Hanzehogeschool Groningen
University of Applied Sciences

Sustainable LNG Technology

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Today’s topics

- Why LNG at all?
- LNG basics
- LNG fuel
- LNG fuel supply chain
- LNG and the environment
- LNG projects
- Education, research and testing in the regio

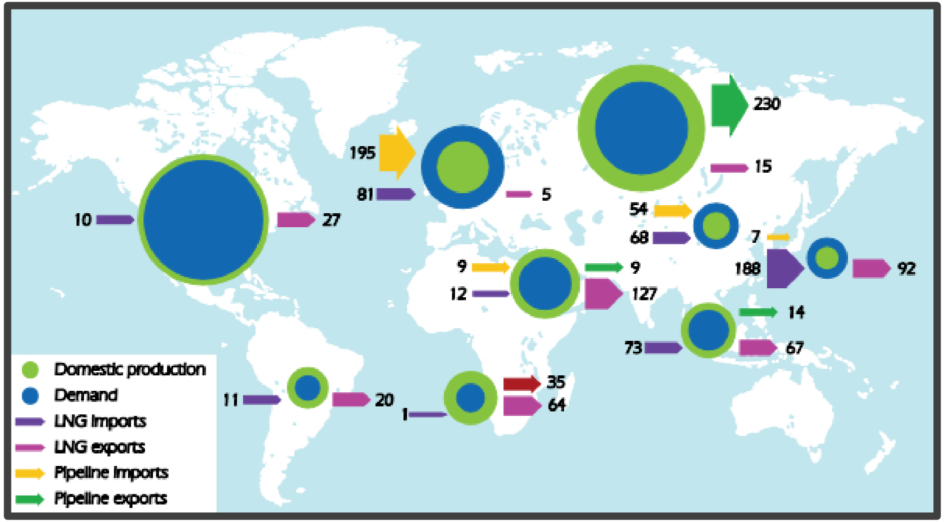
Why LNG at all?

LNG in the world's energy consumption.

The current world energy consumption is approximately **500 exajoules (= 10^{18} J)** per year

or

A continuous average energy consumption equivalent of **57000 billion kWh**



of which in 2010

Natural Gas contributed about **20%**

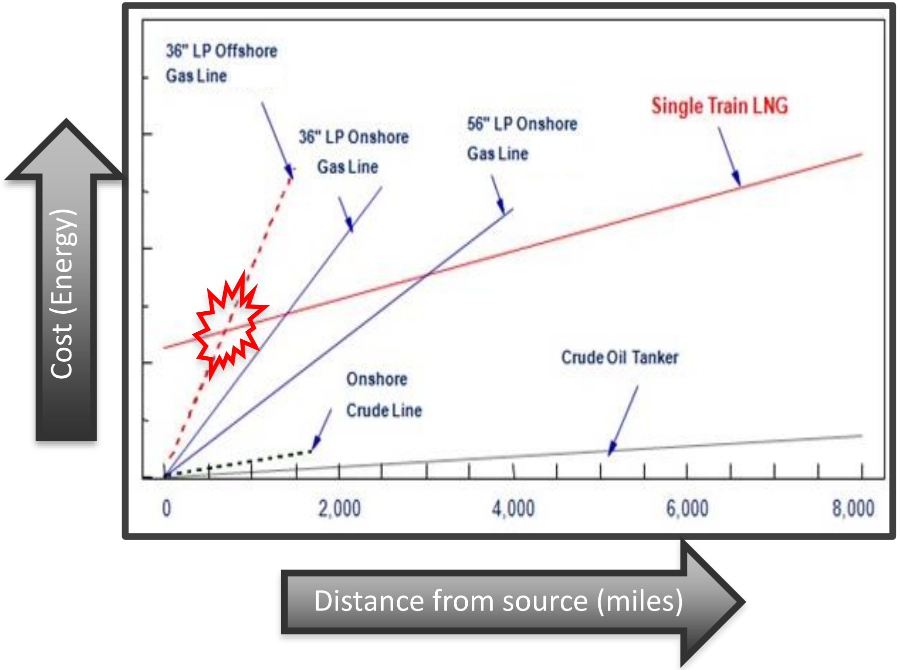
of that

13% as LNG

expected to grow to

17% by 2020

The economic drivers in the LNG production.



The only economic way to transport Natural Gas over large distances.

