Malmö Hydrogen and CNG/Hydrogen filling station and Hythane bus project

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1. Background

The largest private utility company in Sweden, **Sydkraft**, with its head office in Malmö has a history of being in the forefront of the technologically development. Sydkraft belongs today to the E.ON group. Already in 1985 Sydkraft and the Municipality of Malmö started a long-term co-operation regarding conversion from diesel to CNG on the city busses. Now in the region Skåne more than 330 buses, 80 trucks and about 1000 cars are running on CNG and biogas. In 1995 the parties both implemented use of Electric Vehicles in their fleets as a part of a large EV demonstration project in the region. This quest for testing new alternative fuelled vehicles has continued and the latest step is now to test hydrogen mixed together with natural gas for local city buses.

Carl Bro Energikonsult AB has been an active partner in the project from first idea, design, project management, procurement, and start up of the filling station.

2. The hydrogen production plant and filling station,

The hydrogen plant and the filling station is situated at Nobelvägen 66 in Malmö and owned and operated by Sydkraft Gas AB. It started operation in September 2003. At the same site there are filling stations for CNG and also electrical vehicles.

The hydrogen is produced by electrolysis in direct connection to the filling station. The electricity is produced in a nearby windpower plant and distributed to the plant via the electrical grid.

The hydrogen plant including the production and filling station is delivered by Stuart Energy, Canada, The electrolyser unit is manufactured by Vandenborre Hydrogen Systems in Belgium, a subsidiary of Stuart Energy, Canada now owned by Hydrogenics ltd, Canada.

Technical data for the electrolyser as stated by the supplier,

- Capacity: 36 Nm^3H_2/h
- Power consumption electrolyser: 4,2 kWh/ Nm^3H_2
- Power consumption in total: 5,5 kWh/ Nm^3H_2
- Water consumption: 36 l/h
- Pressure from electrolyser H2: 10 bar
- Power requirement: 210 kW
- Load area: 25 – 100 %

Fig 1. Hydrogen storage pressure tanks

Fig 2. Hydrogen storage

The above pictures show the compressed hydrogen storage at the site. The hydrogen storage is placed closed to the electrolyser unit. The pressure vessels are delivered by Dynatech, Canada.

- Pressure 393 bar
- Volume $4m^3$

Fig 3. Dispenser hydrogen and mix of CNG/hydrogen

The dispenser is delivered by FTI, Canada it consists of two hoses one for pure hydrogen and the other for the mix of hydrogen and CNG. The mixture is done in the dispenser directly while filling the vehicle fuel tank.

The different fuelling options at the dispenser are,

- Hydrogen 350 bars
- Hydrogen 200 bars
- H2/CNG CNG with a blend of 8%$_{vol}$ hydrogen
- H2/CNG CNG with a blend of 20%$_{vol}$ hydrogen

The backgrounds to use these four fuelling options are

- Hydrogen 200 bar is a classic standard for delivery of bottled industrial hydrogen and several hydrogen demonstration vehicles are using 200 bar as pressure in the fuel tank.

- Hydrogen 350 bar is a new standard often used for fuel cell vehicles. DaimlerChrysler Evobus has specified 350 bar as onboard storage for the hydrogen fuel on their Citaro buses used in the CUTE and other similar projects. It is also the standard for DaimlerChrysler FCell fuel cell cars and several other modern demonstration vehicles using hydrogen as fuel.

- H2/CNG with a blend of 8%vol hydrogen; this lean mixture of hydrogen into the CNG is considered as CNG according to the specification of natural gas. The mixture can be used directly in the current CNG city buses without any modifications of the fuel system or engine set points or hardware.

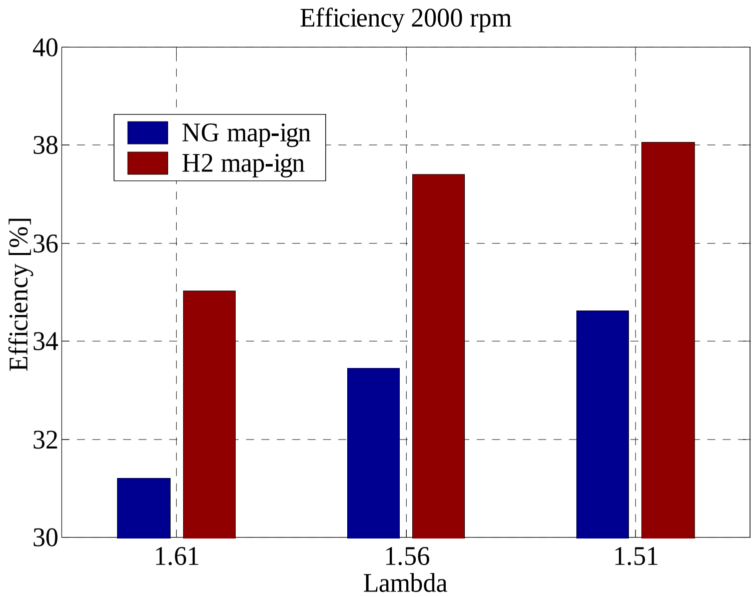
- H2/CNG with a blend of 20%vol hydrogen; A larger portion of the fuel is produced locally and more environmental benefits can be achieved. This heavier mix of hydrogen into the CNG cannot be considered as natural gas. A modification of the engine set points for ignition and fuel injection is required. A comprehensive safety check of the fuel system of the buses has been performed.

