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Sustainable LNG Technology

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Sustainable LNG Fuel Systems and Technology

Introduction

Every aspect of life on Earth is driven by energy. The evolution of the human race especially is closely related to the availability of energy and the development of the technology to harness and control this energy. One early "fuel" was obtained by harnessing the energy of the wind, which brought about the development of windmills and sailing ships. The unpredictability of the wind made it inevitable to search for an independent source of energy, energy that could be stored and utilized at will. Coal became that first dense energy source available on a large scale. From 1700 onwards it fueled the early steam engines that drove the industrial revolution initiated and supported by the strongly emerging development of the technical sciences. From the 20^{th} century on, it has been mainly coal, oil, natural gas and nuclear energy that has powered the ever-growing industrial revolution and transformed the world from a semi-stationary society into the mobile, energy-hungry society of today. However, we have also become aware of how vulnerable we are to the availability of energy, long taken as granted, and the consequences that using them on such a vast scale has for the environment; alleviating this situation has become a principal driver in the further development of more durable energy sources.

Figure 1: LNG in an open vacuum insulated glass dewar

This is where natural gas in both its gaseous and liquid state can play an important role in the future global energy mix. Often the argument is head that LNG is bad for the environment as it is also a fossil fuel and should therefore be abandoned as well. However it is good to realize that even fossil based LNG fuel has the potential to lower the CO_2 emission with 20%. Natural gas, from which LNG is made, is also certainly available for another 200 years and is found on many places on earth in large quantities which makes it political less sensible and helps to ensure our energy needs in the future and allows a sensible time to realize a realistic energy transition scenario. Natural gas can also be produced from bio-waste, which making it a green fuel as well when it becomes available in larger quantities using the same LNG fuel technology. LNG fuel technology is developed for trucking, shipping, aviation and industrial use.

The use of natural gas was mentioned in China as early as 900BC, was re-discovered in America in 1626 by French explorers but was unknown in Europe until its discovery in England in 1659. From 1720 on, natural gas became the fuel to illuminate streets and houses. From 1920 on, natural gas has been used for domestic and industrial heating on an ever-growing scale as the technology for engineering long-distance distribution pipe networks became available.

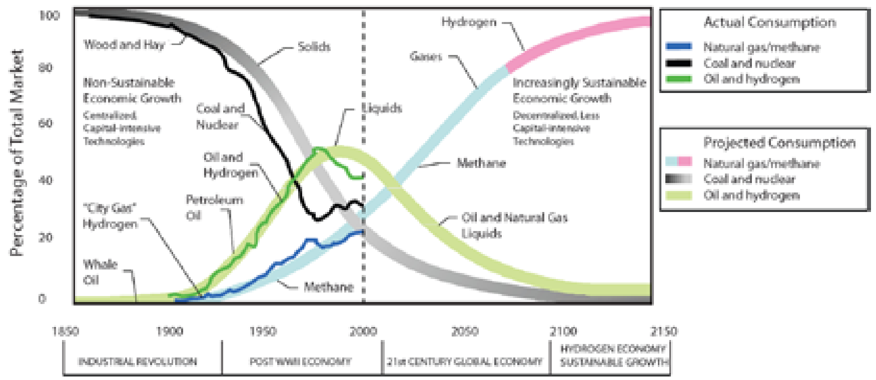
Liquefied Natural Gas (LNG) began its commercial life in 1914 with a patent on LNG handling and shipping followed by the first commercial LNG liquefaction plant in 1917 but it took till 1964 before serious LNG trade developed between Algeria and the UK. After the first oil crisis in 1973 there was a rapid increase in the trade of natural gas and LNG while the growing availability of natural gas (current global reserves estimated at 275 years) underlined the environmental advantages of LNG as fuel: 15% lower CO_2 emission, 90% reduction in fine-particles emission, SO_x and NO_x emissions and the possibility to blend in bio-based hydrocarbons and P2G produced hydrogen.
Figure 2 shows the growth of the fossil fuel market since 1850.

Let us focus on the key challenges and opportunities of LNG fuel technology in a future green LNG fuel supply chain.

The Natural Gas Economy

Let us first define what natural gas is. Traditionally, natural gas is a fossil fuel like oil and coal, and this means that it is, essentially, the remains of organic materials from millions and millions of years ago. But natural gas can also be harvested from the breakdown of recent organic material, or biomass. But how do these organic materials become an inanimate mixture of gases?

