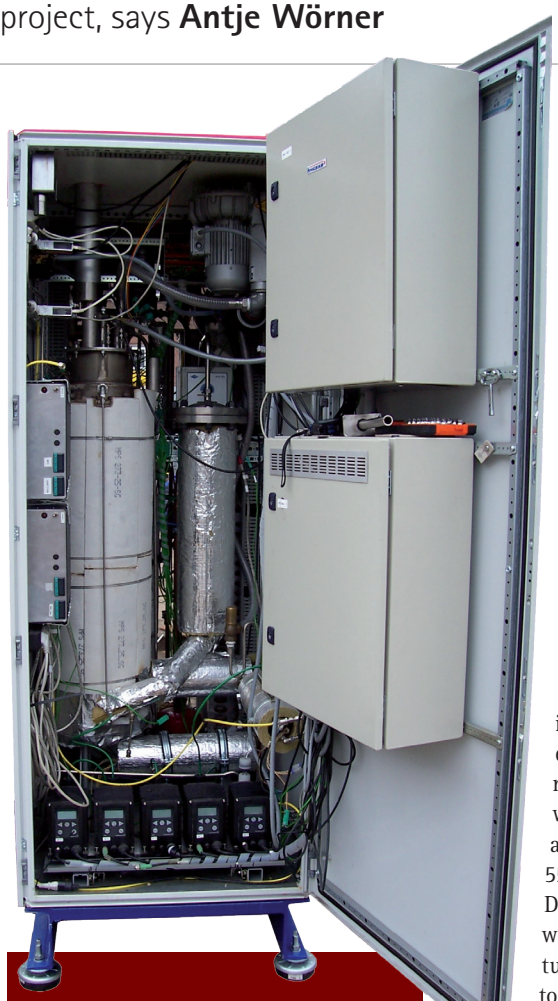
Fuelling future transport via hydrogen stations

Hydrogen could play an essential role as an alternative method to fuelling vehicles but independently managed refuelling stations need to be developed in accordance. This is the target work of the NEMESIS project, says **Antje Wörner**

Continuous depletion of the world's crude oil resources and increasing environmental impact of conventional energy conversion processes, generate the need for an energy scenario in which hydrogen can play an important role as a future energy carrier. Yet there is no hydrogen infrastructure available for distribution with central production from renewables. Decentralised, small-scale units using readily available fossil or bio-fuels as feedstock are therefore needed to meet the short and midterm demand of hydrogen for transportation purposes.

The NEMESIS project, successfully completed last month after a project lifetime of three years, targeted this area.

Based on the highly integrated generic steam reformer technology for natural gas in combination with pressure swing adsorption of HyGear B.V. – one of the core partners of the project – innovative sub-components and functional materials such as catalysts, adsorbents and membranes were included to upgrade this system to a fuel flexible proof-of-principle prototype with an output of 10 kg H_2 per day being generated from natural gas and diesel fuel at refuelling stations. Four research partners from middle and southern Europe as well as China, together with Umicore as a catalyst supplier, contributed their expertise within the highly demanding scientific fields of sulphur removal, catalyst conversion, membrane separation as well as CFD and system modelling. The overall system and fuelling station integration aspects were taken care of by Repsol YPF and Ballast Nedam IPM resulting in an outlook on a pre-commercial design of an up-scaled hydrogen generation system of the NEMESIS type.



Fuel Preparation Module of NEMESIS prototype

The modular system approach pursued within NEMESIS includes a fuel preparation module (FPM) handling the two major challenges of liquid hydrocarbon feedstocks – sulphur poisoning of catalysts and coking or gum formation. Researchers at the Aerosol and Particle Laboratory in Greece investigated various adsorbents for liquid and gas phase desulphurisation, which they prepared by specific in-house techniques. Whereas liquid desulphurisation showed very promising results in lab-scale experiments, it still needs more work on regeneration and continuous operation for an up-scaled unit. On the other hand, a prototype unit comprising three monoliths coated with a mixed Zn-Cu oxide exhibiting excellent adsorption capacity was fabricated and integrated into the prototype.

Working together for results

Umicore, DLR and HyGear worked closely together to realise a pre-reformer unit being installed upstream of the desulphurisation with a noble metal catalyst which is capable of withstanding sulphur poisoning at an operation temperature above 550°C. In a laboratory set-up at DLR various noble metal catalysts were tested, and their preparation tuned, by the specialists at Umicore to achieve maximum performance. Meanwhile, the engineers at HyGear realised diesel evaporation, mixing with steam, and catalytic conversion in the prototype scale. Finally, the FPM underwent extensive pre-testing prior to being mounted in the overall system.