3. The bus project, engine improvements

The background of the bus project to use a mixture of hydrogen and CNG are

- To use a locally produced fuel
- To improve the efficiency and the operation of the engines
- To decrease emissions, both local emissions and CO_2

Two buses of the local bus fleet have tested CNG mixed with 8 $\%_{vol}$ of hydrogen as fuel without any modifications of the lean-burn CNG engines for more than one year. The Lund Institute of Technology at Lund University, Sweden, has confirmed significant improvements in fuel efficiency, more stable operation of the engine and reduction of emissions by performing bench testing of the engines. Measurements of efficiency, emissions, combustion variations, knocking etc have been performed during different conditions.



*Brake efficiency in %
with 8% Hydrogen mix into the CNG
compared with pure CNG for different
air/fuel ratios.*

Fig 4. Brake efficiency 8_{vol} % Hydrogen

It is reasonable to expect that the brake thermal efficiency could increase with hydrogen mixed into the CNG fuel as compared to pure natural gas since the combustion duration is reduced. With reduced combustion duration the effective expansion ratio increases and more work can be extracted from the gas. This increase in efficiency is likely to be the highest where the combustion duration is long with natural gas, i.e. at lean conditions./1/.The Volvo TG100 engine used in the local city is lean burning engine and can thus profit from the use of the mixture of hydrogen and CNG as fuel.

The increase in efficiency together with the reduction of the carbon content in the decrease the emissions of CO_2 substantially fuel when the use of hydrogen as a fuel additive.

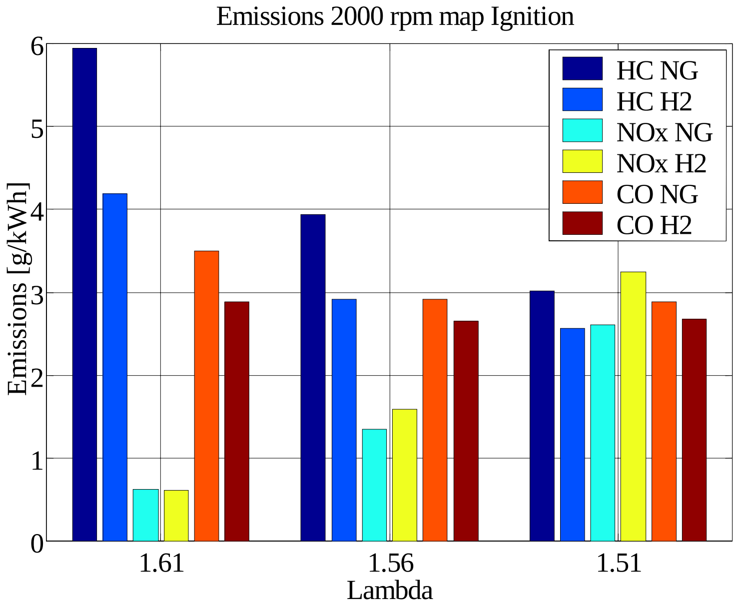


Fig 5. Emissions 8 vol % Hydrogen

Emission values from tests with 8% Hydrogen mix into the CNG compared with pure CNG for different air/fuel ratios

Lambda= air/fuel ratio

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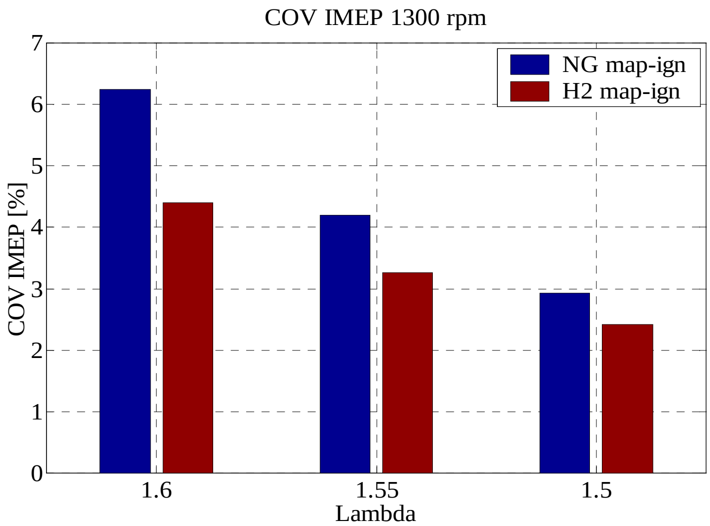
A mix of hydrogen into the natural gas creates a faster combustion and thus more efficient combustion. Lower emissions of HC and CO are then achieved, as the combustion is more efficient. The higher combustion temperature can though increase the NOx emissions. This can be avoided by using a higher air/fuel ratio and/or less spark advance.