Figure 2: The historic growth of the fossil fuel market since 1850 and its expected development..



Source: Texas State Technical College, 2008

Fossil Natural Gas

The most widely accepted theory says that fossil fuels, oil and natural gas were formed when organic matter (such as the remains of plants or animals) was compressed deep under the Earth, at very high pressure and temperature (deep deposits) for a very long time. It is referred to as thermogenic methane. The high temperature breaks down the carbon bonds, and this forms methane, as opposed to oil. At lower temperature (shallower deposits), more oil is produced relative to natural gas.

Durable Natural Gas

Natural gas formed through the breakdown of organic matter by tiny microorganisms is referred to as biogenic methane. These microorganisms are commonly found in areas near the surface of the Earth that are void of oxygen. Methane produced in that way is usually lost into the atmosphere. Also the earth's population produces methane as part of their digestion process that is directly vented into the atmosphere as well (see figure 3).

In the period 2003-2005 the Envisat satellite measured the methane concentration in the Earth's atmosphere, generating the following map (figure 4) that looks spectacular but actually the measured concentrations are very low.

Figure 3: The natural methane emission from earths life.

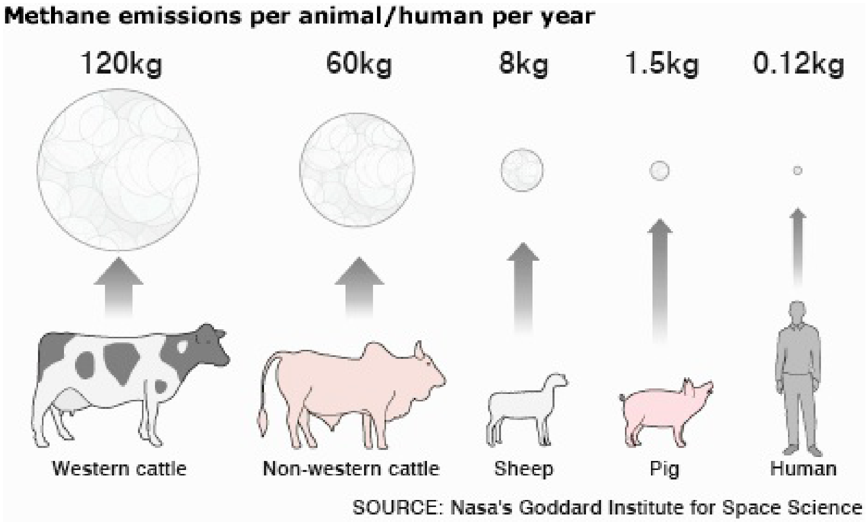
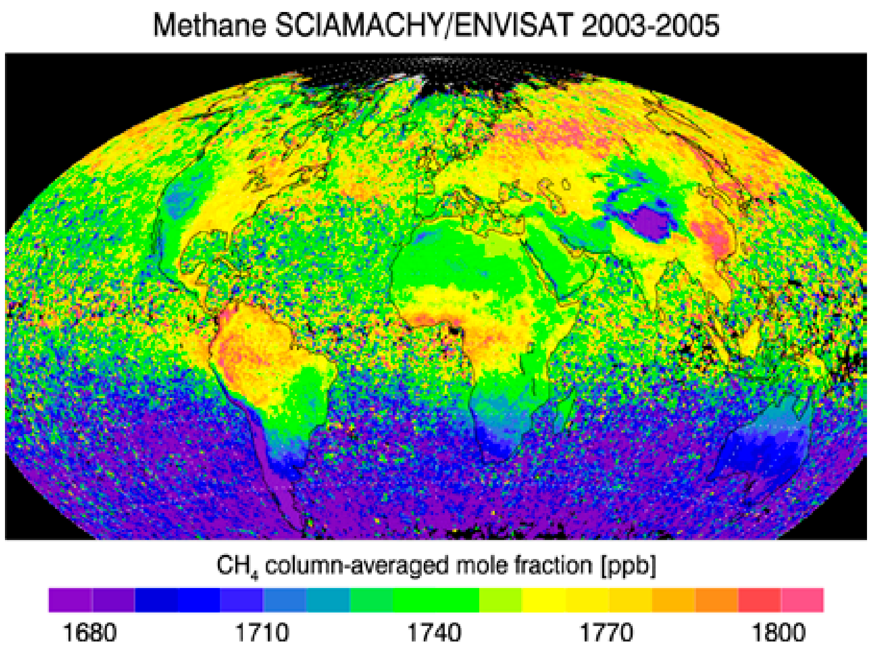


