The Innovative Technology of Hydraulic Compression and Boosting for Filling the Vehicles and Storage Systems with Natural Gas and Biomethane

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Abstract – The article describes the technology of the “hydraulic piston”, as well as the studies that confirm the viability of this technology, implemented in various devices, designed to compress natural gas (CNG) and biomethane (bio-CNG), to accumulate CNG and bio-CNG, to deliver bio-CNG from the production site to the point of its injection into the natural gas network or to the vehicle fuelling stations to fill the Natural Gas Vehicles (NGV). The article presents prototypes of personal fuelling devices and mobile fuelling systems developed by Hygen Ltd. (Hygen), thereby showing the potential of the technology to contribute in the deployment of alternative fuel infrastructure and into the global GHG emissions reduction, mainly in the transport sector.

Keywords: Alternative fuel; compressed biomethane (bio-CNG); compressor; decarbonisation; gas storage; greenhouse gas (GHG); renewable gas

Nomenclature

bio-CNG	Compressed biomethane
bcm	Billion cubic metres
CF	Cascade fuelling
CNG	Compressed natural gas
EU	European Union
EV	Electric vehicles
GHG	Greenhouse gas
ICEV	Internal combustion engine vehicles
NGV	Natural gas vehicle
PF	Parallel fuelling
TRL	Technology Readiness Level
VFA	Vehicle Fuelling Appliance

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1. INTRODUCTION

Accelerating the decarbonisation process, biomethane (renewable gas) can be easily used to fuel the vehicles and to reduce their carbon footprint. Natural gas infrastructure and vehicles are fully compatible with renewable gas, without extra costs. Through renewable gas from municipal waste or Power-to-Gas production pathways, close-to-zero greenhouse gas emissions are achieved. In a recent study from Centre on Regulation in Europe (CERRE) a production potential of 124 bcm/year renewable gas at EU level has been estimated [1].

Implementation of electric vehicles (EVs), especially in highly polluted city centres plays a great role in decarbonisation as well as in noise levels reduction in the urban areas [2]. However, the study of International Energy Agency (IEA) states that in the countries, where electricity production is based mostly on fossil fuels, Well-to-Wheel emissions for EVs are associated even with more GHG emissions than internal combustion engine vehicles ICEV [3].

Natural (also renewable) gas technology is ready to provide a fast and strong contribution to the challenge of decarbonisation. In 2018, several countries devoted considerable shares of renewable gas to transport, namely Iceland (100 %), Sweden (90 %), the Netherlands (55 %), Finland (50 %) and Switzerland (25 %), making carbon neutrality in transport already a reality [4].

The amount of Well-to-Wheel GHG emissions from various automotive fuels, recalculated to CO₂ equivalent, is given in Fig. 1.

Fig. 1. Well-to-Wheel – GHG emissions in CO₂ g/km [5].

The diagram shows that CO₂ emissions are close to zero (5 g/km) only in case, when electricity is produced from the wind (or from similar renewable sources). EU-mix electricity application for transport provides CO₂ reduction comparing to the petrol only as 75 g/km, however bio-CNG shows the same low level of emissions, as E-mobility using wind energy for electricity production. Also, the diagram on Fig. 1 shows that the biogas when blended

with the natural gas, plays a significant role in CO₂ reduction: adding of 20 % biogas to the natural gas gives 39 % of CO₂ reduction, comparing to petrol.

The Directive of the European Parliament and of the Council on the deployment of alternative fuel infrastructure (DAFI) defines the alternative fuels. One of them is the natural gas, including biomethane – the upgraded biogas. DAFI sets out minimum requirements for the building-up of alternative fuels infrastructure, including refuelling points to be implemented by means of Member States' national policy frameworks [6].

The European Biogas Association (EBA), the Natural & bio Gas Vehicle Association (NGVA Europe) and the European Automobile Manufacturers' Association (ACEA) on January 21, 2020 called on EU policy makers to accelerate the deployment of infrastructure to deliver natural gas and renewable gas/biomethane across the European Union [7]. The revised Renewable Energy Directive (RED II), increases the overall EU renewable energy consumption target by 2030 from 27 % to 32 %. RED II sets a minimum transport fuel share of 14 %, which must be produced from renewable energy sources to 2030 [8].