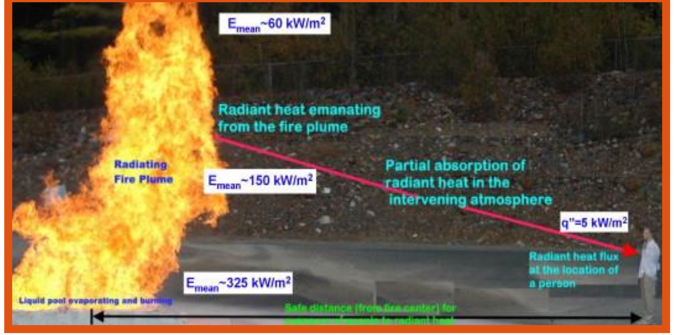
- Efficient Natural Gas storage.
- Can be used as engine fuel.
- Has a favorable emission profile.
- Safe.
- Available in large quantities over the entire planet for years to come.

Gives time for a possible transition to a Hydrogen + electrical economy.

LNG basics

LNG basics

LNG = **L**iquefied **N**atural **G**as is the condensed form of ***pre-processed*** **N**atural **G**as



LNG is a (variable) mixture of gases of which Methane is the main component.

- Boils at 111.51K (or -161.50°C)
- Freezes at 90.72K
- Has an density of 668kg/m³ (aviation fuel 720kg/m³)
- Non-toxic
- Non-corrosive
- Non-odorous
- Non-explosive
- Non-polluting
- Combustion energy 15% higher than aviation fuel
- Safe

Production requires 914.7 kJ/kg of thermal energy (= 0.254 kWh per kg/h LNG)

The difference between Natural Gas and LNG.

Natural Gas Components		Fossil Natural Gas	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

Extensive Fossil Natural Gas and Biogas pre-treatment is required before liquefying it to LNG

LNG fuel

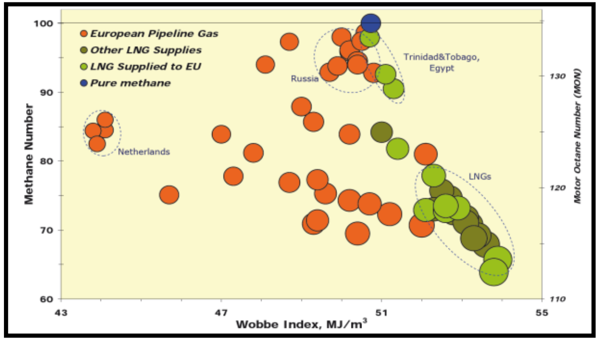
Game-changing developments for LNG usage as fuel

- New concepts for LNG fuel storage
  - Cheap to produce
  - In any shape to produce; single wall, light weight, flexible
  - Not sensitive to accelerations, filling level and orientation

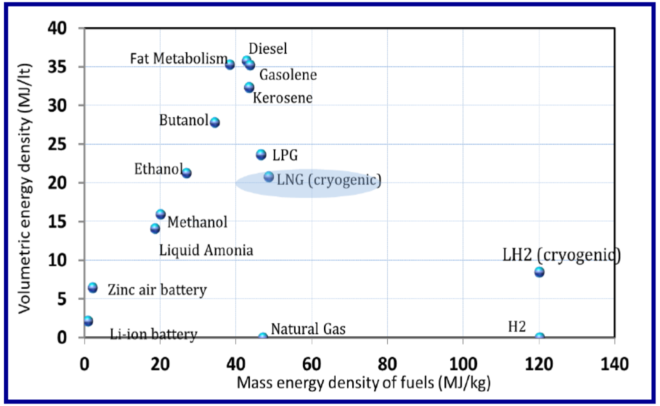
- Use the thermal energy of LNG in the engine combustion cycle
  - Simplifies the lay-out of the fuel system
    - Lowers costs
    - Increases engine thermal efficiency
    - Opens world market for general and commercial aviation

- Maximum use of bio-LNG and bio-based components in a standardized LNG fuel composition, including Hydrogen, that allows combustion optimization (higher efficiency) and emission minimisation
  - *Emission neutral design over the entire LNG fuel chain; not only for CO_2*
  - *No Methane slip*
  - *User friendly design towards the end-user*
  - *Harmonization, legalisation, test & measuring and education on a global scale*

From LNG fuel to power; *direct LNG injection in engines*



Source: LNG for Europe: Some important considerations, Joint Research Center, European Commission, 2009.