Figure 4: Methane concentration in earth's atmosphere as measured from space



Source: University of Bremen http://www.iup.uni-bremen.de

Natural Gas Components		Fossil NG	Biogas	LNG
Methane	CH_4	70 – 90%	45 – 60%	81.57 - 99.73%
Ethane	C_2H_6	0 – 20%		0.08 - 13.38
Propane	C_3H_8	0 – 20%		0.01 - 3.67
Butane	C_4H_{10}	0 – 20%		
Carbon Dioxide	CO_2	0 – 8%	40 – 60%	
Oxygen	O_2	0 – 0.2%	0.1 – 1.0%	
Nitrogen	N_2	0 – 5%	2.0 – 5.0%	0.2 – 1.0%
Hydrogen Sulfide	H_2S	0 – 5%	0.0 – 1.0%	
Mercury	Hg			
Ammoniac	CH_3		100ppm	
Various		H_2, Ar, He, Ne, Xe	H_2, CO, NH_3	traces

Under certain circumstances, methane can be trapped underground or in a controlled way in a biomass reactor vessel, and can be harvested as natural gas. The composition of fossil natural gas differs from the bio-based natural gas as the following table shows.

Based on this table I now want to make a few statements:

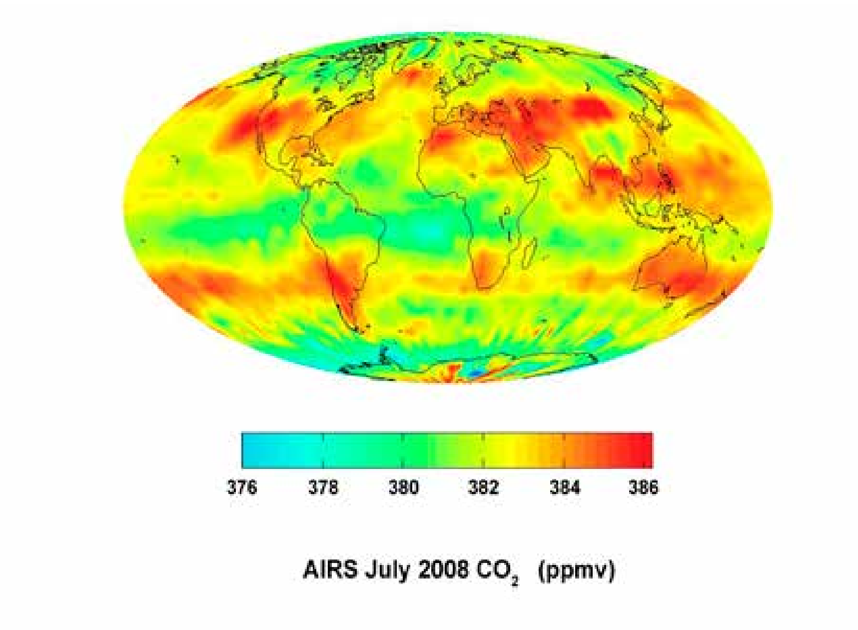
1. Independent of its source, natural gas has to be pre-processed to make it suitable for particular end users.
2. Biogas has a high CO_2 content in relation to the methane content. Both of these gases are greenhouse gases and must be captured in the processing plans to prevent venting to Earth's atmosphere.
3. Fossil natural gas has a low percentage of CO_2 that is part of the natural gas composition as delivered to end-users and that is vented into the atmosphere. The CO_2 concentration in earth's atmosphere in 2008 is shown in figure 5
4. In the LNG production CO_2 must be removed from the natural gas stream and is injected into the source. LNG therefore gives a smaller CO_2 footprint than gaseous natural gas.

Downstream LNG and the LNG fuel supply chain

The LNG fuel supply chain is devided into upstream and downstream LNG chains. Upstream LNG contains the large scale LNG production from natural gas sources, distribution using large LNG carriers and storage in LNG receiving terminals as the Vopak Gate terminal at the Maasvlakte. This terminal can be seen as the starting point for the downstream LNG chain.

The item I particularly want to discuss here is the downstream or small-scale LNG supply chain, part of which is known as the LNG fuel supply chain.

Figure 5: CO2 concentration in earth's atmosphere as seen from space.