The renewable gas produced today is fully in line with the strictest sustainability criteria established through European legislation. By 2030, the gas mobility market has a growth potential 10 times higher than today, reaching a fleet of 13 million units. In parallel, the production of renewable gas will increase drastically: for 2030, a conservative estimation demonstrates a production potential of close to 45 bcm/year, largely overcoming the entire demand for gas fuel of about 30 bcm/year, which corresponds to a 13-million-unit fleet. This would significantly contribute to the European decarbonisation path: 30 % renewable gas will provide a GHG emissions reduction of more than 45 % compared to conventional fuels on a Well-to-Wheel basis [4].

1.1. Biomethane

Biogas typically contains 55–75 % methane and has an energy value of 5.0–7.5 kWh/m³ (energy value of a pure methane is 9.97 kWh/m³) [9]. In order to use biogas as biomethane fuel, it must be purified to an appropriate quality as defined by national directives. Numerous biomethane purification technologies from biogas are developed, allowing to achieve up to 99 % purification. [10]

Biomethane production delivers CO₂ neutral production. It particularly suits on-farm use by agricultural vehicles as farmers already possess the raw materials and the space to produce the biogas and upgrade it up to biomethane. This enables agri-business to be fuel sufficient. In addition, biomethane can be injected into the gas grid to power communities, creating a truly virtuous cycle.

1.2. Currently Available Technologies of NGVs Fuelling

Existing technologies allow biogas compression and dispensing by widely presented on the market mechanical CNG compressors, e.g., *COLTRI* [11] or *FuelMaker* [12]. They can be installed on biomethane production site and perform light duty and agricultural vehicle fuelling by time-fill, requiring 5–8 hours, depending on the productivity of compressor and volume of the vehicle's fuel tank. Existing vehicle fuelling solutions employ reciprocating compressor technology and due to that are less reliable. These compressors use an electric motor to rotate a crankshaft, which is tied to several metal pistons that pump to compress the gas. This technology requires pistons and piston rings, crankshaft and bearings, cylinders and valves. Since all these components generate friction and heat during operation, the compressor and related components require regular maintenance and a complete compressor

overhaul at specified service intervals, which is costly. And, even with a regular servicing, unexpected component failure is often experienced [13]. In many cases, the combined maintenance costs end up being higher than the cost of the equipment itself. Since most of the components in reciprocating compressor solutions are specifically designed and manufactured, these tend to cost more and often have longer lead times for replacement parts. In addition, reciprocating compressors may cause unwanted vibration, and resonance in the pipelines [14].

To deliver biomethane from the production site to the customer or to the point of injection into the gas grid the mobile storage systems are applied. The existing on the market mobile storage systems allow to avoid the development of the costly new pipelines, however they require mother station on the biomethane production site and daughter compressing stations on the vehicle fuelling site, that adds the costs to such a project. Besides that, the existing mobile storage systems, based on free gas flow dischargement principle (both buffer and cascade), does not allow complete discharge of the storage system, - the “parasitic” volume of gas will always present in the storage cylinders [15].

1.3. Main Challenges for Biomethane Application in Transport Fuelling Sector

The technical problems of widening biomethane application to be resolved are:

- storage cylinders filling to high pressure in efficient way;
- bio-CNG delivery to the destination (injection point to the grid or fuelling station);
- development of an efficient fuelling appliance for on-farm application;
- complete gas storage cylinders dischargement.

The complete dischargement of the gas storage cylinders is a quite challenging task, because the fuelling from the gas storage systems, when being performed by a free flow of gas ends when the pressures are equalized between the gas storage cylinders and the target fuel tank. Simultaneous discharge of multiply storage cylinders is named “parallel fuelling” (PF). Another option is a serial discharge of multiply storage cylinders, named “cascade fuelling” (CF).

Comparing PF vs CF, the major benefit of CF is that this method refuels the target tank to higher pressure. Fig. 2 displays numerical simulation of filling of a 130 L target tank with initial natural gas pressure of 5 bars from the storage of four cylinders, 22 L each, being filled with compressed to 200 bar natural gas, by both PF and CF methods.

Fig. 2. Numerical simulation of complete cascade fuelling (CF) and parallel fuelling (PF).