Reciprocating engines & Turbines

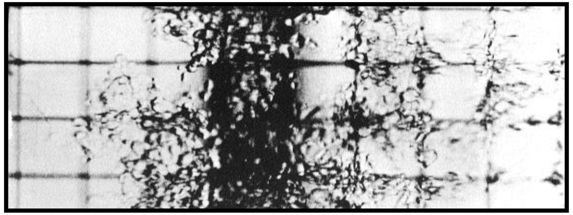
- Wobbe-index (interchangeability)

- ✓ ***Engines with constant performance***
- ✓ ***Reliable LNF (aviation) fuel delivery chain***
- ✓ ***Constant LNG (aviation) fuel quality***
- ✓ ***Engines with optimal performance/emission ratio***

- The energy density of aviation fuel is generally between 43 and 48 MJ/kg.
- LH_2 seems the preferred fuel but: fuel is stored in liters, not in kilograms! Therefore**: LNG densification**

LNG densification (Slush LNG; SLNG)

- SLNG is formed by bringing liquid Methane down to nearly its triple point at 90.7K and partially solidify the LNG by some expansion process.
- With approximately 50% of the LNG solidified, the density is increased by 14% in comparison to liquid Methane.
- The better weight to volume ratio of SLNG over LNG lowers the cost of storage and transport.
- The boil-off of methane can be avoided as heat can be adsorbed in the solid-liquid phase transition.
- In SLNG the phase has a FCC crystal lattice in which gases (Hydrogen, CO_2 or Hydrocarbons) can be captured in much larger amounts than in an equilibrium LNG mixture (constant quality optimization of LNG fuel characteristics for specific combustion processes).
- Fluid like hydraulic properties (stable colloidal suspension) and handling.



Note: A "slush-gun" method for SLNG production was identified by ESA studies in the FESTIP program

Property	Methane
Normal Boiling Point (NBP)	111.7 K
Liquid Density at NBP	***422.4 kg/m³***
Triple Point Temperature	90.7 K
Triple Point Pressure	11.72 kPa
Triple Point Liquid Density	451.7 kg/m³
Solid Methane Density	511.0 kg/m³
Heat of Fusion	60.7 kJ/kg
Heat of Vaporization	510.1 kJ/kg
Slush Density at 50% Solid	***481.4 kg/m³***

Commercial value of SLNG to the world's LNG transport

A total of 4,072 LNG carrier voyages were completed during 2014.

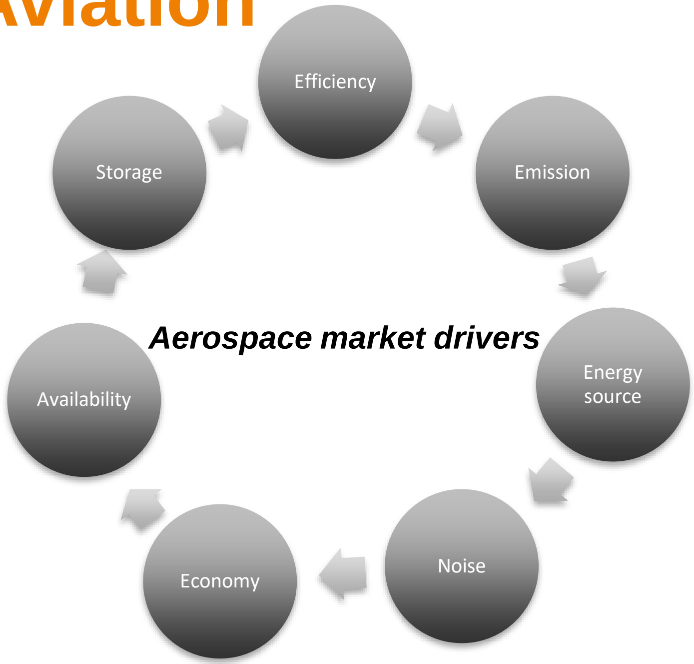
Charter rate: 100,000 USD per day for 147,000 m^3 vessel.
and an average voyage length of 21 day's.

12 billion USD saving on charter rate only
excluding fuel consumption/ LNG boil off and other.

Global LNG trade 2014: 241MTPA against < 0.3MWh/ton.

Additional power requirement SLNG +15% over that of normal LNG production.