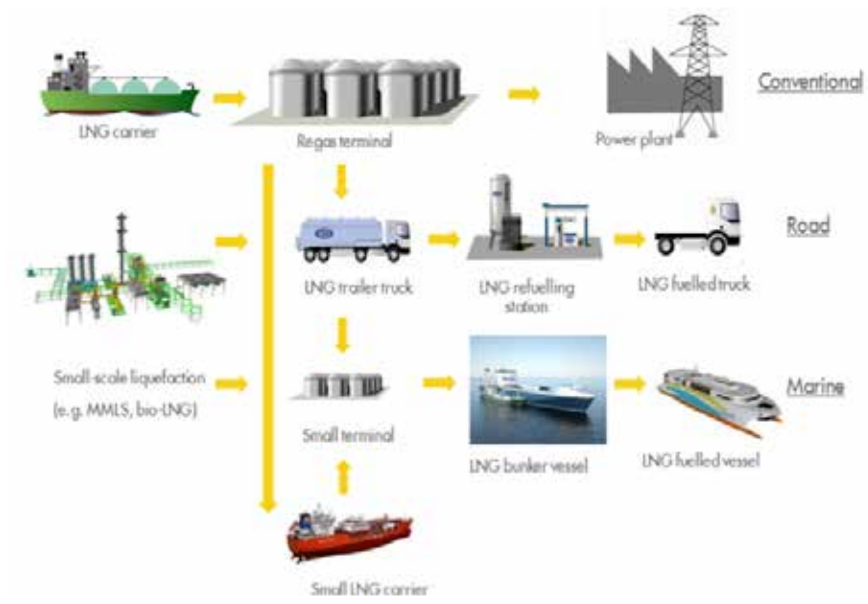


Source: http://www.nasa.gov

The generally accepted, traditional downstream LNG supply chain is shown in figure 6. Apart from the traditional flow of LNG, being regassed, conditioned, and fed to the gas grid, the LNG fuel delivery structure is also shown.

The traditional LNG fuel chain unfortunately does not take into account the vast thermal energy that is added to LNG during its production. This thermal energy, at this moment for the Netherlands approximately 200MW, is completely lost in the regasification process, while this energy can be used for many applications if the central regasification is replaced by a de-central regasification at places where the thermal energy is valuable.
An ongoing PhD research in collaboration between Technical University of Eindhoven and Hanze University of applied sciences of Groningen, has as aim to found out the added value of interlink LNG downstream value chain with Hybrid networks to deliver heat and cooling. It contributes to the Hanze University of Applied Sciences Flexiheat program [1], which boosts the knowledge and realization of heating infrastructures in the north of the Netherlands by developing flexible, hybrid, heat networks, highlighting the role of high-efficiency energy technologies and emphasis the interlink between different energy sectors.

Figure 6: The current downstream LNG fuel chain



Source: http://www.nrgbattle.com/cases-and-innovation/

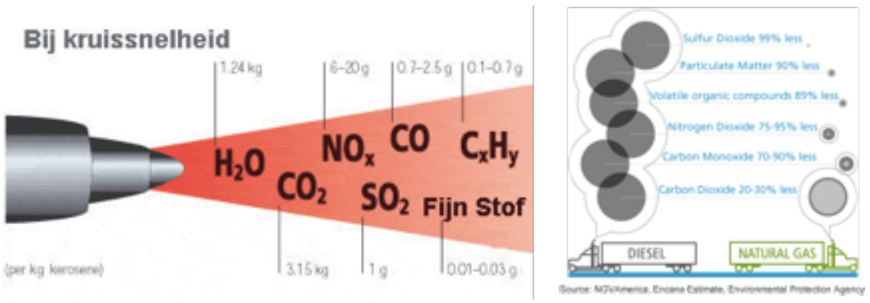
LNG as a Green Fuel for Propulsion

There is a growing interest in the use of natural gas as fuel for the propulsion of trucks, trains, ships and planes. Natural gas is, in relation to already existing and future emission legislation, an excellent fuel and LNG is the most practical way of storing a large quantity of this gas giving the transport sector the endurance they need.

In figure 7 the typical emission gases are shown for kerosene and diesel fuels are shown as well as the positive effect of using natural gas (LNG) as fuel on these emissions.

