	1.8	B	84.2
G	1.0	B	84
F	4.3	L	83.9
E	1.2	B	88
D	4.6	L	82
C	2.0	L	92
B	4.2	B	95
A			79

Test Drive Results at the End of the First Journey
Outward Journey

Position	Distance in km	Drive Mode	Battery Charge Status in %
A	4.2	B	77.5
B	2.0	L	54.3
C	4.6	L	
D	1.2	B	71
E	4.3	H	68.3
F	1.0	H	77.4
G	1.8	H	74
H	1.4	H	74.3
I			73

Return

Position	Distance in km	Drive Mode	Battery Charge Status in %
I	1.4	B	73
H	1.8	B	73.5
G	1.0	B	74
F	4.3	L	75.6
E	1.2	B	84.6
D	4.6	L	77
C	2.0	L	85
B	4.2	B	88
A			73

Test Drive Results of November 23,1998
Outward Journey

Position	Distance in km	Drive Mode	Battery Charge Status in %
A	4.2	H	99
B	2.0	H	84
C	4.6	H	
D	1.2	H	81.5
E	4.3	H	76.5
F	1.0	H	75.5
G	1.8	H	76
H	1.4	H	74.8
I			73.8

Return

Position	Distance in km	Drive Mode	Battery Charge Status in %
I	1.4	H	73.8
H	1.8	H	78.2
G	1.0	H	81.0
F	4.3	H	84.0
E	1.2	H	85.4
D	4.6	H	80.0
C	2.0	H	88.0
B	4.2	H	84.0
A			66

A total of 4,500 km were covered during the test drives including the stretch from the workshop in Plauen to Bolzano for its consignment.

Second Test Course

The second test course to be chosen was that of the Grödner Valley. The stretch is 9 km long and it connects St. Ulrich (1,200 m a.s.l.) with S. Cristina (1,380 m. a.s.l.) and Selva and ends in Plan (1500 m a.s.l.). It has an average gradient of 3.8% with peaks of 12%. This line was chosen to put the bus to the test at relatively high altitudes and on difficult terrains. The bus passed the test satisfactorily.

Fig. 30. View of the Grödner Valley (Val Gardena) and the second test course.

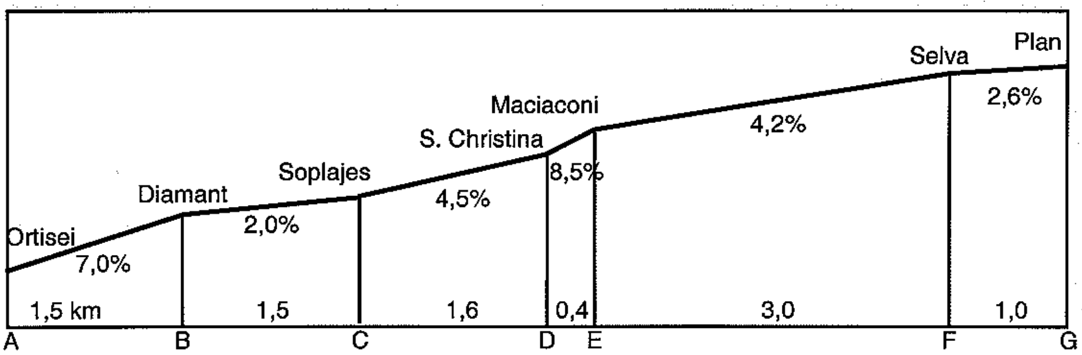


Fig. 31. Schematic profile of testcourse

Outward Journey starting from Plan

Position	Distance in km	Drive Mode	Battery Charge Status in %
G	1.0	B	99
F	3.0	B	96
E	0.4	B	88
D	1.6	B	90
C	1.5	B	85
B	1.5	B	80
A		B	84

Return starting from Ortisei

Position	Distance in km	Drive Mode	Battery Charge Status in %
A	1.5	H	84
B	1.5	H	80
C	1.6	H	78
D	0.4	H	81
E	3.0	H	84
F	1.0	H	86
G		H	87

Service

First Service Line

Public service was started on the aforementioned line on February 14, 2000. The bus covered this stretch twice a day from Monday to Friday for a total of 96 km a day including the drive to and from the depot (including the journeys to the workshop). This service continued with a few interruptions until June 16, 2000. By this date a total of 4,656 km had been covered on this line.

Second Service Line

The bus was then used for tourist service in the Grödner Valley.

The bus was used every day from June 26, 2000 to September 7, 2000. A total of 2,819 km were covered.

Third Service Line

As of the 2nd of October the bus is being used again on the first service line.

Energy Consumption

In order to assess the energy consumption a similar bus was made available by the Neoplan firm for a comparison. This bus was used on the same line. The monitoring was carried out for three weeks for normal passenger service. The results are summarized in the table below:

	Neoplan N 8012 Hybrid Bus	Neoplan 314 K
Length	10.60 m	11.00 m
Total Passengers	66	69
Sitting	26	47
Standing	40	22
Heating/Cooling	Forced air	Air conditioning
Engine	MAN (Euro II)	OM 441 LAI/11 (Euro II)
Power	190 KW	250 KW
Consumption	21.8 l/km	32.3 l/km

The aforementioned data show that the diesel consumption of the hybrid bus with the same performance is about 33% lower than a normal bus. It must be borne in mind that the battery was charged at the depot on average with 10 kWh every night.

Exhaust Measurement

The opacity of the exhaust was measured: the results showed a K value between 0.34 and 0.38, i.e. below the required threshold of 0.40.

SAD

4.4 Operating History UB - ST

Malmö-Uppsala Neoplan MIC 8012 GE

The project started in mai 1996 with the compiling of a complete specification of the vehicles. Two buses for Malmö, two for Uppsala and one for Bolzano.

An absolute condition for Skånetrafiken and Uppsalabuss for participating in the project was that special environmental considerations had to be acounted. This ended in that four of the buses were equipped with bio gas powered engines.

The specification for the Swedish buses and the Italian become relatively different when the bus for Bolzano remained eqipped with a dieselengine.

New technology

The new technology demanded a design specification in two parts. One consisting of conventional bus components, and one with of all the new parts.

The parts belonging to the group of innovative engineering "Innovative Teilen" had to be able to be followed up during the project.

A routine was created with a certain form called "Ausfallmeldung". Whenever a fault was discovered with any of these parts, the operator had to send this form as a report, within 24 hours, to all parties in the project. In the form the operator specified if respectively manufacturer had to be consulted or local help was enough to solve the problem.

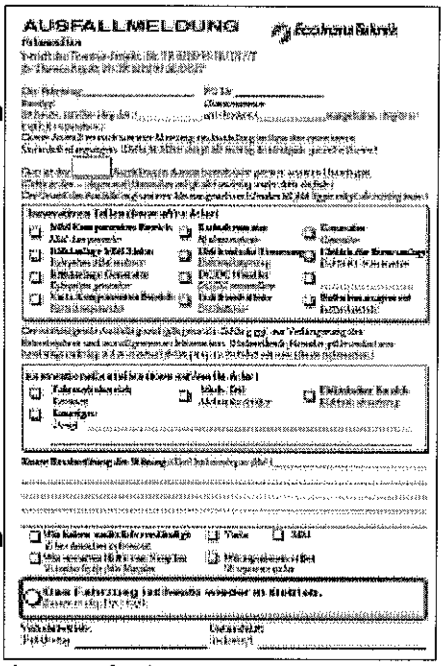


Fig. 32.

Test drives

The technical solutions in the bus design are unique and are characterized as prototypes. According to agreement with Neoplan every bus was to be tested for 5 days in simulated city traffic in Plauen, where the manufacturing took place, before the bus was approved for delivery.

Problems found during the test drives have been taken care of by the manufacturer whereupon a new test period has started. This means a large number of test drives have taken place since several systems and components have had introductory faults.

The testdrives have been recorded and later discussed at several meetings with the production management at Neoplan, Plauen and also with the design department in Stuttgart.

The intention have been to eliminate as many faults as possible and to avoid similar problems in the following buses in the production line.

The systems in the bus have proved to be very complex. It was very hard to carry through a complete test period without problems. Some 30 initial remarks from the test personell was attended to, little by little. Problems that should have had to been taken care of later, were already attended to at the production site.

The test period extended over a period of a hole year, and some 20 test drives. This delayed the start of the project, but at the same time were the systems in the bus developed further which gave a better base for the coming use of the bus.

All test drives have been made with drivers from Linjebuss in Malmö and Gamla Uppsalabuss AB in Uppsala. Also representatives from Länstrafiken Malmöhus, AB Uppsalabuss and accasionally from Neoplan Omnibus GmbH i Plauen and Svenska Neoplan AB, Stockholm have been present. If needed also from Magnet-Motor, Varta or Cummins.

Delivery

The first bus was delayed and delivered first the 10th of mars 1998, but it was approved by the Swedish authorities first the 10th of june 1998.

It was put in regular traffic the 25th of june 1998. After three days and 650 km it was completely destroyed by fire, starting in the exhaust system.

This led to a return of the other three buses 1998 for mayor redesign of these parts, which further delayed other parts of the project. The destroyed bus could not be rebuilt in time to take part in the project.

Malmö and Uppsala

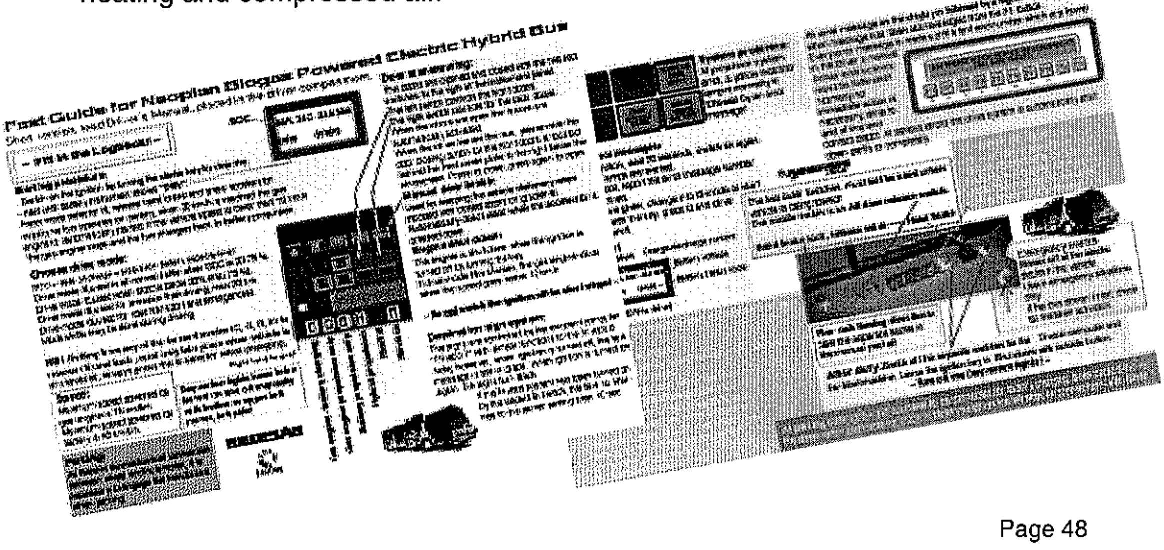
The intention was from the beginning that two experimental hybrid buses should be able to replace one standard bus. In Malmö only one hybrid bus was available.

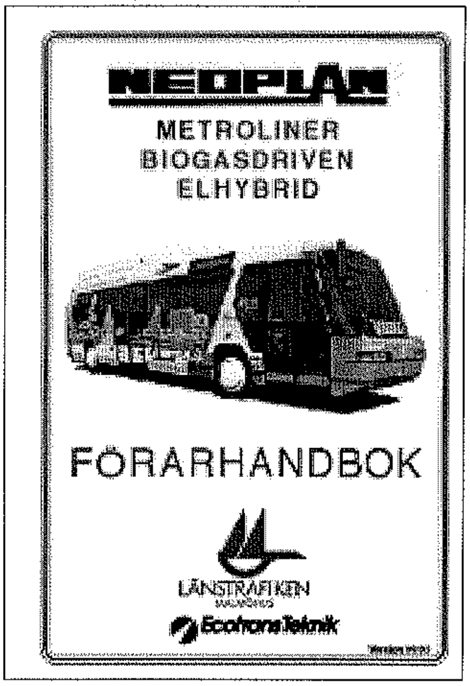
In Uppsala both hybrid buses have been in normal operation, but they also with an accessibility less than 50%. The expectation that a hybrid bus could have an accessibility of 50% has not been fulfilled. All buses have had severel system faults and even "normal" mechanical faults in the conventional bus components.

The accessibility has not even reached 20%.

The bus in Malmö is used on a route between the Central station and a fair at the new Øresound Bridge abutment. The passengers are mostly tourists and the numbers in the bus vary from some 60 passengers (full bus) to only a few.

The bus is at night parked on a designated spot in the depot with supply of methane gas, electricity for charging of the 24V and 400V systems, for additional heating and compressed air.





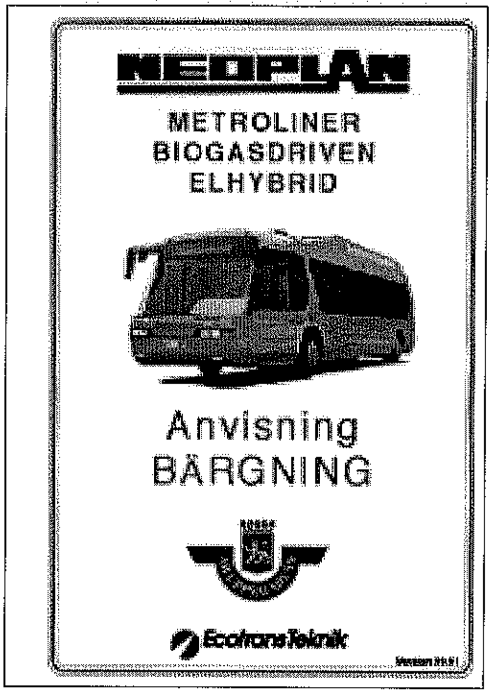
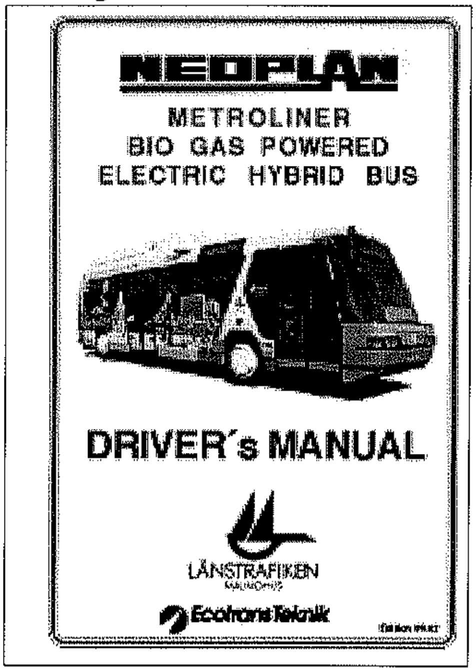


Fig. 33.