H2 = mix of 8% hydrogen and CNG

COV: Coefficient of variation
Lambda= air/fuel ratio

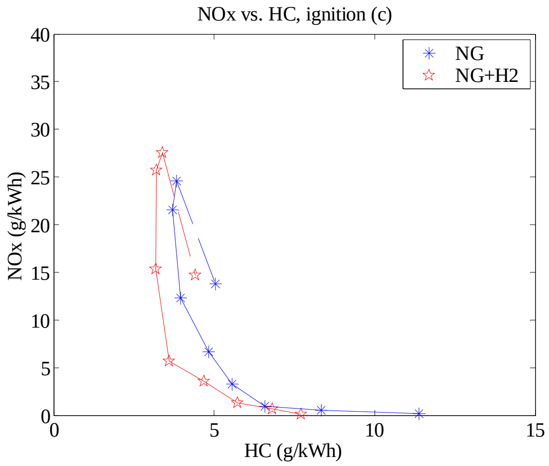
Fig 6. Engine stability 8 vol % Hydrogen

The flame speed of hydrogen is much higher than that of hydrocarbon fuels. Adding hydrogen to natural gas is thus likely to increase the flame speed of the charge. This could be used to extend the lean limit of the natural gas engine to air/fuel rates ratios where pure natural gas provides insufficient burn rate for stable combustion./1/

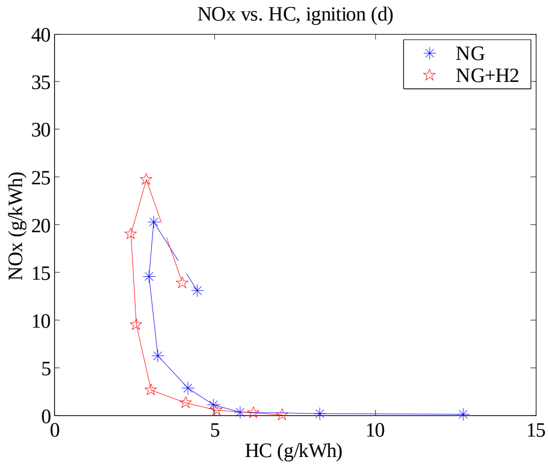
Summary of the conclusion with the measurements in a laboratory with a mixture of 8 $\%_{vol}$ into the CNG using a Volvo TG100 engine.

- Higher efficiency
- More stable combustion, due to a faster combustion (less cycle to cycle variations)
- A slight increase in power
- Lower HC and CO emissions because of higher combustion efficiency
- Higher or similar NOx emissions (with no changes applied to fueling or spark)
- Slightly higher knock tendency

Further test with a 20% hydrogen mix in the CNG have been performed in the laboratory. These tests show significant improvements. The reduced combustion duration increases the efficiency significantly and enables the reduction of NOx emissions by using a higher air/flow ratio combined with optimised ignition timing. The reduction of CO_2-emissions is substantial.



Figur 7: HC - NOx trade-off with natural gas and Hythane. The markers represent different air/fuel ratios. Intermediate ignition timing strategy.



Figur 8: HC - NOx trade-off with natural gas and Hythane. The markers represent different air/fuel ratios. Retarded ignition timing strategy.

The above figures show results from engine tests with $20\%_{vol}$ hydrogen mixed with CNG. It shows the trade-off between HC and NOx emissions when different ignition angels have been used. The different measurements shown represent different air/fuel ratios. Extreme air/fuel ratios can lead to other problems like instable engines or too high knock tendency etc.

Furthermore is also the other the harmful emissions significantly decreased as the carbon content of the fuel has decreased with the heavier blending of hydrogen in the fuel. This is especially significant for the reduction of CO_2 emissions.

4. The status of the bus and vehicles operation

The operation with the mixture of 8_{vol} % hydrogen in the natural gas started in September 2003. Two city buses have used the Hythane fuel with 8 % hydrogen. This has been done without any modifications of the engines. The buses could then also use CNG as fuel if needed.

The heavier mixture with 20_{vol} % hydrogen in the CNG has been used since the beginning of year 2005. This has required modifications of the mapping of the engine both for ignition and the air/fuel ratio. Connecting a PC for adjustments of the control system of the bus engine did the necessary modifications. There have not been any hardware modifications done. A comprehensive study of all components regarding safety has been performed by the engine manufacture.

The long-term vision is to use a mixture of hydrogen and CNG in all the city buses.

An emissions test on the engines on buses in operation will be performed later this year. The test will be made on a certain road where equal conditions can be obtained during the test period.

Several passenger cars have tested the low-grade 8_{vol} % Hythane fuel with good results. There is a foreseen project to test 10 passenger cars including taxis and other service vehicles running on Hythane for a longer test period.

A few hydrogen vehicles have visited the filling station but there are not yet any demonstration projects for vehicles running on pure hydrogen.

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