What can everything said so far on present and future LNG and LNG technology contribute to the layout of a more sustainable LNG fuel chain and thus the LNG fuel market?
Well, a coherent LNG fuel system approach will reveal possibilities that ensure a more sustainable and possibly "green" use of LNG as a transport fuel. By combining Bio-LNG and P2G hydrogen from surplus (windmill) generated electricity as components of the LNG fuel mixture composition, it is possible to define the LNG methane number and Wobbe-index (defining the

Figure 7 : Emission profiles of natural gas fuelled turbines and dual-fuel trucks in comparison with their traditional fuels, kerosene and diesel.



maximum compression ratio in piston engines = thermal efficiency, and the interchangeability of LNG fuels of different composition) relatively independent from the mainstream LNG import and with good opportunities for combustion optimization. This uses a "stabilized" LNG fuel quality definition within a narrow bandwidth, a minimum energy intake for the LNG fuel supply chain and a maximum contribution in achieving the government's environmental goals. It is good to summarize them here because the government's involvement is also an important factor for success.

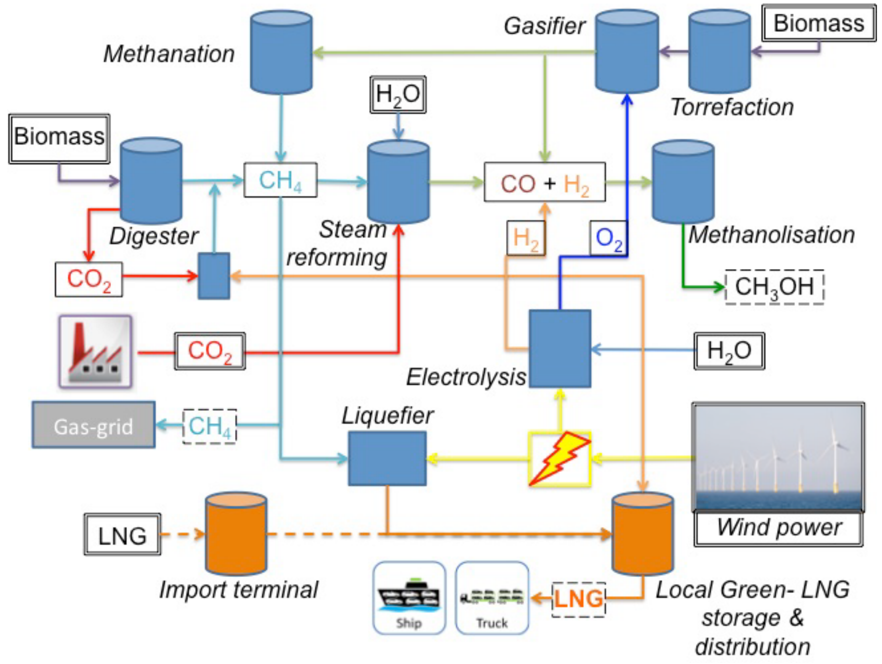
- 20% CO_2 emission reduction by 2020, reference year 1990.
- 20% renewable energy by 2020.
- 20% improvement of energy-efficiency by 2020, reference year 1990.

For LNG fuel this can be translated as:

- Zero methane emission from any part of the LNG fuel chain and LNG combustion.
- CO2 neutral production of LNG fuel (can only be achieved by adding sustainable components).
- Maximum integration of cold energy recovery processes (both CO2 reduction and fuel savings.
- Minimum number of components and/or processes in the LNG supply chain.
- Effective human resource agenda.

It is the intention to start with the development of multi-discipline, multi-scale simulation models that combine mass and energy balances of both physical and chemical processes with economic optimization models for the sustainable fuel chain including wind and bio processes. Simultaneous optimization of the parameters of all processes ensures that the solution of this "smart fuel chain" approach does not only fulfill the environmental requirements but is also an

Figure 8: A template for a sustainable LNG fuel chain combining fossil and sustainable components



economically sound solution that does not depend on subsidy or a special tax or legal climate. These models will be developed in a close collaboration between the Hanze University of Applied Sciences, the TU/e, Energy Technology group with pilot prove of principle at EnTranCe.

Cold Energy Recovery

As already mentioned the use of cold energy is one way to improve the emission neutrality and energy savings in the LNG fuel chain are the use of thermal engines that transfer cold into power. This allows the coupling between the traditional LNG regassification activity with waste heat networks which leads to an different LNG fuel chain where decentralized LNG regasification facilities' are located in area's where the cold energy can be used in an optimum energy and economy setting. This also gives a better possibility to produce a market dependent sustainable LNG fuel quality(see figure 10)
Obviously a second way to improve the emission neutrality and energy savings is by direct use of the cold for cooling of other processes (see figures 9).