From Fig. 2 it is seen that CF reaches 109 bars in the target tank, comparing to 90 bars of the PF. The third cascade fuelling step out of four almost reaches the ending pressure of PF. Nevertheless, the possible achievement of the multiple cascades of reasonable number is far from required pressure, close to 200 bars, in a target tank. Besides that, the cascade principle has a significant disadvantage – multiple cylinders require complicated piping and valve triggering circuits. The only reasonable way to discharge the storage volume close to entirely is to employ a kind of boosting, i.e., to apply a pushing force.

2. METHODS AND METHODOLOGY

Latvian engineer Aleksey Safronov has invented and patented in 2008 a new method for hydraulic compression of gaseous fuels (Hydraulic piston) and a device for implementation thereof (the international application number: PCT/LV2008/000007, dated September 9, 2008) [16]. Hygen has developed the Technology of hydraulic piston and implemented it in various compressed natural gas vehicle fuelling systems intended for gas compression, accumulation and discharge (extortion). Unlike conventional and world-wide available mechanical multistage compressors, the technology of hydraulic piston uses a method of gas compression by means of a working fluid, which is pushed by a sufficiently powerful hydraulic pump. The technology of hydraulic compression allows to solve all problems mentioned in section Main Challenges for Biomethane Application in Transport Fuelling Sector, with minimal costs, since devices made on the basis of hydraulic piston technology use mass-produced components widely available on the market. By solving economic problems of gas compression and delivery the technology opens the door for wider application of bio-gas on transport. This contributes to solving the environmental problems associated with the effects of greenhouse gases from transportation that cause climate change, and the social problems associated with the impact of noise and harmful emissions on human health.

2.1. Method of the Hydraulic Piston Compression

Hydraulic gas compression has many significant advantages over a mechanical, where the latter is characterised by a high noise level, high temperature, rapid wear of moving parts.

The technology of hydraulic piston can be explained with a help of Fig. 3:

Fig. 2. Hydraulic piston compressor and storage.

Cylinders 1 and 2 are paired to form a hydraulic compressor. The amount of the working liquid (red fill in Fig. 3) slightly exceeds the volume on one compressing cylinder. The working liquid is transmission oil that has been chosen to avoid any chemical reaction with the gas, as well as to have minimal gas diffusivity. One of the compressing cylinders is filled with low pressure gas, the other one – with hydraulic liquid. By rotating the hydraulic pump and triggering the valves, the working liquid is alternately pumped from one of the compressing cylinders to another and back. Supplying the liquid to the cylinder, which is filled with gas, results in gas compression and forcing out into the storage cylinder. At the same time, decrease of liquid level in another compressing cylinder allows a new portion of low-pressure gas to be supplied into this cylinder. Such alternative pumping of hydraulic liquid results in gradual pressure growth in the storage cylinder 3 up to 200 bars (at 15 °C), preparing the device for fuelling a vehicle. The main technological problem was to prevent the penetration of the working liquid from the compressing cylinder into the gas line. This problem was solved by invention of the multi-valve, which is placed in the neck of the compressing cylinder and provides a safe shut-off, when the working liquid reaches the top of the compressing cylinder. The multi-valve is a part of the Hygen patent [16].

2.2. Method of Hydraulic Piston Boosting

In order to empty the storage cylinder 3 of gas far behind the free flow principle, the boosting mode is implemented. The principle of boosting is displayed in Fig. 4.

Fig. 3. Hydraulic piston operating in a boosting mode.

At connecting the storage tank to the vehicle's filling nozzle, the fuelling occurs by free flow until pressure equilibrium is achieved. After the free flow stage, the remained high-pressure gas from the storage cylinder (light blue arrow) is supplied to the compressing cylinder for boosting, where it is further compressed (by acting the hydraulic piston) and forced out directly into the vehicle's fuel tank (dark blue arrow). Boosting cycles repeat alternately in the compression cylinders. The number of boosting cycles to achieve 200 bars pressure in the vehicles fuel tank depends on the volume and initial pressure of the tank. In case

of a light duty vehicle with a standard fuel tank, 1–3 boosting cycles will be enough to fill the vehicle completely.

3. RESULTS

The hydraulic piston technology was tested in the framework of *Plan of Latvia Development 2020*, in a research project KC1.2.1.1/18/A/008 lead by *Mechanical Engineering Competence Centre* and by *Hygen* proven team of high-level specialists from engineering, hydraulics, electronics and physics. The tests were performed on a *Hygen* testing bench.