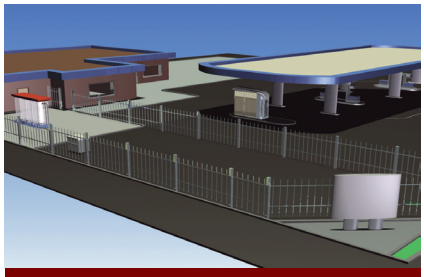
The pre-reformate emerging from the Fuel Preparation Module is converted into a hydrogen rich product gas by steam reforming in the Hydrogen Generation Module (HGM) – the two main components being the reformer for the catalytic conversion and the burner that provides

the heat necessary for the endothermic reaction. This unit is realised with a high degree of thermal integration resulting in a complex combination of heat exchangers for pre-heating, steam generation, catalytic reaction and cooling of the reformate gas stream. The burner can be run on natural gas or pre-reformate for start-up and on off-gas during normal operation. To optimise the design in terms of safety and to guarantee for a stable combustion of the various feedstocks, numerical simulations of the combined reformer and burner section were conducted at Instituto Superior Técnico in Portugal. A half-scale replica of the hardware was built and tested to validate simulation results. The improvements achieved for the reformer unit are represented by a higher safety level, increased mechanical strength to allow for pressures up to 6 bars and temperatures above 700°C, and a simplification of the design.

In order to upgrade the reformate to a hydrogen purity with fuel cell standards a Hydrogen Conditioning Module (HCM) is added downstream of the reformer. Within the NEMESIS project three purification technologies exhibiting different levels of development were covered: The HyGear systems are normally equipped with a pressure swing adsorption unit that guarantees for a high degree of purity at the expense of being rather energy and cost intense. An optimisation in cycle time combined with an improved adsorption bed, resulted in a better performance of the PSA unit during laboratory testing. A consecutive reduction in size was not realised within the running project, but is recommended for the future. Also, the hardware concerning valves and manifolds has been improved to increase reliability and efficiency of the unit.

The quest for Hydrogen purity

A more innovative technology for hydrogen purification was investigated by the Chinese project partners from Nanjing University of Technology. Thin palladium membranes on a porous ceramic support were used to separate hydrogen from the other product gas components. The challenge was to produce a very thin Pd layer by electroless plating without pinholes to achieve a high degree of purity, in combination with sufficient recovery rates or flux of purified hydrogen through the membrane. Various membranes were prepared using different types of supports, such as single tubes and multichannel



Refuelling station with NEMESIS hydrogen generator

arrangements, which bare a great potential in terms of volumetric capacity of a membrane separator unit but are more difficult to prepare and seal in an assembly for a prototype. After extensive testing at laboratory scale a decision was made to realise a prototype unit based on single-channel membranes to achieve the NEMESIS goal of producing hydrogen with a purity of 99.99 per cent. This unit was shipped to DLR for testing with simulated reformate gas mixtures.

A third alternative, using metal hydrides in a temperature swing adsorption setup, turned out to be not a tehnologically applicable level as of yet. Investigations were therefore targeted towards rather basic issues such as sorption kinetics and poisoning influence of contaminants such as CO, CO_2 and CH_4 in the reformate gas stream.

Support needed to develop further

In summer of this year the overall prototype system was installed at HyGear and testing started with natural gas. Thereafter the feed was switched to diesel and by the end of November already 200 hours of operation were completed. The desired hydrogen output of 5 Nm^3/h could be reached with a gas purity of 99.9 per cent and a pressure above 2 bars.

These results build an excellent basis for bringing a hydrogen generator of the NEMESIS type to a level where 20 fuel cell cars can be refuelled per day at a demonstration site. Ballast Nedam has pictured the integration of such a system, including underground hydrogen storage and compression to 700 bars, into an existing refuelling station. Economic evaluations have shown that these systems are commercially feasible but need to be supported by grants in order to bring them to the market. Therefore, the results researchers can accomplish to go one step forward towards a new energy world has to be complemented by strong governmental decisions and support. ★

At a glance

Full Project Title

New Method for Superior Integrated Hydrogen Generation System (NEMESIS)

Project Partners

4 industrial partners:

- HyGear B.V. (NL) – system manufacturer of small scale hydrogen generators
- Umicore (D) – catalyst manufacturer
- Ballast Nedam IPM (NL) – study on commercial scale-up and integration into fuelling station
- Repsol YPF (E) –fuel supplier, overall system aspects

4 R&D institutions:

- DLR e.V. (D) – system modelling and catalyst testing
- Aerosol and Particle Technology Laboratory, CPERI/CERTH (GR) – desulphurization
- Instituto Superior Técnico (P) – burner and reformer modelling, metal hydrides
- Nanjing University of Technology (China) – membrane separation

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NEMESIS coordinator

Antje Wörner is the coordinator of the NEMESIS project. She is heading the research group on hydrogen production and hydrogen storage at the German Aerospace Center (DLR e.V.) in Stuttgart. Having a strong background in chemical engineering she has been working in this research field at DLR since 1993.

NEMESIS