Figure 9 : LNG cold utilization reduces the CO_2 emissions with 50-75% depending on the application in which it is used!

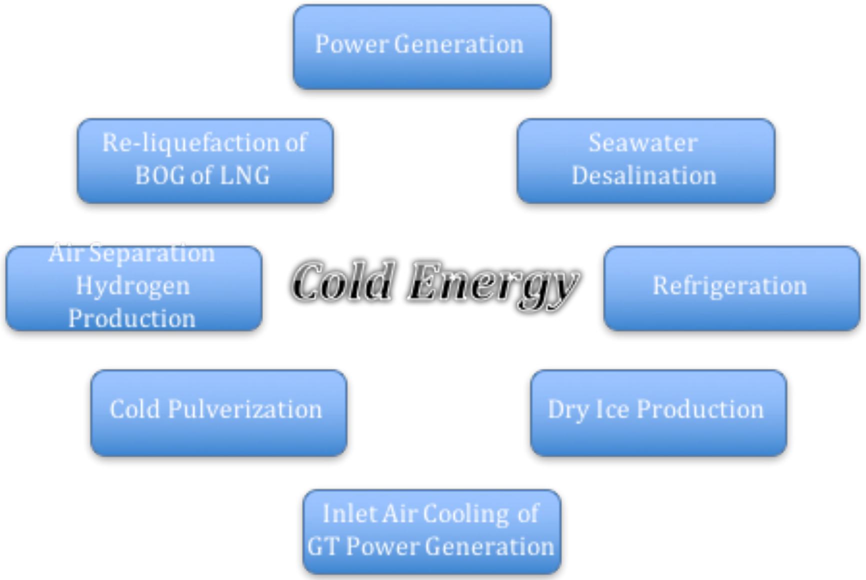


Figure 10: The possible role of fossil LNG regasification in a Waste to Energy plant

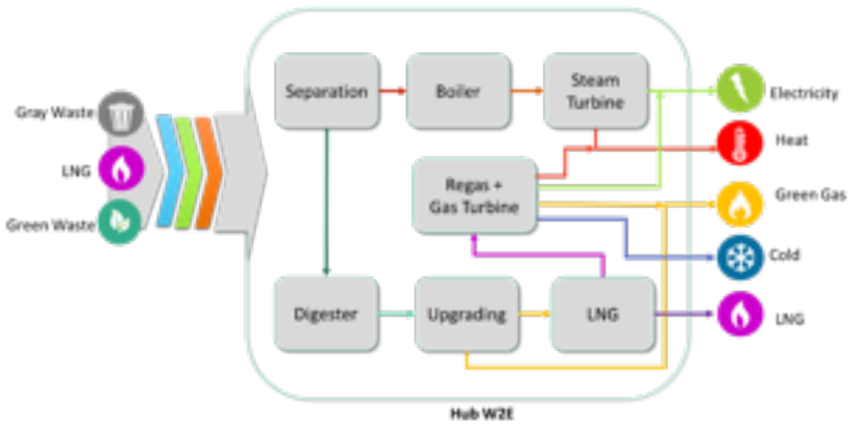


Figure 11a : The "traditional" LNG fuel system approach (here for a Lycoming IO360 airplane engine)

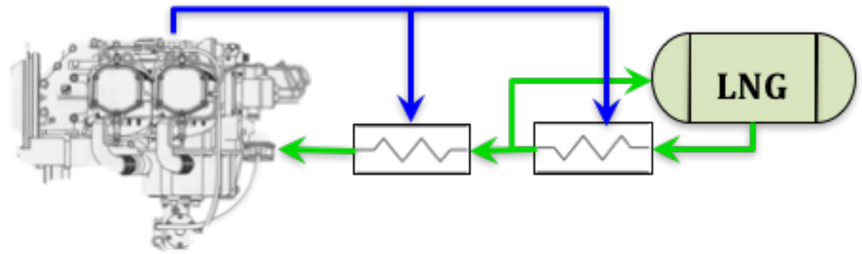
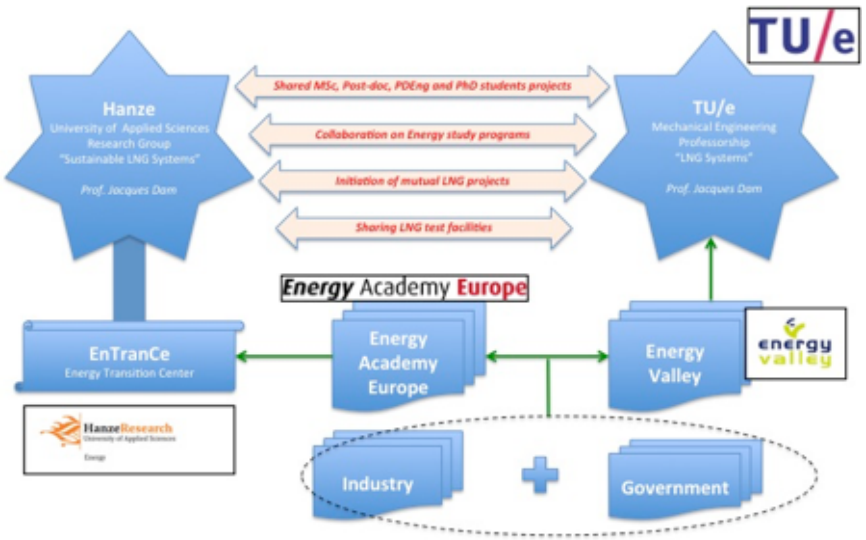