The aim of the project was to test the behaviour of hydraulic piston at different inlet pressures and to study the technology at higher inlet pressures and flow rates, i.e., at boosting stage conditions. All tests have been performed with the aim to develop economically efficient smart vehicle fuelling appliance, capable to provide vehicle fuelling up to 200 bar pressure. Performed tests simulated different vehicle tank volumes, different inlet pressures and different emergency situations. The boosting mode was tested on the testing bench with two pairs of compressing cylinders and four storage cylinders. Electricity consumption, as well as gas quality after its contact with hydraulic piston were measured.

3.1. Gas Inlet Pressure Tests

The compression mode has been tested at various gas inlet pressures in a wide range. The hydraulic pump with productivity of 8.6 L/min, driven by 4 kW electric motor was applied. During each test a 100 L storage cylinder was filled with natural gas up to 200 bars. Gas flow rate has been calculated at three gas inlet pressure steps, Table 1.

TABLE 1. HYDRAULIC PUMPING RATE AT THREE GAS INLET PRESSURE STEPS

No.	Gas inlet pressure, bar	Flow rate, m ³ /h	Pumping rate to inlet pressure, m ³ /h·bar
1	3	1.14	0.38
2	6	2.3	0.38
3	16	5.17	0.32

Results of Table 1 testifies that flow rate, related to gas inlet pressure, starts slightly reduce after 6 bars, and the reduction is less than 20 % up to 16 bars. Such characteristics is eligible for a proper compression of gas at inlet pressures in impressive 17 mbar – 16 bar range.

3.2. Boosting Stage Tests

If the volume of the target tank is smaller than that storage capacity of the testing bench, fuelling up to 200 bars is rather simple and fast. For example, to fill a volume of 240 L the compressor operated in a boosting mode for about 13 min, and the total electrical consumption of the device during this period is 1.12 kWh. The gas temperature in the tank first decreases until –8 °C due to the gas expansion and then increases to 35 °C at the end of the filling (ambient temperature at 8 °C). Fig. 5. displays fuelling the target tank of 240 L at 85 bars from the storage capacity of 400 L at 200 bars.

Fig. 4. Boosting stage of fuelling a target tank.

As the volume of the target tank is smaller, 400 L storage capacity is enough to fill the target tank up to nominal 200 bars. It takes 5 hydraulic boosting cycles and about 760 s of time, Fig. 5.

3.3. Temperature Tests Results

The tests proved that during both compression and boosting cycles the downstream temperature of the gas does not reach the safety threshold of any type of a standard fuel tank.

Two different cooling systems were tested: liquid and air. Both of them showed good results. Temperature of the gas supplied to the target tank after compression and after boosting modes did not exceed 60 °C. The air-cooling system was chosen for application in the prototype due to its simplicity comparing to the liquid cooling system.

3.4. Gas Analysis

With the liquid piston compression and boosting the gas fuel is in molecular contact with the working liquid, periodically up to 200 bars pressure. It is necessary to ascertain, are not the liquid molecules captured by gas, thereby making the gas fuel polluted.

Gas analysis was performed as follows: the natural gas sample has been taken at the outlet of the Hygen testing bench on a 1 L 40 bars pressure cylinder. Additionally, natural gas at the outlet of the network has been sampled in order to evaluate the composition modification after a contact with working fluid under 200 bar pressure. The analysis has been performed using *Thermal-Desorber/Gas-Chromatography/Mass Spectrometry (TD/GC/MS)* and *micro-Gas Chromatography (μGC/MS)*. The results of these gas analysis are presented in Table 2.

If the general differences regarding the Aliphatic hydrocarbons are not significant between the two samples, one can notice that the heavy aliphatic hydrocarbons C14-C16 is rather high (0.9 mg/cm³). This might originate from the working liquid of the compressor that could volatilize into the gas fuel.