Drivers instructions

The routine for the driver at start is to disconnect all external lines, check gas supply and voltages, and await go-ahead from the computers.

A complete Drivers Manual hav been put together to the drivers help at any uncertainties. Furthermoor have short lealets been produced for easy help during driving.

To increase accessibility have following measures been taken:

1. A small group of designated driver have been appointed for the bus.

2. A special training program with theoretical and practical parts have been accomplished for this group.

3. A technical training program have been carried through with bus mechanics from Malmö, Uppsala and Bolzano. Here have also representatives from Neoplan, Magnet-Motor, Varta and Cummins taken part. As a result of this a the creation of a network between personell from the bus operator and the different manufacturer.

4. The driver is obliged to fill in a Log book with data concerning the drive.

5. Experts from the Departement of Industrial Electrical Engineering and Automation at the University of Lund have taken part in solving problems in the electronic systems.

6. Service agreements have been concluded between the operators and Magnet-Motor and Varta.

Experiences from the operations in Malmö and Uppsala

During the initial driving in normal city traffic operation many small irritating faults appeard, originating from standard bus components, such as when the lock on a battery hatch opens itself, a microswitch indicates “open hatch” and the entire electronic system break down without any message to what is the cause.

Furthermoore the bus is consuming so much power from the 24V system for the different subsystems, that the supply from the generator sometimes is not enough. The voltage in the 24V batteries could sometimes fall to a level at which the computers didn´t work (a level as high as 22V), and the bus was unusable. The 24V batteries had to be charged every night.

The innovative parts have performed well in their mechanical parts as electric wheel motors, engine-generator and drive battery. The electronic managemant sytems however had to be regarded as prototypes and as such not functioned properly.

Partly the systems have had the quality of laboratory production and thereby could not manage the harsh environment in a bus. Partly they wasn´t developed enough in the beginning, something that have giving us a lot of faulty functions and non operationable bus. During the project much of this have been corrected by the manufacturers but not all.

During the latter part of the “Monitoring Phase” the accessibility has been increased considerable for the buses, both in Malmö and Uppsala, today it exceeds the stipulated 50% level.

With increasing accessibility and a more continuous operation, the confidence of the drivers also have increased, they see them today as environmentaly friendly public transport vehicles, dependable enough for their purpose.

The passengers note positively the new environmental profile the buses represents and should very much like to see an increased number of hybrid buses, later on developed into fuel cell powered electric buses.

4.5 Performance – Emission measurements

In co-operation with Skånetrafiken, Volvo Aero Corporation in Malmö has built a test hall for measuring heavy vehicle emissions. The tests are carried out on a chassie dynamometer with emphasis on repeat perforformance abilities and quality testing of a number of fixed load points.The test results are not directly comparable to results from other test routines or other test cycles.

To make a large number of tests possible on different groups of buses a simplified testing scheme has been produced to register CO, HC, NOx and smoke emissions and to control the fuel consumption.

Measuring environmentally friendly characteristics of a combustion engine is normally a question of test bench procedures. The 13 fixed load point ECE R49 standardized testing protocol is often used. An alternative to engine bench testing is characterization on a chassiedynamometer. Such a testing mode has several advantages, specially from a purely practical point of view as the the engine functions constitute only one part of an entire system.

There are static as well as transient testing modes, some more some less established. There are, however, no unambiguous testing modes or standardized testing models established at hand.

The realization of the tests is attached to the fixed load points along a road weight curve. The setting of the chassiedynamometer load is carried out in two steps. Testing procedures include speeds up to 60 km/h. A load setting of 10 and 20 kW on the chassiedynamometer respectively corresponds to a power outlet to that of the Malmö city traffic.

Emissions are registered at set load point. Levels regarding carbonmonoxide (CO), carbondioxide (CO2) nitric oxides (NOx), hydrocarbons (HC) and smoke density are established. The measured fuel consumption provides the basis for an emission exchange rate conversion into an emission/time unit and distance covered respectively. To obtain a high degree of repeat performance ability the tests were always set at fixed gear shift modes/engine speed.

By making our own tests we found out that the emisissions varied considerably depending on vehicle speed (engine speed/power loading). Emissions reached peak values at low speed and subsided to a relatively even level at speeds over 50 km/h.

The results clearly show how well the hybrid electric bus operates in an environmentally friendly manner. It should be pointed out though that a standard bus can carry more passengers.

4.5.1 The Malmö Emission Measurements

Emission tests were made in the Malmö bus in traffic.

The tests were made by Volvo Aero Corporation (VAC). The results showed that comparisons can be made as VAC has made a number of previous tests on different buses and fuels on behalf of the Skåne Region Public Transport Corporation. The tests were carried out according to a simplistic measuring cycle called the "Malmö-cycle". The CO-, HC-and NOx emissions including smoke and fuel consumption were measured at idle and at 10, 20, 30, 40, 50 and 60 km/h respectively.

The measuring tests were made at set speeds and not during transients, which means the tests were carried out at set engine speeds and power effects and cannot set a standard on real life emissions, they only compare vehicles and fuels at similar testing situations. The electric hybrid bus results give an even worse picture of the real conditions as the brake regeneration gives positive transient properties which don´t show in the test results. The results may nevertheless be of interest as certain characteristics can be elucidated.

Sadly the results were worse than expected and i.a. we found out that the catalyst had crashed, a phenomenon which happened to all the electric hybrid buses. As the gas engine works according to the lean burn principle the HC and CO figures should have been lower due to lack of a functional catalyst. The test results showed high NOx -emissions, possibly due to the fact that the engine monitoring had been given too low a Lambda setting. The Lambda figures ranged between 1.1 to 1.4, which naturally results in high NOx-emissions. A better setting for operational purposes would have been 1.5.

As the engine seemed to have so many faults at the time of testing, it seems the actual test results were of less interest than the fact that the electronic engine monitoring device were unable to provide acceptable figures at the power- and engine speed points the engine normally work at in a hybrid application. As usual the manufacturer has constructed an engine, adapted for a measuring cycle rather than real live bus operations, and as the standardized measuring cycle doesn´t reflect reality in itself, hence the result.Not until a higher engine speed than expected the emissions showed really low values.

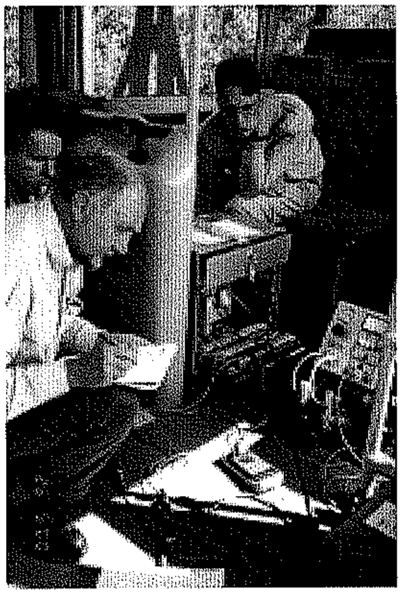


Fig. 34. Ass prof. Bengt Simonsson and grad.stud.Christian Andersson, LTH/IEA and eng Alf Andersson, Volvo Aero during data collecting.

The diagrams on the following pages show measured emission results for city buses with alternative fuels as well as the electric hybrid bus. Please note the electric hybrid bus changes into battery propulsion at speeds lower than 20 km/h.

The changeover from battery propulsion to engine propulsion takes place in two ways; method one is to allow the engine to idle, method two is to stop the engine completely and then start up via the generator when the speed has reached the set value.

Which one of the two methods has the lowest emissions has been discussed, as the engine starting phase normally gives high values.

Equally results showed this is the case, but when tests were made over time it became clear the total amount of emissions were less if the engine were to be stopped. Hence it was important the engine was shut off at bus stops, as this is the time people come really close to the bus.

The Test Equipment
Emission test equipment type HORIBA PG 250 serial no 6907006 (Turbec)

Equipment maximum measuring capacity:

NOx	0-2500 ppm
CO	0-5000 ppm
SO_2	0-3000 ppm
CO_2	0-20 vol %
O_2	0-25 vol %

HC 0-10000 ppm. Make Bernath Atomic Mod BA 3006. (FID)

Remaining test signals were collected by a test sampling system set up in the bus by the Lund Technological University (LTH). The sampling frequence was 5 times per second. In order to feed the electric equipment the instruments were connected to a power generator.

Methodology
To equal previous chassie dynamometer tests as much as possible,these tests were run on a non gradient even road surface. The two direction tests were repeated.

Starting from a bus stop standstill the bus accelerated to about 40 kmh. Test samples were collected for 40 seconds.

Tests Carried Out
The testing procedures contained two different types of tests.

- Steady state driving at different speeds, 0 to 70 km/h in steps of 10.
- Starting up tests from bus stop.

The latter tests were carried out in three different ways:

1. The bus accelerates to 20 km/h when the engine starts. Engine almost cold after about a one hour standstill.
2. The bus accelerates to 20 km/h when the engine starts. Engine warm as it has been in operation before starting off.
3. Engine in idle during acceleration up to 20 km/h when the engine starts operating.

The Results
The idle and even speed tests showed that power to the wheel hub electric motors amounted to about 40 kW at 70 km/h, while engine speed varied between 800 and 1600 rpm. Fuel consumption was estimated to about 1,5 kg/10 km which corresponds to a diesel engine consumption of about 2 liters/10 km .

The idle and even speed emission tests showed generally high emissions results. Average means were: HC=8 g/h, CO=26 g/h NOx=23 g/h. The corresponding means for a Volvo catalyst gas bus are ca HC=10, CO=2 and NOx=2 g/h.

At even speed emissions were high, too. Over a larger section of the operational field the electric hybrid bus regulations gave a Lambda setting between 1.1 and 1.4, which mainly contribute to the high NOx results. The measured Lambda value is based on saturated emissions which provide an irregularity of about +/- 0,1 but even such a slight misreading shows the engine is run on too rich a fuel mix for a lean-burn engine. Not until speeds round 70 - 80 km/h the Lambda value starts closing up to 1,5.

The NOx-formation is at its highest round Lambda 1.1. A Lambda of about 1.5 +/ - 0.1 is most favourable from a NOx-point of view. From a driving point of view there are deviations.

SO_2 During the tests SO_2-contents of 40 to 100 ppm were recorded which might chemically damage the catalyst.

Starting from a bus stop

- The first test was made with a half warm engine.

At speeds up to 20 km/h no emissions were produced as the engine was shut down. The recorded emissions were guaged during 30 out of the 40 seconds the test lasted.

- The second test was made with a warm engine, otherwise like above.
- Third test was made with an idling engine.

The results show the lowest HC figures with a warm engine starting at 25 km/h. The CO figures give no clear-cut pattern. The NOx-figures were at their lowest at a cold engine start up.

The total fuel consumption during the 40 second test reached a peak value of 98.4 g when the engine was idling and a minimum of 48.1 g with a warm engine start up. Figures regarding cold start up were so high they couldn´t be measured , which may well be in concordance with case 3, idling.

Studying the three different starting up methods shows a clearly natural HC-peak at the 'cold start moment'. The fact that the CO-emissions reach a peak during a warm engine start up is however, not self-evident. The total NOx-value reaches a peak in test three, with an idling engine, which can be partly explained by the fact that the engine produces NOx during the entire starting up phase.

Starting from a bus stop is best carried out by an engine at standstill, which starts driving at 20 km/h.

Comments

Studying the test results the first reaction is that the emission figures are unusually high. This is, however, not representative for gas engines generally but should be seen as a result of an incorrectly tuned engine. The conclusion to be reached is that the engine isn´t performing good enough as a gas fuel engine.

A correctly tuned gas engine will give considerably lower NOx-figures, about 1/6 lower. However it isn't possible to adjust the regulation technique and the emissions without access to proper software and emission test equipment.

Despite the lack of catalyst and an incorrectly tuned engine, the emissionfigures are no higher than what is normal for a diesel engine. Correctly tuned, the level would have been below that of the blue curve of the charts on the following pages, as these represent figures from a considerably larger gas engine.

Furthermore, the engine is not completely adjusted to electric hybrid propulsion. The conclusion is that a correctly adjusted engine, optimated for a complete and total electric hybrid system should give considerably better results.

Charts

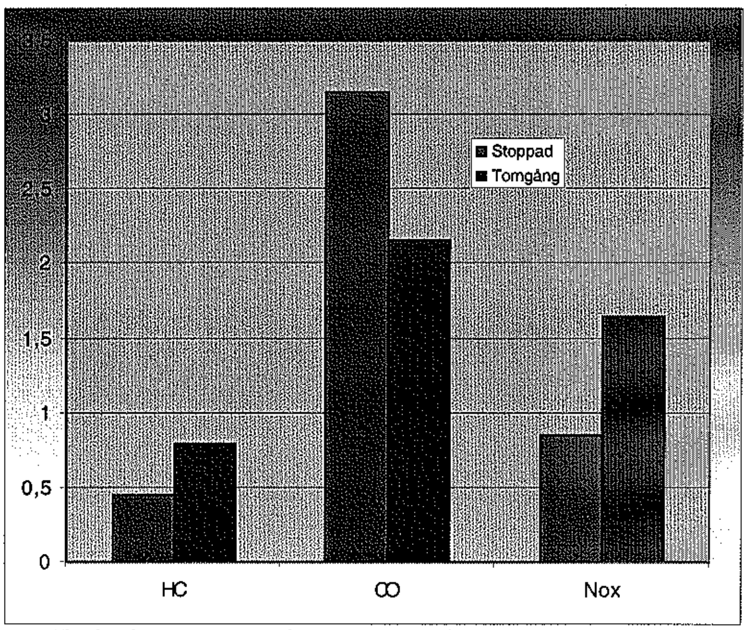


Fig.35. Emissions comparison at start from standstill up to 40 seconds after start with engine switched off respectively idling at start. NB time spent at the bus stop has not been included, if so had been the case the difference would have been even greater. The high CO figures were caused by a crashed catalyst. Unit gram.