Figure 11b : The "direct injection" LNG fuel system approach
· Higher thermal efficiency.
· Fewer components so better MTBF and MTBF.
· Lower investment.

LNG in combustion processes.

For the future, the use of LNG as a fuel also opens the way for an efficient gas turbine-electric drive concepts using HTS superconducting engines, but we will not go into detail today on this concept. It is subject in the general goal of finding interesting technology solutions for the LNG fuel chain, including end-users. Apart from the obvious, but certainly not naturally, R&D topics as LNG fuel storage and transfer, also the traditional LNG combustion chain: "LNG *constant pressure storage ▸ LNG regasification to cold CNG ▸ CNG heating to ambient temperature ▸ injection in the engine for combustion*", is modified by my idea of injecting the LNG directly into the combustion chamber of the engine thus combining the thermal and combustion processes bringing the engine to a higher level. This approach is currently, with partners, under study for piston engines (Otto cycle and Diesel cycle) and turbine engines (Brayton cycle) for truck, shipping and aviation markets. The influence on the fuel system complexity of an airplane fuel system is shown in the figures 11a and 11b.

Figure 12 : The intended LNG collaboration model for “Sustainable LNG Technology”.



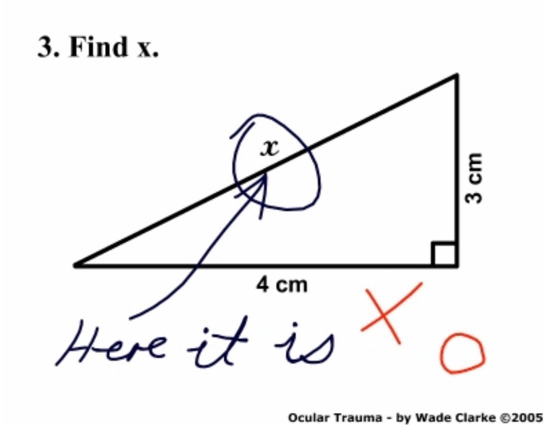
Education, research and testing.

Obviously, education of students is the core business of the Hanze University of Applied Sciences, however obtaining a high level profile in the world of LNG, participation in unique, game changing research programs is required. This level of ambition will inevitably have impact on the organization however will also strengthen Hanze University of Applied Sciences Research Programme in achieving its goals. Joint programs of the Hanze University and the Technical University of Eindhoven, couples scientific research with experimental research that will significantly shorten the time to market of research programs. For the LNG market, this collaboration will prove to be a unique selling point. The collaboration model is shown in figure 12.