TABLE 2. RESULTS OF GAS ANALYSIS

Permanent gases	C Number	Reference	HYGEN
CH ₄ %	–	92.64	89.92
CO ₂ %	–	0.8	1.79
N ₂ %	–	1.43	1.22
COV mg/m ³	C Number	Reference	HYGEN
Total Aliphatic Hydrocarbons mg/m ³	–	79 539	111 200
Ethane	C2	53 831	69 170
Propane	C3	11 498	24 023
Isobutane	C4	6825	7520
Butane	C4	3132	6112
Aliphatic hydrocarbons >C6–C8	C6–C7	2158	1626
Aliphatic hydrocarbons >C5–C6	C5	2005	2717
Aliphatic hydrocarbons >C8–C10	C8–C9	85	24.5
Acetylene	C2	3.8	4.4
Aliphatic hydrocarbons >C10–C12	C10–C11	0.82	1.26
Aliphatic hydrocarbons >C12–C14	C12–C13	0.07	0.09
Aliphatic hydrocarbons >C14–C16	C14–C15	< 0.06	0.9
Alcohol mg/m ³	C Number	Reference	HYGEN
1-Butanol (n-Butanol) mg/m ³	–	< 0.06	2.9
Ester mg/m ³	C Number	Reference	HYGEN
2-Propenoic acid, 2-methyl-, butyl ester	–	< 0.06	0.07
Mercaptan /Sulfure mg/m ³	C Number	Reference	HYGEN
Hydrogen disulphide (H ₂ S)	–	< 1.5	< 1.5
Silane/ Siloxane mg/m ³	C Number	Reference	HYGEN
Cyclotetrasiloxane, octamethyl- (D4)	–	< 0.06	0.09
Total COV (without H₂S) mg/m³		79 605	111 250

The presence of siloxane was observed at the outlet of *Hygen* testing bench with a non-significant value closed to the detection limit. One of the reasons of this observation could be a pollution of the *Gas Chromatography* column. Measured 0.09 mg/m³ is however compliant with the limit of EN 16723-2 [17], which set the limit of silica compound at 0.3 mg Si/m³.

The overall gas composition at the outlet of *Hygen* testing bench is satisfactory for the use in a gas engine of an NGV. The marginal differences in term of permanent gas and hydrocarbons does not seems to originate from the compressor but rather on the fluctuating composition of natural gas coming from the network.

3.5. Products Developed on the Basis of Hydraulic Piston Technology

Hygen has implemented the hydraulic piston technology in three products: *GasDroid*, *HYGEN+* and *GasLiner*.

3.5.1. GasDroid

GasDroid, (Fig. 6) is developed to TRL 8, i.e., the device is complete and qualified.

Fig. 6. VFA *GasDroid*.

GasDroid is a certified vehicle fuelling appliance (VFA) intended to fuel light duty vehicles with CNG and/or bio-CNG by self-flow of gas from *GasDroid* internal storage to the vehicle's fuel tank. *GasDroid* is equipped with two compression cylinders 33 L each and four storage cylinders 21 L each. *GasDroid* is capable to supply a vehicle with a portion of fuel providing 120–150 km of the daily run. The specifications of *GasDroid* are detailed in Table 3.

TABLE 3. SPECIFICATIONS OF GASDROID

Compression flow rate	1.2 m ³ /h
Gas outlet pressure	200 bars
Storage capacity	84 water litres
Fuelling time	4 min
Electrical power	0.5 kW max 6 A
Power supply line	220 V
Gas inlet pressure	17–25 mbar or 3 bars
Dimensions L x W x H (cm)	90 × 50 × 1765 cm
Weight (with working liquid)	390 kg

GasDroid can be installed on the biogas/biomethane production site to be operated as follows.

1. Preparation for the fuelling or high pressure gaining: biomethane is compressed within compressing cylinders and accumulated in the storage cylinders. Compression mode can last up to 3 hours, depending on the pressure of the biomethane on the outlet of the upgrade plant (usually 10 bar) and on the pressure left in the *GasDroid* internal storage after the previous fuelling.
2. Vehicle fuelling: compressed biomethane flows freely from the internal storage cylinders of *GasDroid* to the vehicle's fuel tank. Fuelling process lasts 4 minutes to equalize pressure between the storage and the target tank (approximately 80–110 bars, depending on the size of the target tank), thus supplying the vehicle with a daily portion of fuel for 100–150 km of run.

3.5.2. *HYGEN+*

HYGEN+, (Fig. 7) is an Alpha prototype of VFA, which is supplied with the boosting feature.

Fig. 7. VFA *HYGEN+* for commercial vehicle fuelling, with a boosting feature, manufactured by *Hygen*.