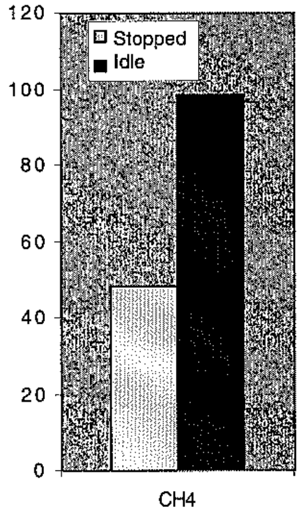


Fig. 36. Fuel consumption comparison starting at standstill until 40 seconds after start with engine switched off respectively idling at start. NB time spent at the bus stop has not been included, if so difference would have been greater. On some routes the bus stands still some 40% of the turnaround time.
Unit gram - CH_4 - Methane consumption..

The data material in the following charts stems from a long series of emission tests regarding citybuses powered by alternative fuels. The tests were carried out by Länstrafiken Malmöhus.

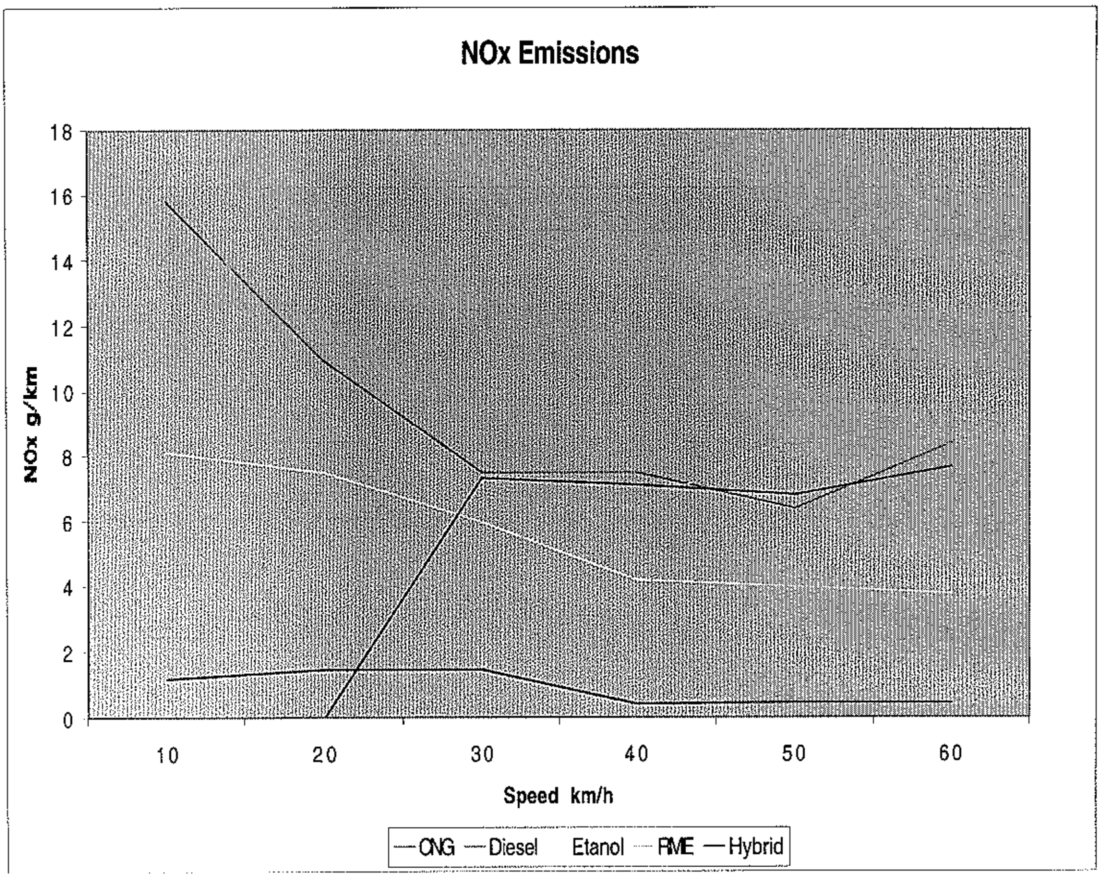


Fig. 37. NOx ; comparison between emissions from different buses and fuels.

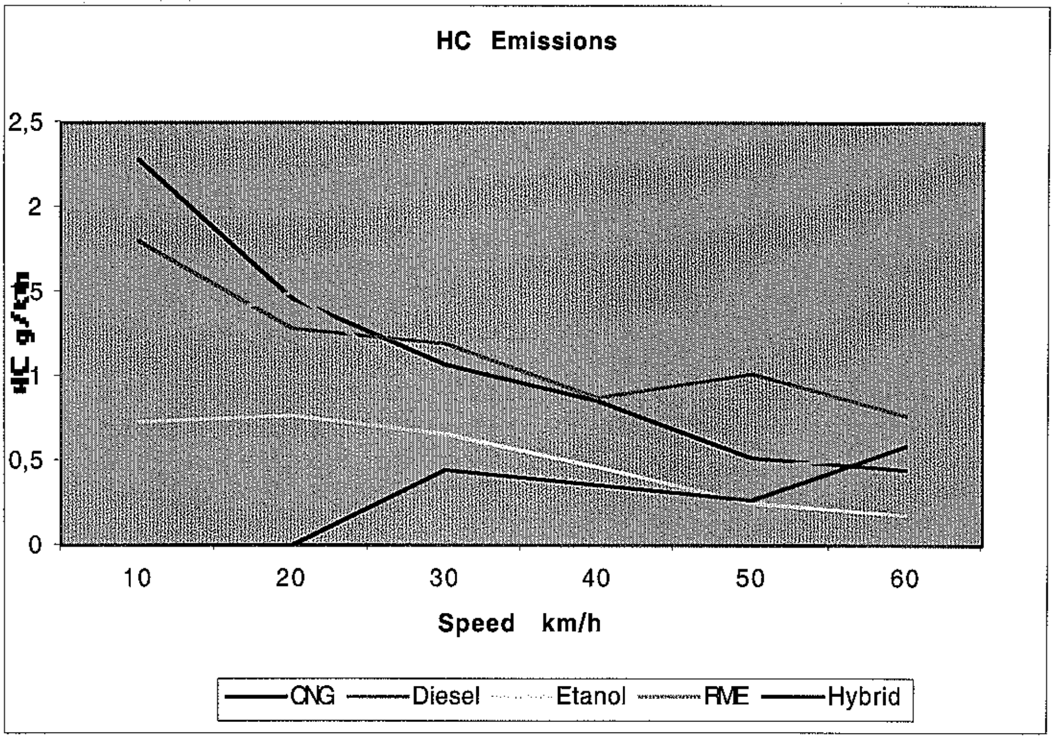


Fig. 38. Hydrocarbons HC; comparison between emissions from different buses and fuels.

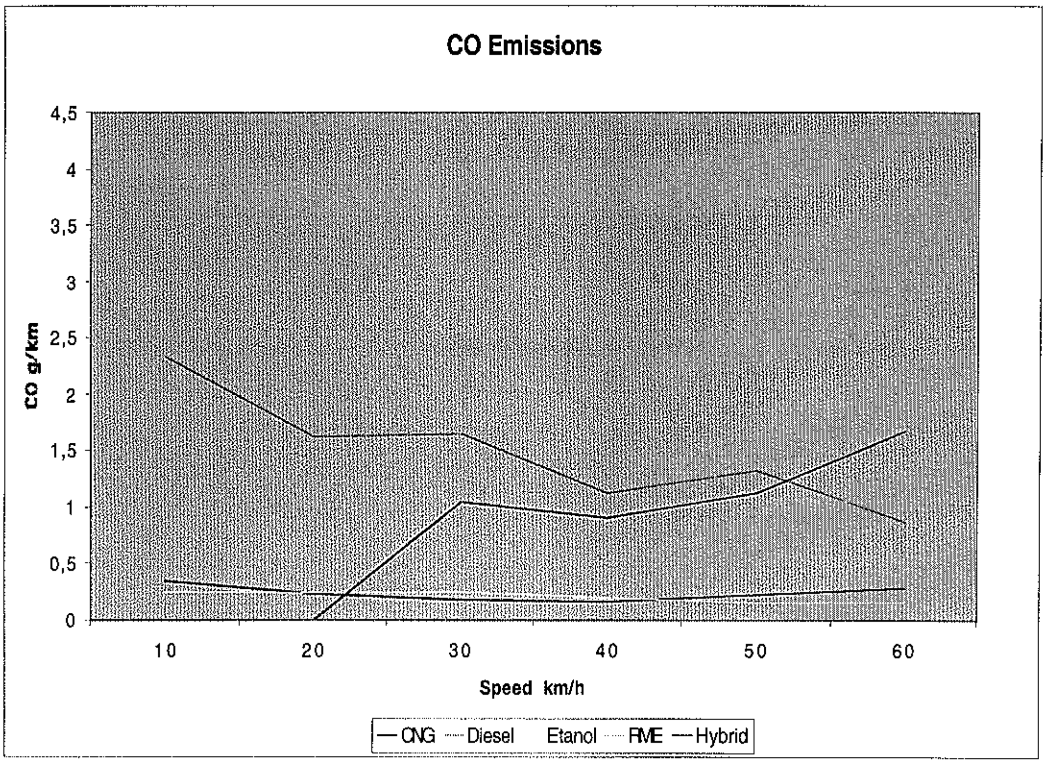


Fig. 39. CO; comparison between emissions from different buses and fuels.

Power and Gas consumption
Average values from two test

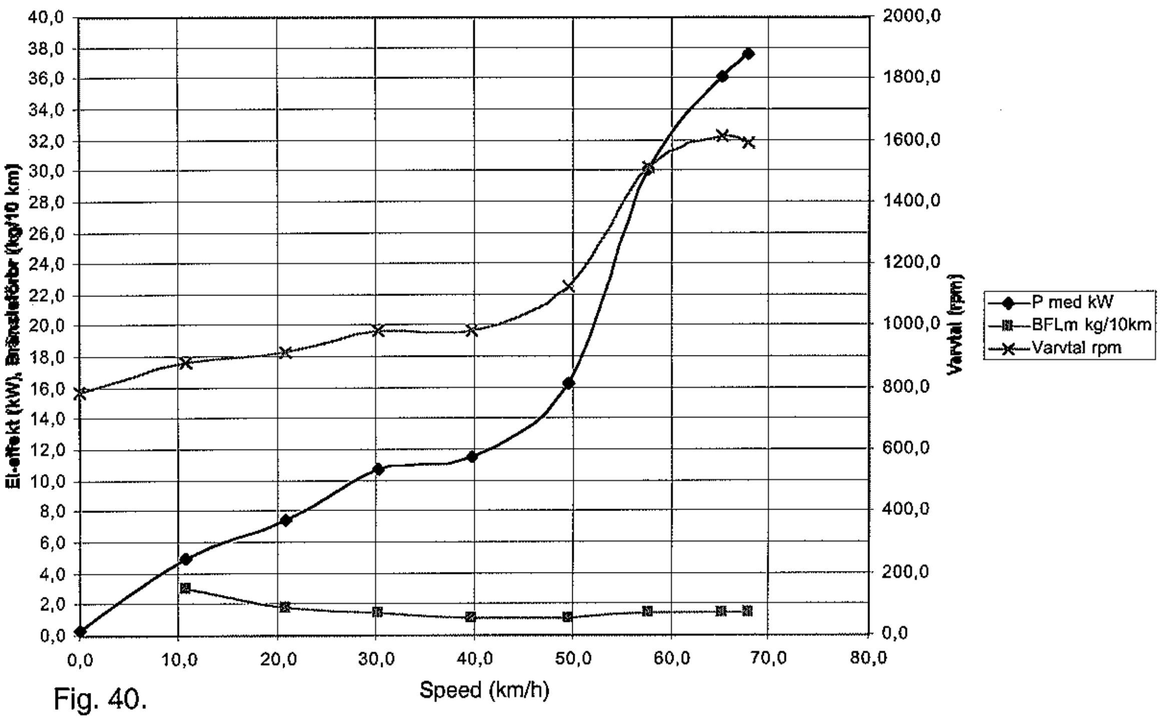


Fig. 40.

Emissions in g/h in relation to Speed
Average values from two test

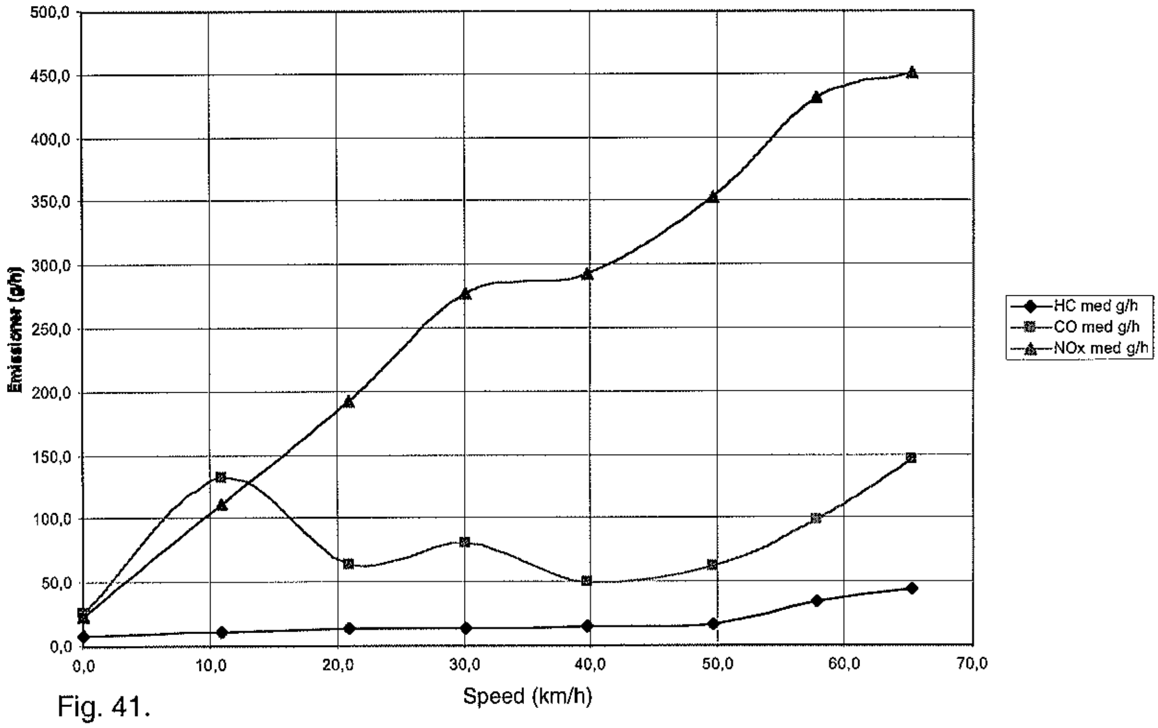


Fig. 41.