Conclusions

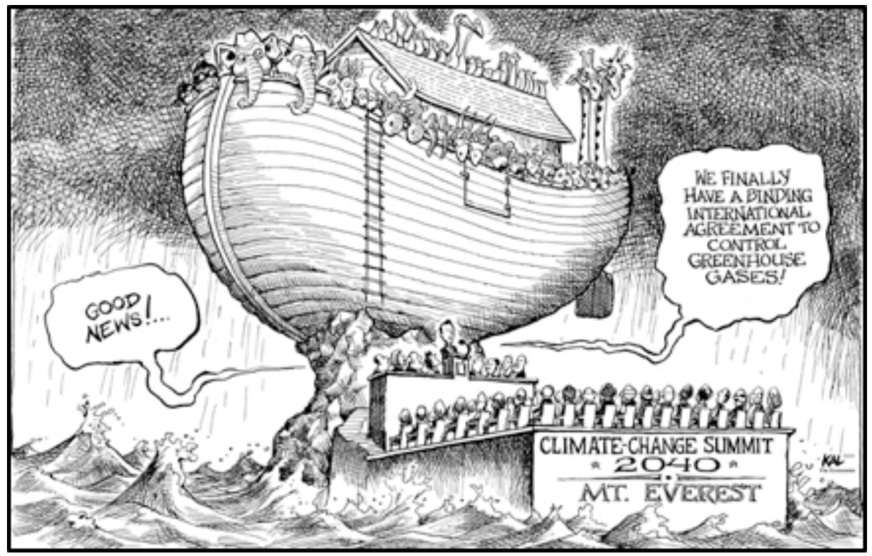
In LNG fuel chain there is a never-ending search, sometimes easy, sometimes difficult, for more efficient and “green” techniques: “x” More efficient and sustainable techniques are directly translated into a smaller carbon footprint and less a more economic use of LNG fuel. Efficient storage, direct LNG injection and decentralized fossil LNG regasification in combination with cold energy recovery and the coupling with bio-based and G2P technology are here key developments.

For all these challenges, new sustainable, energy-efficient, processes and compliant components have to be developed in relation to environmental regulations and



economic models within a social accepted framework. EnTranCe will play an important role here to prove these developments on a real or pilot scale to the potential users.

As has been mentioned, physical-mathematical models and numerical simulation techniques are required that make it possible not only to descend from a system simulation approach to a sometimes molecular approach to include certain effects and thus have a multi-scale simulation capability but also to lower costs as cryogenic experiments are expensive. Apart from that, thorough experimental validation will always be mandatory.



The research on 'LNG fuel' is typically a multi-disciplinary subject that encourages collaboration between universities, knowledge centers and the industry, and fulfills all the requirements for connecting to the Dutch 'top sector' policy and European funded projects on (green) energy. The possibility to define a sustainable, for the future robust LNG fuel chain, LNG fuel quality and a for LNG fuel optimized combustion processes is here and now, so let's start today and let's not wait till the scenario below becomes a reality.

Background literature

1] Intergovernmental panel on climate change IPCCI, climate change 2013 report, the Physical Science Basis, Cambridge University Press, 2013.
2] Well-to-wheels analysis of future automotive fuels and powertrains in the European context, R.Edwards et al, JRC Scientific and Technical Reports, 2011
3] The prospects for natural gas as a transport fuel in Europe, Chris le Fevre, Oxford Institute for energy studies 2014.
4] Waste and gaseous fuels in transport-final report, J.Bates et.al., 2014
5] LNG for trucks and ships: fact analysis, Review of pollutant and GHG emissions R.Verbeek et.al, TNO report 2015
6] Calculating the environmental impact of aviation emissions, C.N.Jardine,, Environmental change institute Oxford university center for the Environment 2005
7] Masterplan LNG Energy Valley, "big in small scale LNG", Stichting energy Valley 2013
8] CO2 emissions from fuel combustion, International Energy Agency, 2012

LNG market innovate!!!

because

LNG still is a fossil fuel!... Not a significant impact on CO2 reduction!... Total waste of thermal energy!... Methane slip!... Does not contribute to renewable energy ambition of the government!... "Green" Bio-LNG is not a competitive option!... Old technology instead of innovative technology!... Engines must work with relative large spread in LNG fuel quality!... No 100% zero CH4 venting approach!... No relation between LNG fuel quality and optimal combustion efficiency!... LNG supply is in control of only a few countries!... LNG energy projects are the most expensive in all the energy sectors!... Still no cost-competeveness!... LNG is technically very challenging so expensive!... All components of the LNG fuel supply chain introduce thermal energy and/or CH4 losses!... LNG costs 0.3kWh/kg to produce!... Fewer km on a tank of fuel!... Component lack on Intrinsic safety properties!... Shale gas needed to ensure long term delivery of LNG fuel!... Not convenient for private use!... Large infrastructure footprint!... Complex LNG handling and logistics!... Insufficient knowledge on downstream safety issues!... Availability is coupled with Oil!... Unburned CH4 is 20 times worse as greenhouse gas in comparison with CO2!... Not sufficient trained technicians available!... Make it an European development!... Poor social acceptance and legislation!... No flow measuring standard!... No failure data!

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