It has integrated four compression cylinders 33 L each and four storage cylinders 95 L each. The whole system is optimized for complete fuelling of vehicles having fuel tank capacity up to 300 L, up to 200 bars in 15–20 minutes, depending on the remaining pressure in the vehicle's fuel tank before fuelling. The specifications of *HYGEN+* are detailed in Table 4.

TABLE 4. SPECIFICATIONS OF *HYGEN+*

Compression flow rate	4.4 m ³ /h
Gas outlet pressure	200 bars
Storage capacity	380 water litres
Fuelling time	up to 25 min for 60 m ³ at 200 bars
Electrical power (2 pumps)	4 kW max 7.9 A
Power supply line	380 V (three phase)
Gas inlet pressure	17–25 mbar or 3 bars and above
Dimensions L × W × H (cm)	120 × 100 × 170 cm
Weight (empty)	1500 kg

HYGEN+ can be installed at biomethane production site and serve for vehicle working as follows.

Preparation for the fuelling or high-pressure gaining that lasts for 4–6 hours, depending on the pressure of biomethane after purification (approximately 10 bars) and initial pressure in the storage after the previous fuelling. Biomethane will be compressed within compression cylinders and accumulated in the storage cylinders.

Vehicle fuelling proceeds in two stages:

Stage 1: Free flow of gas from the internal storage cylinders of *HYGEN+* to the vehicle's fuel tank, that lasts for ca. 4 minutes to equilibrate pressure between the storage and the target tank (70–120 bars, depending on the size of the target tank);

Stage 2: Boosting – remained medium high pressure gas from the storage (70–120 bars) is supplied to the inlet of the compression cylinders alternately for additional compression and pushed to the target tank, until 200 bars pressure in the target tank is achieved (it can take up to 6 compressing cycles to fill the target tank of 240 L).

3.5.3. GasLiner

For various off-grid situations *Hygen* proposes a cost-effective and convenient solution – a mobile bio-CNG system named *GasLiner*. Currently an Alpha prototype of *GasLiner* is developed. It is capable to:

- compress the gas (biomethane) by itself, i.e., without usage of a mother station;
- accumulate compressed to 250 bars gas in its storage cylinders;
- deliver gas (biomethane) to the selling/distribution points;
- fuel simultaneously any number of vehicles (being connected in parallel) with CNG (bio CNG) in 1.5 hours without using a daughter station.

Avoiding employing the mother and daughter stations in the virtual pipeline system, *GasLiner* allows a significant reduction of the whole virtual pipeline costs for all kind of gaseous fuels. *GasLiner* has a modular structure that allows to form a system of any capacity. Developed *GasLiner* module with dimensions (L × W × H) 162 × 240 × 271 cm is shown in Fig. 8. Eight modules can be placed on a standard platform, carrying up to 8000 m³ of CNG/bio-CNG) on board.

Fig. 8. *GasLiner* modules in mobile and stationary application.

As measured, off-grid fuelling process reached very high 98 % efficiency with a flow rate of biomethane of 80 Nm³/min. Besides that, *GasLiner* module can also be used as the stationary fuelling off-grid station, to be supplied with bio-CNG by *GasLiner* mobile trailer and providing vehicles fast fuelling with CNG/bio-CNG.

4. CONCLUSION

To accelerate the decarbonisation of the planet, the biomethane, as a motor fuel, has a promising potential. The greatest challenge for that is to create an efficient fuelling infrastructure. *Hygen* has developed an innovative technology of hydraulic piston, allowing to produce a wide spectrum of vehicle fuelling appliances for bio-CNG fuel. The further development of this technology shall be focused on creation of flexible solutions, applicable at biogas/biomethane, production sites, for bio-CNG compression, transportation and fast

discharging to the NGVs or injection into the gas grid in a cost effective and convenient way. The technology has a great potential and needs to be explored and developed further for application with hydrogen. As stated by European Commission in 2020, hydrogen is predicted to be the fuel of the future [18], [19]. Hydraulic compression allows to achieve higher compression ratios required for hydrogen, solving the existing problems arising from employment of reciprocating compressors [20], as well as benefits the idea of combustion hydrogen enriched CNG in sparkle ignition engines of NGVs [21]. Potentially the technology of hydraulic piston allows to develop the emerging hydrogen market in two ways: enabling gas grid decarbonisation through hydrogen blending with natural gas and as a new compression solution for hydrogen as vehicle fuel.

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