Comparison Volvo Gas buss 316 (with cat)
and Cummins Gas Engine in the hybrid bus

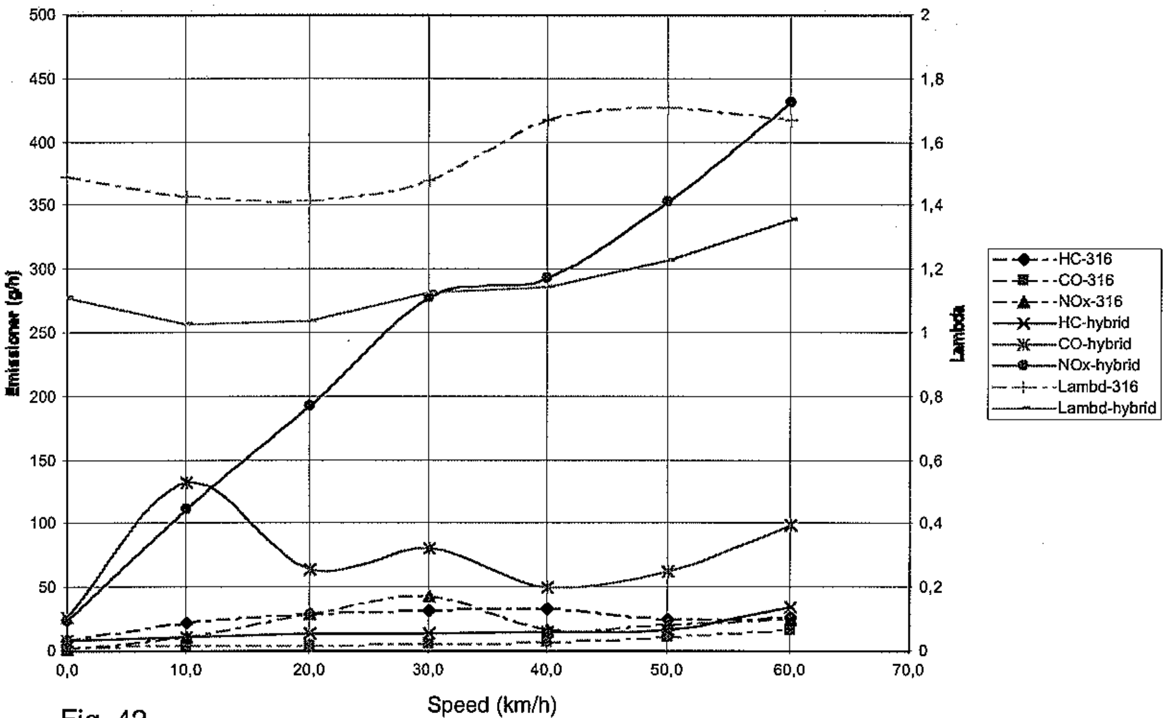


Fig. 42.

Emissions in relation to Lambda
Average values from two test

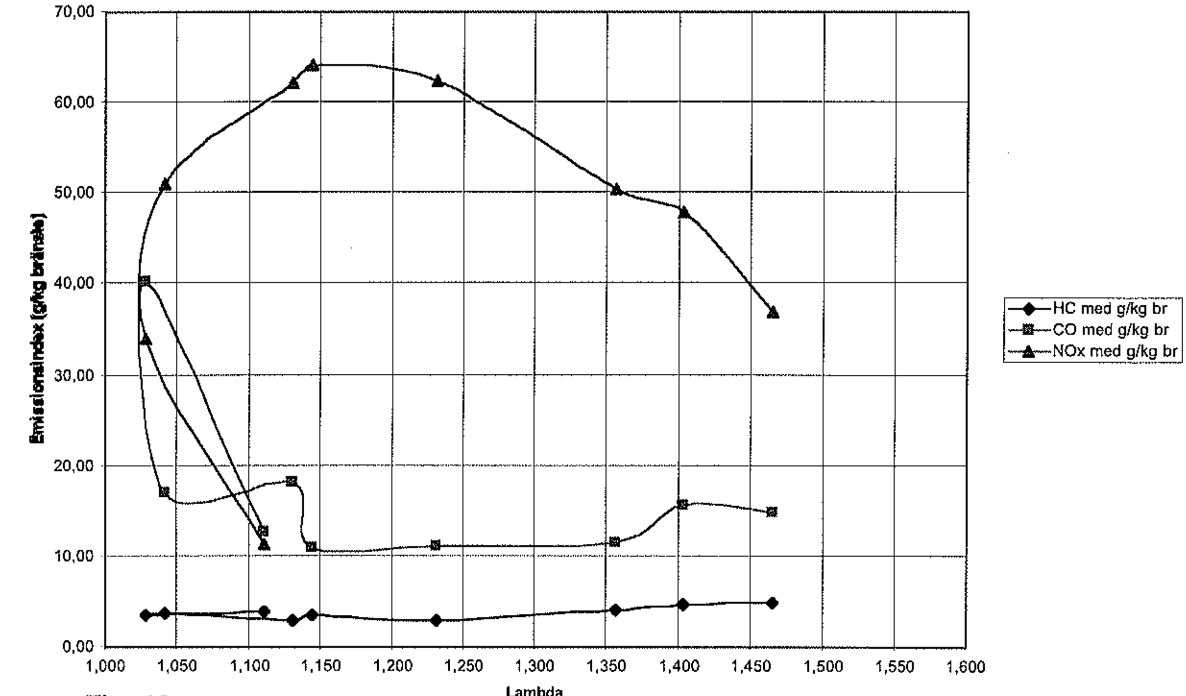


Fig. 43.

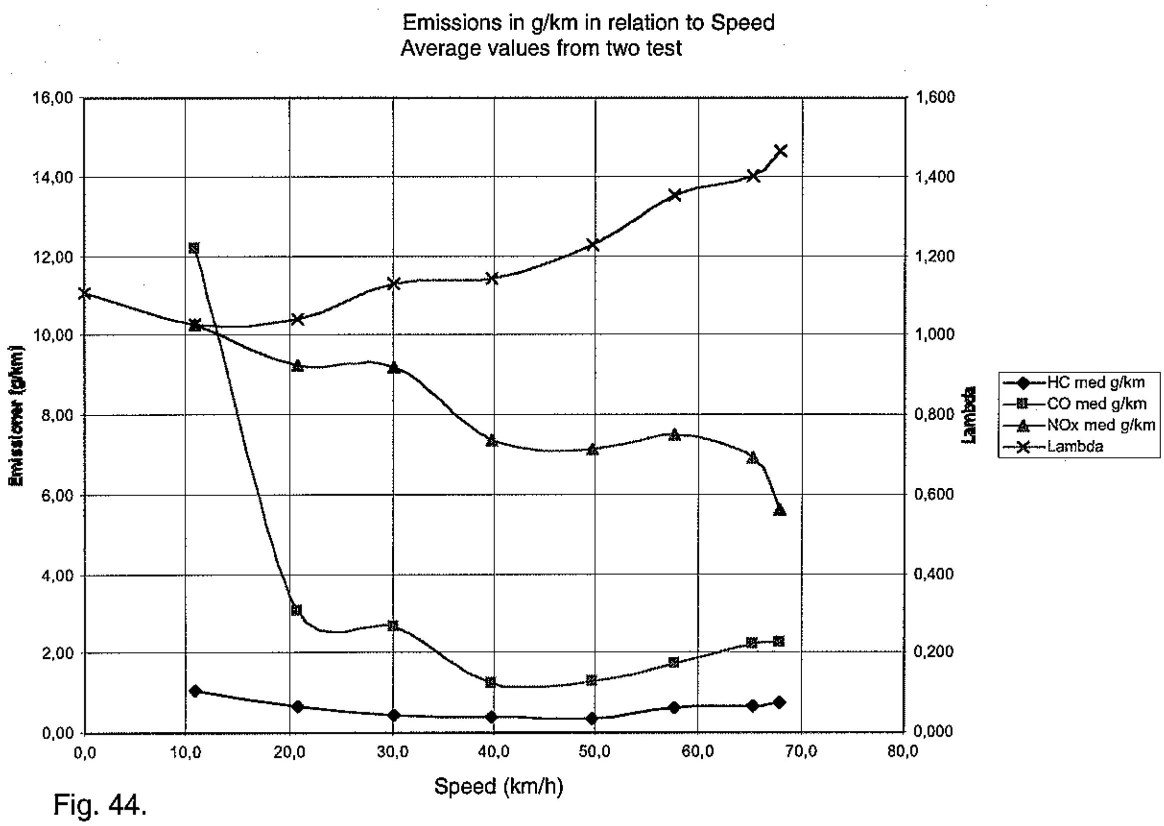

Emissions in g/km in relation to Speed
Average values from two test
Emissioner (g/km)
Lambda
Speed (km/h)
16,00
14,00
12,00
10,00
8,00
6,00
4,00
2,00
0,00
1,600
1,400
1,200
1,000
0,800
0,600
0,400
0,200
0,000
0,0
10,0
20,0
30,0
40,0
50,0
60,0
70,0
80,0
HC med g/km
CO med g/km
NOx med g/km
Lambda

Fig. 44.

Start from 0 with engine stopped

Varm engine

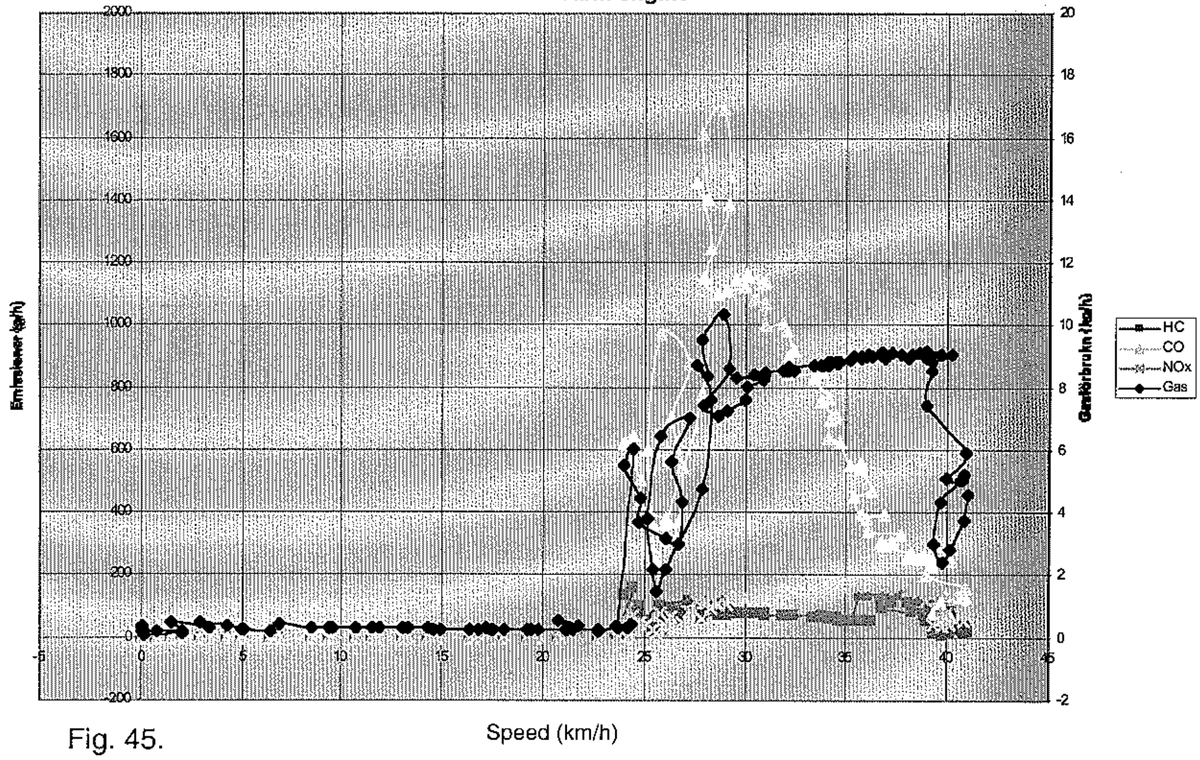
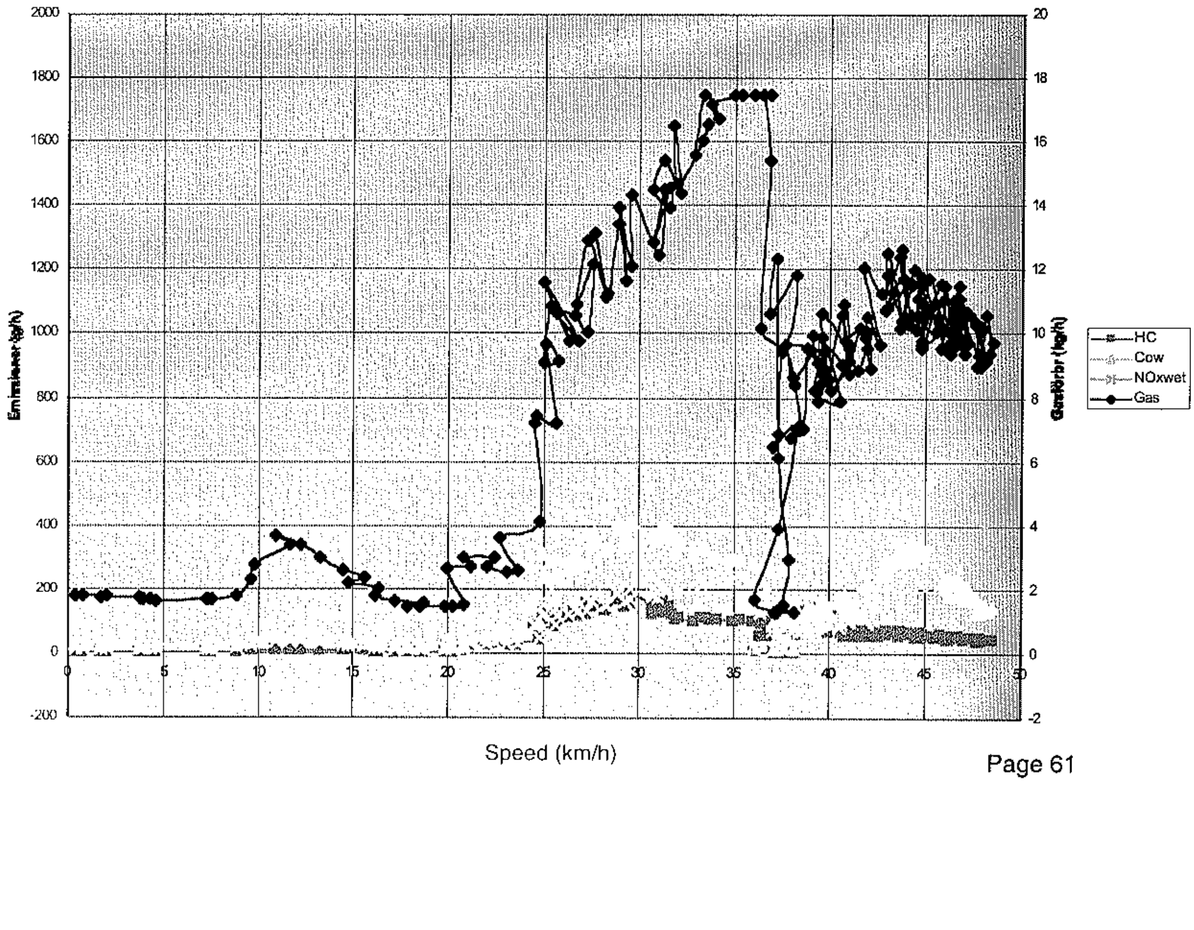


Fig. 45.

Fig. 46.

Start from 0 with engine in idle



4.5.2 Noise Measurements

The current noise measurement norms were set up to measure road traffic truck noise. As regards a modern city bus the dominating sound sources are sounds from tyres, transmission, wind rush etc at about 40 km/h, not the engin.

The norms still prescribe measurement of when the bus accelarates at full speed along a 20 m long measuring stretch starting at 50 km/h. A situation, it should be pointed out a normal city bus almost never comes near.

Due to the fact motor sound and vibrations are reduced from a change from diesel to gas power, the differences cannot be measured by standard norm methods. Particularly as the real difference is felt the strongest – inside the bus and especially at a stand still or idling and – from outside when the bus starts from standstill after a bus stop, a red light shift to green or at cornering. This is particularly noticable in narrow streets.

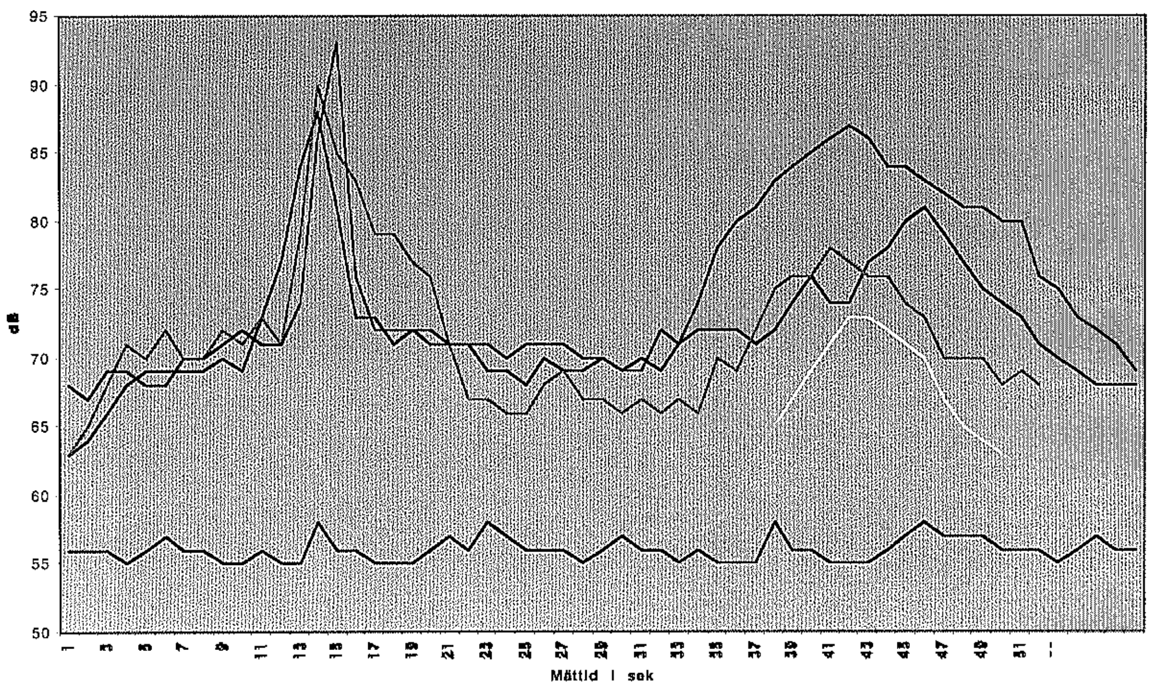
Another kind of unpleasantness in city bus traffic is the break squeaking noise at stops which has increased in later years due to changes in the break constructions. This kind of noise is completely non-existing in the electric hybrid bus as it is stopped electrically via a break effect regeneration system almost until a complete standstill.

In order to get a picture of how "bus noises" are felt in a narrow street situation a series of noise measurements have been carried out in a narrow Malmö inner city street, where there is city bus traffic only.

The measurements regard noise as perceived by people waiting at bus stops when a bus departs. No interior measurements have been carried out. .

The results shown in the diagram speak for themselves.

Fig. 47. Dieselbuss — Gasbuss — Hybridbuss motor — Hybridbuss batteri — Dieselledbuss — Ingen trafik



Catalyst Temperatures

Discussions regarding the importance of the catalyst in the Cummins 6 litre lean burn gas engine (for the NE8012 bus) were raised. For that reason the catalyst temperatures have been measured under different operational conditions.

Instrument Placement

Two thermoelements were mounted ca 10 cm before and 10 cm after the the catalyst, respectively, on bus UB 0021. The element points were centred in the exhaust pipe. The element voltage was measured under varied operating conditions by a digital voltmeter with a resolution of +/- 100mV. The element sensitivity is 41mV/ °C. The measurements were carried out without any particular temperature reference. The surrounding temperature was ca +15 °C.

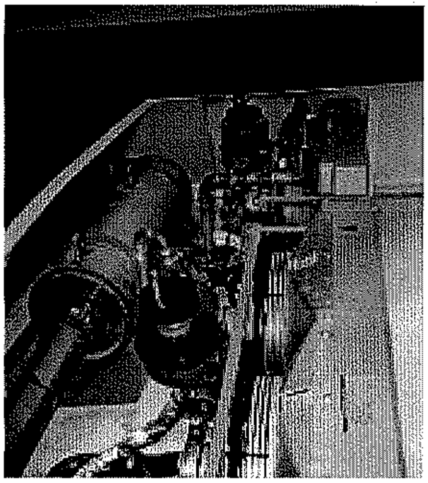


Fig. 48. The catalytic converter on the roof.

Measurement - Idling

The engine was idling before the temperature equilibrium was set. After about five minutes of operation stable conditions were established. Final temperature was ca 210 °C.

Measurement - Normal Driving

With the bus driving in gas propulsion mode the test took place in an industrial estate. Incoming gas temperature varied with the engine load between 310 to 350 °C. After about 3 to 5 minutes drive the outgoing temperatures had reached the value.

Measurement - Hard Driving

The bus was driven in gas propulsion mode on a country road at full speed . Incoming temperature was ca 400 °C after a few minutes.

Measurement - Maximal load

Operating conditions with maximal load were simulated by running bus at full throttle at the same time as the brake was applied to limit the speed to ca 35 – 40 km/h. The highest recorded temperature was reached after ca 1 minute and amounted to ca 500 °C. When the bus afterwards was driven at normal conditions the temperature sunk to ca 350 °C within about 30 seconds. The temperature guage mounted after the catalyst had a higher timing constant.

Analysis

A reasonable deduction is that the exhaust temperatures are proportional to the given off power. Suppose the engine is run at full load according to the maximal load measurement above then the approximate average effect is ca 70% at normal drive, a reasonable figure considering engine power in relation to vehicle weight. The catalyst temperature is here ca 350 °C.

Conclusions

The highest exhaust temperature measured at maximal load was ca 500 °C. At normal driving the temperature is 300 – 350 °C.Normally the catalyst operating temperature ranges between 500 - 800 °C and if that is the case it is doubtful whether the catalyst can be expected to have any crucial effects on the emission figures.

Fig. 49. The inside of a [illegible]-way catalyst

The buses are equipped with lean-burn engines. To achieve low emissions, specially of hydrocorbon and carbon monoxide, a two-way catalyst is needed in the exhaust system. The Nelson catalyst with Engelhard fittings is mounted on the roof of the bus due to lack of space in the engine-room. The placement is not optimal as the catalyst requires relatively high temperatures to work as intended. The long exhaust pipe up to the catalyst has a considerable cooling effect.

The bus average power output is, furthermore, far too small to obtain the exhaust temperatures demanded for the catalyst to ignite and remain in function. Propulsion mode ´engine shut off´ at stand still hardly improves a possibility of a good catalyst functionability.

Tests in both Malmö and Uppsala shows that it is very difficult to make the catalyst work as intended. Temperature tests have shown that the temperature on the incoming and outgoing sides don´t differ, which leads to the conclusion that the catlyst probably doesn´t ignites and burns as it is intended. The mechanical firmness has, furthermore, proved to be too bad. All four catalysts have broken down mechanically. The picture above shows how it may look.

Awaiting the development of a more well adapted catalyst the project buses are now equipped with ordinary silencers.

It probably takes a pre-turbo mounted net catalyst to achieve the high catalyst temperatures needed to effectively burn the remaining gases and especially the sulphoric rests obtained from the mercaptan additive. At the emission tests sulpher was measured and even this tiny little remains of sulphur can quickly destroy the catalyst function.

4.5.4 Passenger Quality Experience onboard the Electric Hybrid Bus

Background and Aims

In Uppsala och Malmö a total of four Neoplan so called gas powered electric hybrid buses have been tested (two buses in each city) in a common evaluation project. The Principal Purposes of the study have obviously been focused on traffic operations and questions related to environmental matters.

Besides the above mentioned areas a preliminary study have been carried out. The purpose of this study was to find out how passengers experienced travelling on the Electric Hybrid Bus and how they look upon the AB Uppsalabuss commitment regarding environmental issues.

Method

During two weekdays in March, 2000, 119 passenger questionnaires were distributed and collected onboard the Electric Hybrid buses. Of the 119 people who answered the questionnaire ca. 30 were asked to complement their answers with regard to what they had said in the questionnaire

Operations results

Passenger structure

Table 1 - Distribution of sex

74 % were females 26% men

Table 2 - Distribution of age

Age	%
Under 29 yrs	43
Between 30-59 yrs	37
60 yrs or more	18

Table 3

Aim of the trip	%
To/from work	26
To/from school/university	25
Shopping	12
Other spare-time trip	8
Official business	6
Otherwise	23

For half of the passengers the aim of the bus trip was to travel to/from work or school

Table 4

How often do you travel by bus?	
Daily	50
Ones/sometimes per week	34
Ones/sometimes per month	8
More seldom	8

A fully 80% of the respondents are very frequent passengers, i.e. travel at least once a week or more.

Qulity Experienced
Table 5

Embarking/Disembarking the bus	%
Very Hard	3
Hard	3
Easy	43
Very Easy	51

A large majority of the passengers, 94%, experience it as easy or very easy to embark or disembark the bus. Looking at the various age groups 10% of the 60+ group finds it hard to get on/off the bus. See figure below.

Fig. 50: Getting on the bus

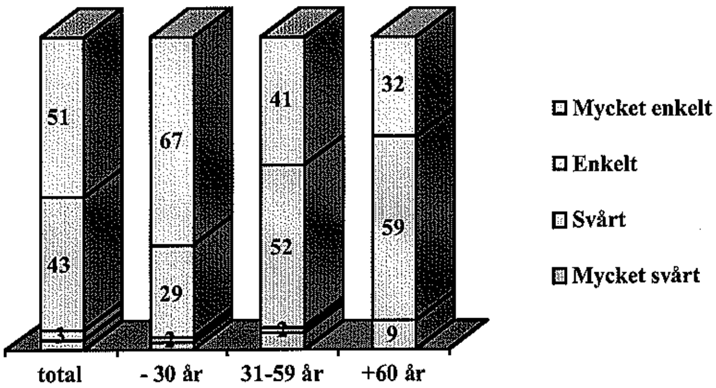


Table 6 – Getting seated	Total	- 30 yrs	31-59 yrs	+ 60
Very Hard	2	2	2	
Hard	5	2	7	9
Simple	55	49	59	64
Very Simple	38	47	32	27

It is noticable the +60 group finds it difficult to walk fram the driver to the passenger seat.

Table 7 (a-d) – Seating comfort
Tabell 7a –

Leg space	Total	- 30 yrs	31-59 yrs	+ 60
Very Poor	8	6	14	
Poor	24	27	27	9
Good	51	47	50	64
Very Good	18	20	9	27

About a third of the passengers found the leg space as poor or very poor. We may assume the +60 group is the most satisfied group (90%) Despite technical intrusion of the seating space 2/3 of the respondents give high or very high marks. An explanation could be that 75% of the respondents were women.

Table 7b

I sit	Total	- 30 yrs	31-59 yrs	+ 60
Too low (1)	4	2	2	14
Well (2)	86	96	73	86
Too high (3)	10	2	25	

Regarding seat height 86% were satisfied.

Table 7c

Seat space for me is	Total	- 30 yrs	31-59 yrs	+ 60
Very narrow (1)	3	4	5	
Narrow (2)	18	12	32	5
Good (3)	68	69	64	77
Very good (4)	11	16		18

Almost 40% of the 31-59 year group say the seat space is narrow. A total of 79% however say it is good or very good.

Table 7d

Easy to look out through the window	Total	- 30 yrs	31-59 yrs	+ 60
Do not agree	1		2	
Agree	45	53	36	45
Definitively agree	54	47	61	55

The over-all mark for seating comfort is good. The only negative aspect was that a large number of middle aged passengers found the seats narrow.

Table 8 – Riding qualities

When the bus moves it feels nice and comfortable	Total	- 30 yrs	31-59 yrs	+ 60
Do not agree	12	4	23	9
Agree	68	73	66	64
Definitively agree	20	24	11	27

A large majority of the passengers thought the bus had comfortable driving qualities.

Table 9 – Spacious and open environment

The bus feels spacious and open	Total	- 30 yrs	31-59 yrs	+ 60
Do not agree (2)	4	4	5	5
Agree (3)	61	65	61	50
Definitively agree (4)	34	31	34	45

An even larger percentage (95%) found the bus spacious and open. There were no differences between the groups.

Table 10 – Noise level

The noise level in the bus is	Total	- 30 yrs	31-59 yrs	+ 60
Very disturbing (1)	2	4		
Disturbing (2)	9	2	18	9
OK (3)	62	69	68	32
Quiet (4)	20	22	14	32
Very quiet and comfortable (5)	7	4		27

Two thirds of the respondents say the noise level in the bus is all right, 20% say the bus is quiet. There are, however, differences of opinion, in the 31-59 group almost every fifth respondent (18%) says the noise level is disturbing. Most positive was the +60 group.

Table 11 – Over-all impression

My over-all impression of the bus	Total	- 30 yrs	31-59 yrs	+ 60
Bad (2)	2		5	
Passed (3)	27	20	41	18
Good (4)	45	51	39	41
Very good (5)	27	29	16	41

Two thirds of the respondents grade the bus as good or very good. Most positive were the young and the +60 groups where 80% in both groups say the bus is good or very good. None of the respondents graded the bus as very bad. Only 2% totally thought the bus was bad.

Table 12 – Better environment at the cost of comfort!

For me it is more important Uppsalabuss take part in the development of environmentally friendly traffic.

Do not agree	4
Agree	96

A vast majority regards it as important that Uppsalabuss takes part in the development for an environmentally friendly public transport system.

4.5.5 SAFETY ANALYSIS OF THE BATTERY

Introduction

Safety in electrically powered vehicles and buses is a matter of increasing importance. In Sweden a number of near accidents have emphasized these aspects. The following analysis will, however, focus on the drive system and its related components only. No live destruction tests have been carried out. Three different vehicles with considerable differences have been examined.

The battery is of a fully modular design. Twenty cell packs form an aluminium module container. The cells are electrically isolated from each other, via polymer stands within the module. The narrow slots between the cells are used as cooling passages. The cells are connected electrically via thin metallic slabs.

Eight modules are collected in an aluminiun container placed about five cm above floor level in order to allow a cooling air to pass. A screwed on lid covers the box. Two electric fans enforce cooling airflow through the construction. One of the two battery boxes contains seven compartments as the remaining eighth are used by the BMS battery monitoring system.

The battery boxes are placed in separate compartments, on each side behind the front axle of the bus, underneath the seats. The compartments can be reached from outside lids, and by unscrewing the bottom centre lids, situated under the seats. The battery box is made of GRP.

Battery Safety and Protection Devices

The primary electric protection device is consisists of a power relay able to separate the battery from electric load. The relay is controlled by the driveline power electronics. By sending a signal to the power electronic packet the Battery Management System (BMS) opens the relay.

The BMS will disconnect the battery by opening the relay via the power electronics at too low a tension, at too low or high a charging level and at too high or low a temperature.

The battery is protected by standard fuses of a melting type, one in each box. The fuses also protect the connecting cables linking the boxes including those feeding the power electronics.

Mechanical protection includes the GRP box, structurally integrated in the bus, which in turn contains cell pack stainless steel containers. The aluminium container is screwed on to the coachwork floor.

Chemical protection primarely consists of the stainless steel cell fitted with a safety valve at the top. The electrodes, welded onto holders, are fixed in gas tight feed throughs.

Cell Safety Analysis

Possible cell errors are short circuiting due to mechanical reasons. This will result in a fast internal cell discharge.

Fully charged the internal resistance will limit the current flow. The resistance is typically 1 mΩ, hence the internal current will be of the order 1000A.

As the battery discharge time will be between 3.5 to 4 minutes at an effect in the region of 1kW it is likely the safety valve will release due to overpressure in the container. Should this occur it is likely to assume there will be an emission of both lye and hydrogen. The emission of hydrogen will reduce the speed of the electro-chemical process.

The consequenses of a cell-pack short-circuiting will be roughly the same as the above mentioned, however, the resistance would be slightly higher. In such a case it is also possible the insulation would melt and that the heat would spread to nearby cell packs.

The BMS might detect a short circuit cell by a voltage drop or rise in temperature. At normal operational conditions the BMS will not respond single short-circuited cells, Single BMS steps or measurements will moreover not prevent or reduce damage.

Module Safety Analysis
A module consists of 20 module box cells. The module is monitored from both a voltage and a temperature aspect. A module breakdown could be caused by short-circuiting between one or several cells. In such a scenario an electric current will flow between two or more containers. The lye resistence will limit the electric current flow. Should the resistance be ten times as great as the internal resistance the discharging time will be of about 30 - 40 minutes. Heat dissipation will probably cause the lye to boil and the extended cell-temperature to stimulate hydrogen wastage. The safety valve will be released and both the lye and the hydrogen gas will be vented off.

In a possible scenario the polymer stands between the cells might melt and further short-circuits might occur. The aluminium made module box is covered by a lye-resistent polymer paint, which eventually will prevent short-circuiting between cells at a further distance.

The interconnection between the cell packs provide another problem. Poor contact may cause overheating of the cells and a melt of the feed throughs. Furthermore the module box plastic lid may melt and catch fire.

The BMS in itself will hardly detect a single short-circuit; should, however, two or more occur the battery managing system will register low tension. The rise in temperature will too be detected and signalled. The BMS response to break the main relay will not affect the process.

Box Cell Safety Analysis
The box cell contains seven or eight modules covered by polymer and aluminium lids. There is no reason to expect the box will collapse unless it is exposed to external force. Should a box cell collapse due to mechanical failure the module containment will protect the cell packets from short-circuiting.

Battery interconnection
The two battery boxes are interconnected via polymer-isolated cables, connected by bolted eyes to both the terminal and the relay. The cables are fixed to the floor by bolted wire holders. A well-known problem in such arrangements is over-heating due to poor contact, depending on poor tightening, cable movement, vibrations or magnetically induced forces.

A typical case is that heating makes copper oxidize, which in turn will increase resistance and temperature until the copper melts and a light arc forms. The heat thus induced will affect the cable insulation and melt and possibly cause a short-circuit between the two cables provided they are in close contact. Should the affected cable area be in contact with the GRP body structure it may cause highly inflammable gases to emit and thus cause fire and further damage.

Another scenario is that the light arc will set fire to nearby insulation, paint etc. Should the cables not be properly fixed vibrations may in a long-term perspective cause insulation errors.

The BMS is unable to detect this type of error, as it monitors module voltage only and assumes the voltage is the sum of the module voltages.

Main Relay and Output Terminal
The output terminal connector is mounted on the outside of the box which contains the main relay. The cables are bolted to the connectors. Connection takes place via a foldable flipp-handle device. The main relay is of a heavy-duty type with three connections , able to handle normal currents. Whether the main relay can handle short circuit currents is not known.

Two sort of problems are known for these two kind of components – poor electric contact in the bolted joints and poor electric contact in the relay itself. The latter is already described above. Normally the chosen materials are flame resistant and would carbonize rather than burn.

Poor electric contact might cause light arc effects which in turn might cause the components to melt. A more critical situation would occur, should the contact surfaces be welded together in such a way the main relay could not be opened.

External Effects
The above mentioned Internal effects are caused by construction, manufacture and wear. The below mentioned External effects are caused by exterior influence.

Head-on-Collision
The batteries are mechanically well protected and placed behind the front wheels inside a rigid cellular plastic/fibreglass box.

The battery has a considerable mass. Because of body rigidness a head-on-collision will cause heavy strain on the battery fastening devices. Some of the screws might be expected to shear off or be pulled away from the body and the battery will hence hit the battery box front partition wall and partly be demolished in such a way that the cell packs will move out of position.This in turn will lead to short-circuiting in the cell packs including large explosions. It is likely the cell packs would be demolished from internal short-circuiting.

Hot spots are likely to form and some of the safety valves will probably open and let out hydrogen. Firstly, a volume of free hydrogen above the electrolyte will assemble, secondly, hydrogen will be released from the metal electrodes. Given proper conditions hydrogen will ignite. Hydrogen is likely to burn, not explode. As soon as the hydrogen fire has been quenched, the only form of fire remaining will be flames frrom the safety valve openings. Hydrogen will furthermore be set free continuously, and as soon as conditions permit there will be a number of short-lived flames. It is not likely electrical insulations or the body of the bus will be set on fire.

As the battery box is air ventilated, over pressure from the fire will not cause the box to be destroyed by excess pressure. Flame velocity is comparatively low - 2.5 m/s.

Should larger amounts of lye leak out from the cell packs the following process is dependant on the position of the vehicle. Lye will affect aluminium and steel details but not the glassfibre body. Should the protective battery box paint be defective and the aluminium exposed to lye a spontaneous chemical reaction will take place forming aluminium hydro-oxide. A heavily irritating and corrosive gas.

Rolling over
Should the bus roll over sideways the body is expected to resist the pressure as would the battery containments. As the battery box is bolted onto the body and the cell packs well-fixed in their structure, nothing will happen as long as the battery box is kept in place.

Side-on collision

Should the bus be hit sideways just by the battery box, the rigid body construction will probably not collapse if hit by a private car or a truck at a low speed.

Should the colliding vehicle, or indeed the object hit, be of a more pointed nature occurances might be different. Should a small surface of the body material be subjected to severe loading it would be likely to collapse and the battery box situated less than 10 cm inside the body wall will come to harm.

Should the penetrating object have a larger frontal area the battery box will be pressed into the passenger compartment. Should the penetration go further the battery box will be stopped by the opposite body partition. A number of cell packs might be pressed together and get direct contact between the cell containers following an explosion. The safety valves will open and emit hydrogen and lye. Light arcs as well as "hot spots" might also occur. Should there furthermore be hydrogen in the vicinity a short term hydrogen fire will take place.

Should the penetrating object have a small frontal area it will quite easily force itself through the body of the bus and the battery box including some of the cell packs. Such an intrusion will cause short-circuits including fast discharges. Furthermore lye will be freed and form contact with the aluminium structure and in form aluminium hydro-oxides. Should the structure come to harm short-circuitings are likely to occur between electric parts, cell packs and module packets. Because of high voltage it is likekely a fire will break out should the battery container lid be dislodged.

Fire
Three causes of fire can be separated
- Self-ignition due to poor contact or cable-insulation
- Self-ignition due to short-circuiting in cables and contacts
- Ignition due to external causes

The bus is not equipped with an automatic fire-extinguishing system which means external fire-extinguishing activities will be needed in case of emergency.

Usually cable insulations are fire-restricting and hence open flames rarely occur due to burning insulations. Hot connections may, however, set fire to surrounding objects. Heat-radition from a poor contact might reach temperatures high enough to start a fire.

Should the cable insulations from the fuse box be destroyed because of fire a short-circuit will probably increase the fire. Another connsequence of fire is that the battery cell lids might melt and if so the internal structure will collapse.

The battery in itself is well secured, short-circuits are not normally calculated to start a fire. A poor contact point may,however, cause heating which in turn will set fire to surrounding objects via heat-radiation.

Should there be a fire from external reasons the body of the bus will be on fire. Should the fire start from on-top of the bus the battery is fairly well-protected until the bus completely collapses, or until the fire reaches the battery containments.

Should the fire heat up the cell packs the inner pressure will increase with temperature. This will cause the safety valves to release and hydrogen will be set free. Should open flames occur from the battery containments the hydrogen will burn. Hydrogen forms here rather slowly as it is controlled by the heat passages in the cells. When the hydrogen finally is released and the lye has boiled away the plastic details inside the cells will melt and finally the cells will do the same.

A note of caution: in case of fire and the fire has been extinguished by CO_2-equipment it is possible the battery will self-ignite due to the fact the electro-chemical processes inside the battery itself were not stopped. One way of preventing this is, is to cool down the battery to minus 30°C with liquid nitrogen; the pressure of the hydrogen will thus be very low.

Recommendations

From a safety point of view the batteries in the NE8012 buses are well protected. Some matters are however to be considered.

- The fixation of the battery containments seem somewhat too weak in collision situations.
- A gas tight and fire-proof lid should be mounted in relation to the passenger compartment in order to prevent gas leaking out in case of fire.
- A tray should be mounted underneath the battery in order to take charge of leaking lye.

4.5.6 MAINTENANCE AND REPAIRS

To be able to maintain a high level of maintenance quality, we have concentrated a lot of our efforts on status control and training.

All buses have a logbook which the driver has to use every time he/she starts/ends a tour.

The logbook is the base for the "Traffic and Fault Log", compiled regularly and sent together with the "Ausfallmeldung" to the project partners.

These forms are used for reliability measuring of the buses. 100 % reliability is described as 8 hours of traffic each day, 220 days of the year. Suspension of traffic caused by "Innovative Parts" of the bus will mean a prolongation of the warranty time according to the conditions partner agreement.

In order to minimize driver caused reliabilities, it have become very important to train drivers in the special technique involved in the buses. A "Driver´s Manual" has been produced. It is made in a format specially designed to suit drivers. It has been produced in Swedish, English and Italian. As completely new technical solutions are found in these buses, the manual has to be updated when new questions and answers appear.

Working on the project, we have found the manual an indispensable tool in the daily work, not least due to the big differences in technique these vehicles present compared normal buses. Since only five buses of this type exist it has been necessary to compile the existing information in an appetizing form in connection with the project.

A more detailed technical handbook has been compiled for workshop use. It consists of material gathered from a variety of sources e.g. component manufacturers leaflets and handbooks.

For particular reasons a special "Fire Manual" – "Anvisning Brand" is being prepared, it contains directions for the fire services and the bus operator staff. During the Malmö fire incident, we found that an increased general knowledge regarding bus specific features, should have made the fire-extinction easier and faster, not to mention that less damages to the vehicle would most likely have occurred, had that been the case.

Furthermore behaviour slips during fire-extinction creates unnecessary risks.

For particular reasons a special "Towing Manual" – "Anvisning Bärgning" has been compiled. It consists of instructions on how to prepare the bus for towing, as these procedures are very different from those of a normal bus. If the instructions are disregarded the bus will be subjected to severe damage.

4.6 ECONOMIC VIABILITY

The economic calculations for the electric hybrid bus are compared to those of the diesel bus. The total cost for the diesel bus is SEK 17 per kilometer allocated according to the table below.

Other costs are roughly considered to be the same irrespecive of vehicle type. Motives for choosing a different driveline as well as an alternative type of fuel should from an economic point of view balance capital costs and fuel costs including environmental fees.

The table below includes the estimated (fuel) cost for the hybrid bus. It assumes that all fuel costs, except the CO_2 tax, are the same. The reduced fuel cost is balanced by an increased capital cost and investment.

Hybrid propulsion is expected to reduce the fuel consumption as the engine is monitored to achieve a higher degree of average efficiency . Idle and low power operations are excluded. Preliminary tests indicate that the original objectives of a 30% reduction of fuel consumption can be reached. Trials show this and more can be achieved.

Seen from the table below there is considerable space for a higher vehicle price should a lower fuel consumption be reached including a tax reliefe on fuel.

Allocation of costs directly affecting the choise of driveline and fuel are typed in bold. (Cost level spring 1999.)

Cost SEK/10 km	Normal diesel	El. hybr diesel	El. hybr bio fuel
Fuel	**18**	**12,6**	**12,6**
CO_2 tax	**4,5**	**3,2**	**0**
Garage	3	3	3
Tax and insurances	2,5	2,5	2,5
Maintanance	1	1	1
General operation, tyres	1	1	1
Capital cost	**17**	**23.7**	**26.9**
Capital million of SEK	*2*	*2,8*	*3,2*
Profit	0,4	0,4	0,4
Driver	120	120	120
Total cost SEK/10 km	170	170	170

At a first glance the hybrid vehicle has a larger complexity and several more components. On the other hand the electric propulsion system replaces a number of components including a number of advantages;

- Several heavy components like the rear axle differential, gear box and hydraulic clutch are replaced by wheel-hub motors, generator and batteries
- It is considerably much easier to mount the drive line into the frame and the body if power is transferred via soft cables rather than stiff mechanical transmissions. Frame, body and wheel suspension are simplified and body space increase and to be used more efficiently
- Experiences from other applications indicate that elictrical appliances require less and more simple maintainance than a corresponding mechanical one.

The "electric" driveline will probably have similar investment costs as a conventional driveline provided a large scale production is at hand.

5. LESSONS LEARNED/CONCLUSIONS

5.1 Comments and conclusions from the manufacturers

Gottlob Auwärter GmbH - Neoplan

Hybridbus N 8012 GE

Following up the Thermie I Project from 1992 a Thermie II Project was started 1996, together with Malmö and Uppsala in Sweden and Bolzano in Italy.

For design of the new systems and the electric drive we turned to the company Magnet-Motor in Starnberg, Germany. For the Nickel-Metall-Hydrid battery we turned to the company Varta also in Germany.

The buses are low floor city buses with a body of high quality composite material with critical elements reinforced with carbon fibre. The buses to Sweden were equipped with gas engines from Cummins but the Italian bus with a diesel engine from MAN. Both enginetypes mounted together with a generator. All vehicles have for the electric drive, electric wheel motors in the rear wheels.

A summary of gained experiences by Neoplan in this project.
An important part to test was the body of the bus in synthetic materials. Sides, roof,floor, front and back is made of fiber material to a sandwich design. Outer- and innerlayers are of glass fiber reinforced epoxi plastic. The middel layer is of FCKW-free PVC foam.

This means a lot of advantages as:

- 50% lighter structur than a traditional steel body.
- beautifully formed body due to the greater freedom in design.
- corrosion-proof body.

In spite of a these advantages this way of building bus bodys have ceased at Neoplan. The main reasons are:

- The high costs for moulds for the different variants. That is, to save high investment cost we are forced to limit the possibility to vary the design and use of different drive lines and different inner space arrangements.
- Furthermore the noise characteristics of the body was not the best.

The bus operators normally specifies their own vehicles. The number of sitting- and standing passengers, door design (inner-, outer- or swing doors) and door mechanism (air or electrically actuated), as well as make of heating and cooling systems. And also different drive lines, engine size, gear box etc is individually specified by the customer.

This means that in spite of a advanced standardization of a city bus, the operators wishes will anyhow bring demands of individual body design. These variants have brought increasing costs for moulds for the body.

Different distances between the chairs is needed because of different make. This brings changed wheelbase and the complete design of the body. It has also been hard to follow up on news within the art of bus building as new doortypes, door mechanisms, drive variants etc.

To sum up, resumption of this methode of building buses will need longer number of identical buses.

The noise characteristics of the body is a technical problem. A satisfying damping is only possible with high mass, heavy damping mats or by absorbing the noise energy with distance between the source and the passenger compartment.

These measurements gives drawbacks to a body type with light compact design, which questions the light weight design as such. A considerable improvement is possible if the primary source of the noise, the cobustion engine, is removed and instead a fuel cell is used as primary energy source.

Now is the second important part of the project mentioned, the electric drive. The electric drive has in this project shown to be reliable. The wheel motor mounted directly into the hub of the wheel is a solution for the future. It has already been used in several variations by Neoplan. The advantages with a compact light drive unit directly in the wheel gives the best possibility to find a place on the market for the unit.

To begin with a energy source in the form of a combustion engine with generator or a high energy battery – a Nickel-Metall-Hydrid battery – will be used.

In Sweden they use a Cummins gas engine to obtain lower emissions in traffic. The drawback in this design is only the gas supply. This means the arrangements around the gas tanks, and in increased exhaust- and engine room temperatures.

It is possible to drive the bus in different modes:

- in hybrid mode, this means that both battery and engine delivers power.
- in battery mode, this means the battery is the only power source.

The battery mode gives an exhaust and noise free drive. Todays experiences show that the Nickel-Metall-Hydrid battery is usable in city traffic. The high cost however (1kWh ≈ 5000 Euro), makes it hard to use in normal bus manufacturing. First when the battery is obtainable in a large scale production the price will reach a competitive level.

The battery management system (BMS) needs development. The calculated state of charge (SOC) at a dynamic hybrid drive mode is not reliable enough. To obtain an optimal charge - discharge and a optimal life time of the battery is not yet feasible, even if the charge strategy of today is acceptable.

At hybrid mode with combined battery- and combustion engine drive it is possible to reach large decrease in the emissions from the engine. Measurements has shown:

- CO_2- emissions can be reduced with ca 30%
- CO - emissions can be reduced with ca 60%
- NOx - emissions can be reduced with ca 50%

To lower the emissions at stop-and-go traffic, is the engine only started when the vehicle reaches 22 km/h. At the start an engine emitts enhanced emissions, as the drive conditions is far more unfavourable for the engine than at higher speeds.

Here the battery takes over and first at higher speeds the combustion engine produces enough energy for the drive and for recharging of the battery.

A further charging of the battery occurs at braking, when the wheel motors starts working as generators. Here is a energy recovery when the brake energy is used for charging of the battery. To optimize this drive mode an electric brake ought to be added. The limited capacity of the battery to receive high charge currents is a restriction for the optimal energy recovering.

Further development of the electrical drive used in this Thermie Project will occur at Neoplan the during the next few years.

Another problem have been the maintenance of the 24V system onboard. At the market available components have not been approved for use in a bus and furtermore been rather more expensive. The technical problem have been solved with a water cooled DC/DC with considerably higher capacity.

To conclude it can be said that the Thermie Project II cleared the way for essential technical and commercial knowledge about the electric drive. Since the electric drive is the basis for all future development of emission free energy efficient vehicles, the Project was both a test and an important milestone in the development of public transport vehicles.

VARTA

Modern battery systems will play an increasingly important role in the future of the automobile. More security, greater comfort, less fuel consumption and fewer emissions are the automotive industry's goals.

New vehicle concepts provide a whole raft of possibilities in this regard. This goes for both modern hybrid vehicles, whose combustion engines and electrical motors are coordinated to optimize energy consumption, and for conventional vehicles, whose fuel consumption and emissions are being reduced thanks to the introduction of a number of new electrical and electronic components. A vital factor in the success of these new technologies is the choice of the correct battery. Varta is addressing these requirements with a range of high-performance batteries. Although there is a general consensus that lead batteries will continue to play an important role in the future for vehicle applications, new battery systems are regarded as a key prerequisite to being able to meet the increasing demands of vehicle manufacturers in the future. This is of particular relevance to areas where lead batteries are already pushing against their technical limits. It is therefore assumed that, in addition to the Nickel-Metal-Hydride battery system (NiMH), the Lithium-Ion system (Li-Ion) will also play a significant long-term role in augmenting the lead battery systems which have thus far dominated the market.

Nickel-metal-hydride batteries

Varta has two product lines for the nickel-metal-hydride system.

NiMH high-performance batteries (High Power: HP) supply electrical energy to hybrid vehicles which can cover a certain distance running on purely electrical power alone. Applications include vehicles that can be used in zones which have traffic calming and where exhaust emissions are banned. Here too, high performance, support of rapid charging and a long service life are needed. With a specific energy density of 55 Wh/kg and a specific power output of 300 W/kg, the NiMH high-performance system from Varta has proven itself over many years, particularly in the bus operator sector.

NiMH high-performance batteries (Ultra High Power: UHP) represent the most significant long-term potential from today's point of view. With a specific power output of up to 900 W/kg for charging and discharging, they offer a significant gain in performance over ordinary NiMH high-performance cells. Their principal use is to boost performance in state-of-the-art concepts. Key emphasis is on improved energy efficiency and a dramatic reduction of harmful exhaust emissions.

In modern hybrid vehicles, the battery supports the vehicle's drive system whenever the combustion engine is experiencing difficulties or is running inefficiently - for example when starting off or accelerating. Additional energy savings can be achieved by virtue of the fact that energy which would otherwise be lost when braking can be stored and made available to the drive system.

Due to their power and long-term cycle stability, NiMH high-performance batteries are also ideal for new vehicle electrical systems with higher performance and energy requirements. The weight-dependent power consumption and output of NiMH high-performance batteries is two to three times that of the lead batteries in use today. Batteries with a weight of around 15 kg can be discharged with a power in excess of 10 kW. This allows, for example, energy-efficient starting in urban traffic, or rapid preheating of an exhaust gas catalytic converter.

The service life is of major importance for the economical use of an on-board battery system. Nickel-Metal-Hydride is the best of all the battery systems around today. With relatively low discharge depths, an energy throughput can be achieved which is up to 50 times higher than that of conventional lead batteries.

High-performance batteries are based on round cells. Varta uses time-served and cost-effective production technology-technology which is already in use in the manufacture of commercially available portable batteries.

Lithium Ion batteries

Lithium Ion batteries are the most recent product to have been developed in the field of battery technology. They are already playing a leading role on the portable batteries market. A high energy density of more than 100 Wh/kg is this system's most striking feature. Lithium-Ion batteries are therefore around 30% lighter than Nickel-Metal-Hydride batteries. Compared with lead batteries, the weight difference reaches 60%.

Since high weight-related power densities of more than 800 W/kg can also be achieved with the Lithium-Ion battery system, this system is becoming an increasingly attractive proposition for use in vehicles.

Development and production engineering aspects of the lithium-ion system are still lagging some way behind NiMH technology. The main problem currently lies in the short service life. This is particularly true at the temperatures which prevail in vehicles. The current life cycle of two to three years must be at least doubled, in order to meet the demands of the vehicle industry. The significant advances in Li-Ion technology which Varta has made over the last five years are bringing these targets within reach, however.

Part of an intelligent electrical system

The vehicle industry's goals in relation to energy-saving and improved environmental friendliness can only be achieved if the battery is included in the vehicle's energy flow control process as part of the electrical system. In the future, this cannot be done with the battery acting as an energy-storage device alone. It must become part of an intelligent vehicle electrical system, with optimized energy and performance management. In conjunction with a battery monitoring system, vehicle battery systems will develop into high-tech products capable of transmitting important information about the charging status, performance and general technical condition to the vehicle's electronic system, thereby contributing to the optimization of the overall system.

MagnetMotor

has continued the development of the electric drive system. The present design is shown with pictures and data. Compare to pictures on page 12. Extreme caution has been taken to serviceabilty and easy exchange.

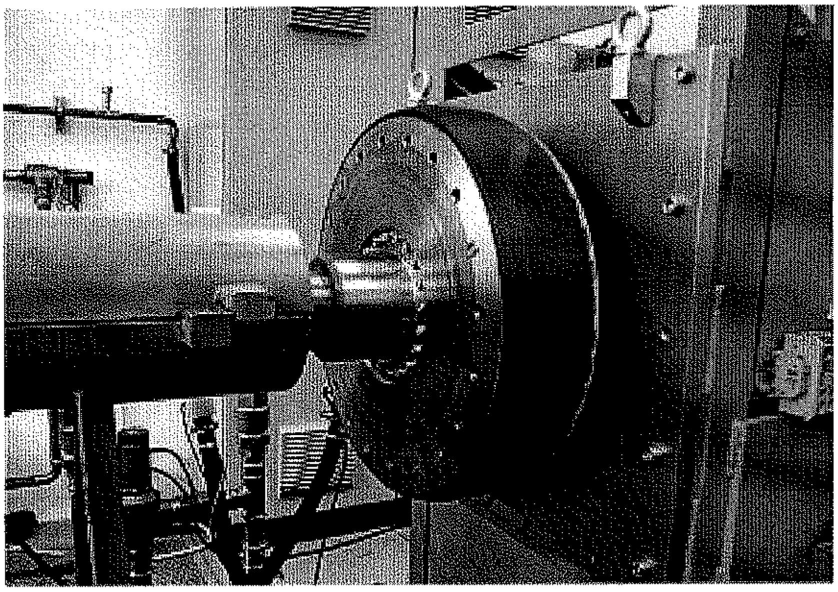


Fig. 51.

The New Wheel motor

- Rated Power: 50 kW
- Peak Power: 150 kW
- Speed Range: 0 - 3250 rpm
- Peak Torque: 730 Nm
- Cont. Torque: 600 Nm
- Operating Voltage: 750 V
- Phases: 3
- Max. Current: 240 A
- Lenght:100 mm
- Diameter:429 mm
- Weight:44 kg

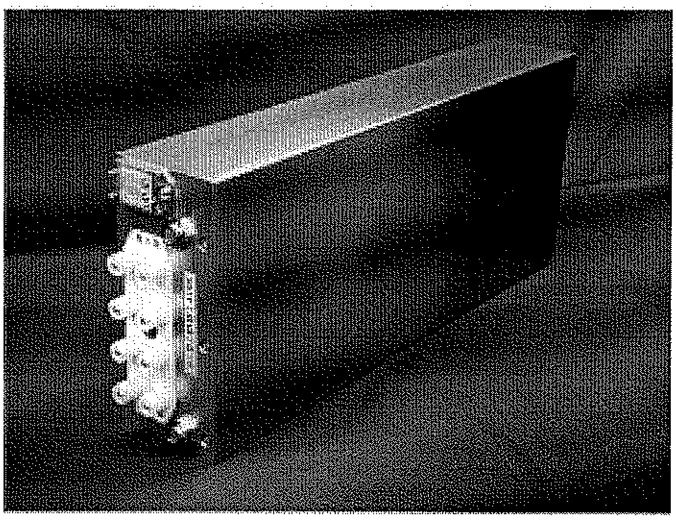


Fig. 52.

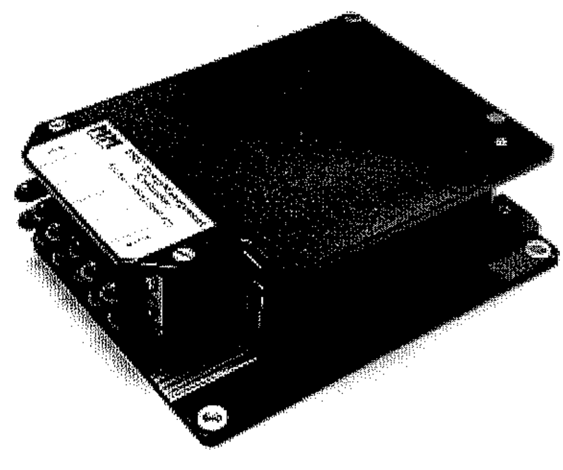
The New Powerelectronic

- Quick Pluggable Unit
- Ruggedized (40 g, 11ms) Shock
- Water Tight Wheel Motor
- IGBT Power Electronics
- Quick Connector System
- Interchangeable for Motor and Generator
- Max. Switched Power: 576 kVA
- Ruggedized (10 g, 11 ms Shock)
- Weight: 23,5 Kg

Fig. 53.

The New Power Management Controller

- Size: 650 x 110 x 260 mm
- Controller for the E-Drive System
  - CAN-Interfaces
  - Fibre Optic Interfaces
  - 20 ms Communication Rate
  - Weight: 1,050 kg



5.2 CONCLUSIONS SAD

SAD-Nahverkehr A.G. believes that the technical performance of the bus has met with its expectations. After the shortcomings encountered at the beginning and successfully eliminated (save for those of structural nature as for example the bus's rigidity) the bus has been used hitherto without encountering any major problems. An important step has been made with this project towards the reaching of the target set at the beginning, i.e. driving through inhabited areas without emissions while saving energy. However, greater comfort for passengers has to be provided for cross-country journeys.

The current costs however are still a problem. Despite the willingness to spend more for the additional performance of this bus, the current costs even for such a bus are beyond our means.

At any rate SAD-Nahverkehr A.G. is glad to have taken part in this project and to have made a concrete contribution to research.

5.3 CONCLUSIONS UB - ST

The serial hybrid concept and the use of two wheel motors is found to be an attractive design which gives many advantages

- No rear axis (including the differential gear) makes it possible make a low floor vehicle design throughout the vehicle.
- Heavy and costly components can be avoided
- Simple design of the individual wheel suspension system
- Advanced control of the wheel power and its distribution to the wheels should give attractive properties in winter condition. (A typical problem when driving at wintertime is that one of the driving wheels often stands on an icy spot and, when the vehicle starts, the wheel will start spinning and the other wheel, with friction, will not get any torque to drive the vehicle forward.)
- Possible four wheel drive system for enhanced driving properties.

The flexibility in the design, which an electric system offers is not fully explored. The absence of shafts and axis make it possible to design a very compact engine compartment. Much more attention must be paid to ensure easy access to the equipment. Since stiff torque transferring axis are replaced by soft cables where simple electric connectors can be used it should be possible to organize the engine compartment in a more simple way to improve easy access to all parts than what is the case in the prototype buses.

The efficiency of a well designed BMS has been truly demonstrated. The performance of the BMS is perhaps the most important and critical individual component to ensure a reliable operation of the hybrid vehicle.

The development work of the BMS must continue. When selecting battery the performance of the BMS is an important issue and must be included in the evaluation. This is not only a matter of cost and performance when buying the battery but also matter of lifetime and reliability of the system as well.

The performance of the vehicle, in terms of acceleration, is set by the electric drive motors. They do have enough torque to comply with the required acceleration. In a heavier bus more torque is required though. The maximum speed of 70 km/h is acceptable for city services.

The vehicles tested in this project are to be considered prototypes. Hence the present design is by no means optimized from a manufacturing, service and maintenance aspect. By means of closer cooperation between designers specialized on manufacturing, power electronics, mechanical drive systems, battery etc from the very first beginning of a project, great over-all advantages should be gained.

The documentation of the present vehicles is intended for the designers and the trained specialist rather than any other group. To make it possible to repair and manage the vehicles when in use, much attention must be paid to documentation and trouble shooting routines. Since most systems do include microprocessors it should be possible to use computer based software systems as a complement or alternative to traditional paper manuals. Nevertheless the training of the service staff is crucial.

General
The hybrid bus offers a number of potential advantages in terms of high fuel efficiency, low emissions and a number design features. At the same time the hybrid bus includes some new technologies although all of them are well known from other applications, e g railways, industrial applications etc.

The hybrid bus has shown a way to reduce emissions, exhausts as well as noise, from the public transport vehicles. It has also shown a way to reduce fuel consumption substantially.

But, it is not just as easy as just building a hybrid bus. The vehicle has to be a very good application if the goals are to be reached.

Higher fuel efficiency
Higher fuel efficiency is reached in two ways. By choosing a **smaller engine** than needed in a normal bus, but N.B. this engine has to be chosen carefully.

Choosing an engine without careful consideration may even make problems worse. It has to be just exactly the size needed. The needs of the actual traffic and road conditions have to be measured. The engine has to run in the speed and power sector which makes for clean operation at all time, and this sector is not big.

Should the engine be over-sized it will run with too low a load and the emissions will be higher. Should it on the other hand be under-sized, the performance of the bus will suffer.

Regeneration of the brake power, a city bus is almost always either accelerating or braking, if the energy needed for acceleration is collected when braking and used again when accelerating an enormous amount of fuel is saved. The fuel consumption will be only what is needed to cover the losses in the process.

Our tests have shown that most of the fuel savings and emission reduction is due to brake power regeneration.

The brake power regeneration system has to be the best available, and have a computerized control system. The power receiver, a kind of battery or other device, has to be capable of receiving and give off high amounts of power during short periods.

Engine optimization
Of the four driving modes three, are so to say, “natural” – the battery-, gas engine- and charging modes. In these modes the design criteria is straightforward. Longer operating distance and better acceleration in battery mode requires more battery capacity and power. Better acceleration in gas engine mode requires a larger engine-generator and electric drive motors etc.

Only for the hybrid mode it is required to make a more complex analysis, and to specify the system. Should such an analysis be made, it is necessary to set up precise goals before the design, rather than the other way round. Below a number of such possible goals are described:

•If the goal is to minimize the fuel consumption the engine should, when in operation, work at a high torque where engine efficiency is at its highest. Operation at an intermediate torque and idling should be avoided.

•If the goal is to reduce emissions other than CO2 a compromise must be found according to some formula and the engine should follow a minimum emission “load line”.

•Should the matter of emissions be properly esteemed by the public, the use and operation of the engine should be combined with information inside the vehicle.

Already when planning the route the operater should decide which parts of the route where the engine is prohibited for use and where it could be used more freely. Such a control could be carried out via one of the navigation systems available on the market today.

•Should economy be optimized the investments must include operating as well as maintenance costs for the whole vehicle life span.

The control system is the crucial part of the drive system since it controls all functions. The software constitutes all the system characteristics, operating tactics, strategy etc. In short, within the performance of the mechanical and electric components, the software of the control system sets all the limits of the vehicle drive system.

In order to understand the vehicle characteristic properties the control system and its software must be well documented. This is especially important when the required specifications are compared to those offered by the manufacturers.

The documentation of the vehicles should not only include normal drawings etc but comprise troubleshooting and repairs as well. Such documentation could be stored in the software on board the vehicle, in the monitoring software programs or as traditional paper based manuals.

Furthermore the documentation should comprise basic instructions on which status the system should be in when tested, testing equipment to be used, reference values, measuring methods etc.

The training of the staff is crucial. The staff must have a basic knowledge in order to understand and handle the systems in question. It should be pointed out that some of the electric equipment requires authorized personnel for repair and maintenance.

Much of the **repairing and maintenance** work could be simplified if a thorough module system was used. Much of the repair work has to be done by simply replacing a faulty module with a new one. Such a system should include self diagnostic systems, i.e. systems which in themselves would find out their own status and need of replacement.

Maintenance matters should too be part of the offer procedures, i.e. when vehicle specifications are formulated.

The hybrid design includes a number of new components on board the vehicles beside the common ones. This is one reason for considering safety schemes in case of accident and to install preventive systems to prohibit possible harm to both passengers and environment.

Hence, there is need for a thoroughly set up **safety analysis** for this type of vehicles. The analysis should result in instructions and/or regulations to be followed by manufacturers and operators when designing and manufacturing the vehicle as wells as maintain and service the vehicles.

5.4 OUTLOOK

The hybrid bus is a **necessary step** prior to the introduction of the fuel cell bus. And so is the methane gas powered bus. The two bus types, almost unknown in bus operator circles, contain the technology needed for the fuel cell bus and if the fuel cell powered bus is to become a reality, driving and maintenance experience from the less radical "near related" vehicles must be created. This experience is preferably gained from the hybrid bus before the fuel cell bus is on the market.

Sadly there is no market for hybrid vehicles at present. Manufacturers are uncertain about both technology and customer interest. Customers are interested but sensitive to price and reliability and to some degree suspicious to new technologies even though they understand the technological advantages. For instance the possibility to create completely closed bus stops indoor at shopping malls etc.

To make a market for new drive systems like the hybrid bus system both manufacturer and customer must feel confident. The manufacturer must be confident that development costs will be paid and the customer must be confident that the manufacturer takes full responsibility for the product, for service as well as spare parts. There is need for long term agreements based on long term planning in order to reach the future goals of efficiency and environmental protection.

Within this project a group of individuals, scattered across Europe, have obtained a deep knowledge about hybrid bus design, how it ought to be and what solutions that are not so good. This kind of experiences could not be obtained within the design departments of the bus manufacturers, they have to be created during use of the buses in normal traffic.

To **gain from these experiences** and not lose them, the project should continue in some form. One way is to write a specification for a hybrid bus with all functional requirements in a manner that allows for the design departments of the bus manufacturers to find their own technical solutions. This specification could later become the basis for purchase of the next generation of hybrid buses.

6. PUBLICITY

6.1 Publicity and Publications

In a project of this type information has always top priority. The aim is to prepare decisions makers, operators and the public for new technical solutions. As changes are always troublesome for the individual, one has to act on a long term basis.

Fig. 54.The public period of this project started with an inauguration ceremony performed by the Swedish Environmental Minister Anna Lind on 26 September 1997

Later on a continuous flow of information has reached the interested people and groups via magazines, television, conferences, information leaflets, advertising and the world wide web (www).

As the bus is on route to the Malmö Öresund Bridge Exhibition only, the vehicle acts as its own advertising platform, by just appearing. Needless to say the livery has been completed with bold overall information regarding the Öresund fixed link.

On the homepage www.ecotransteknik.se where among other bus and environmental information, several pages deal with this project and its vehicles.

The buses have been seen on television on several occasions.

This project and its vehicles has been subject to national and international interest at both national and international conferences on several occations, when environmental friendly transport issues have been the main subject.

Fig. 55. The hybrid bus on display at the Bus 2000 fair in Malmö in july 2000. Kerstin Ovander, Olle Lundin Linjebuss

Fig. 56. The King of Sweden leaving the hybrid bus in Uppsala after a tour around the city. (Photo Matz Gerentz, SLU)

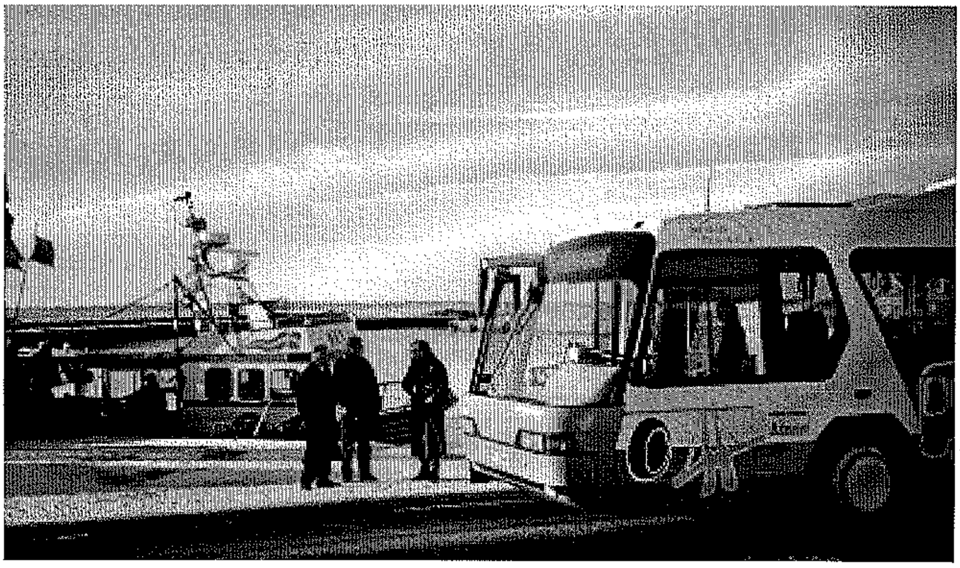


Fig. 57. The hybrid bus on a vist on the island of Hven in the middle of Øresound a winterday.

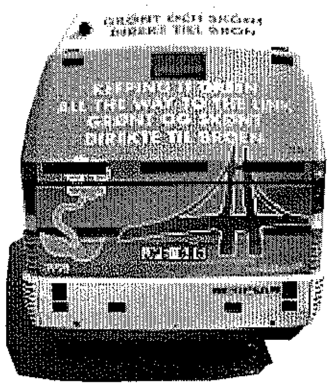


Fig. 58. The hybrid bus from the back, painted for its job, transporting visitors to the Øresound Bridge abutment.

Fig. 59. The hybrid buses on display in Lund during "A City free of cars" in september 2000.

Fig. 60. The SAD hybrid bus leaving the bus depot in Bolzano.

Public Relations SAD

As mentioned above the bus was presented to the press and the general public in the framework of the Bolzano trade fair. To sum up it can be said that the bus met with great interest.

The scheduled passenger survey was not carried out for the following reasons:
• Since the bus was designed for urban use, it cannot provide the same comfort as a cross-country bus;
• Owing to the rigidity of the bus for example, the seats are not comfortable for cross-country journeys and there is no air conditioning system.
• The passengers who are accustomed to modern and well-kept cross-country buses are not satisfied with the comfort of this bus.
• In the light of these premises a passenger survey would not have been interesting, as the passenger would have paid more attention to the travel comfort and the technical innovations and the energy savings would have been discarded.
• The SAD attached great importance to the technical innovations and it was aware right from the beginning that this bus could not provide greater travel comfort.