LNG fuel for General and Commercial Aviation



Market motivators

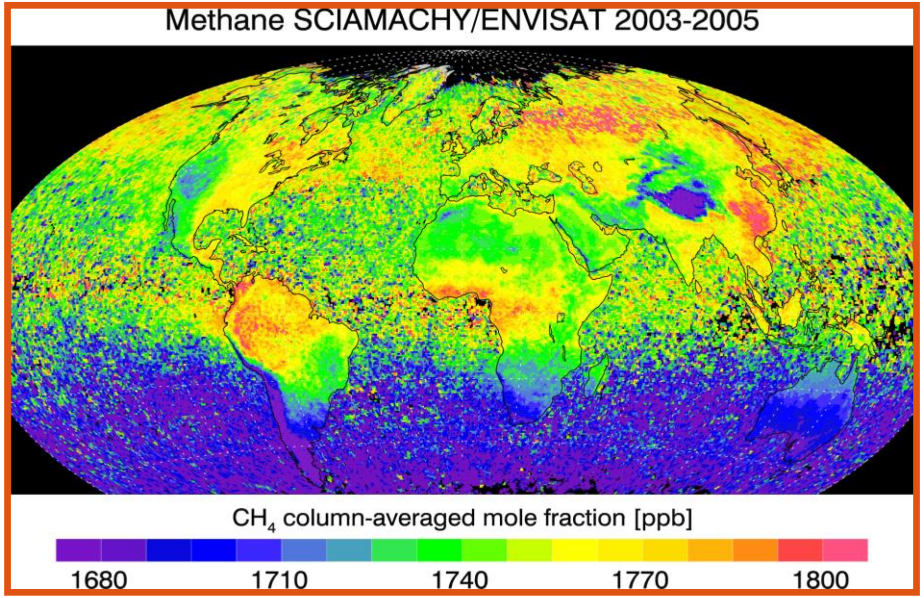
•Global market from start.
•Relative easy conversion (depending on LNG storage system).
•Possible to make it more "Green" using blending with bio-based components.

Hanze - TU/e research program:

•LNG aviation quality fuel is not defined yet so its optimal composition is open.
•A sustainable LNG aviation fuel production and delivery chain.
•Solution for LNG storage and transfer system.
•Efficiency improvement (direct LNG injection).

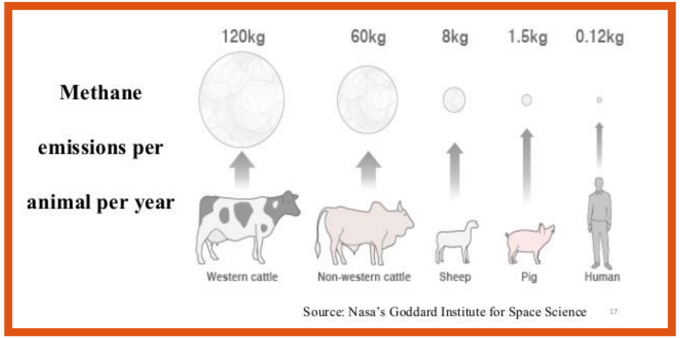
LNG and the environment

LNG use and world global warming.



Methane is a greenhouse gas and:

- CH_4 has 25x more impact on global warming potential (GWP) than CO_2
- Till 2005, the Methane concentration in the earths atmosphere was of biologic origin



Therefore:

- ✓ Prevent the emission of unburned CH_4
- ✓ Minimize the energy requirement of the entire LNG chain.

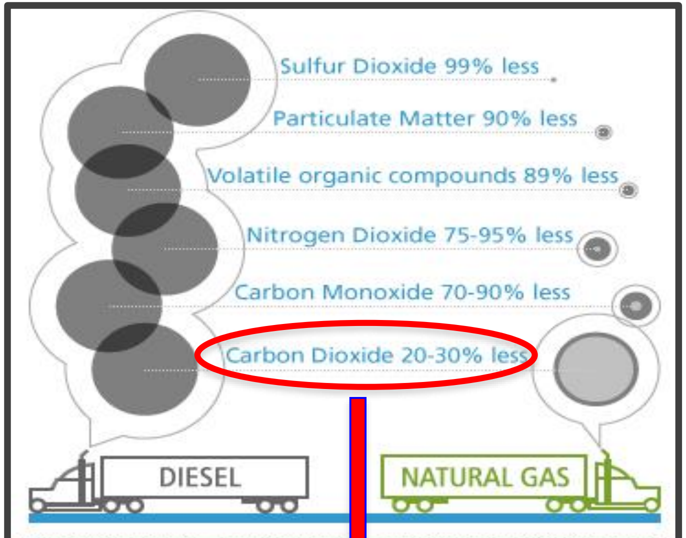
So LNG is not a “Green” fuel?

Yes, partially, because it has a favorable emission profile in comparison with other fossil fuels,

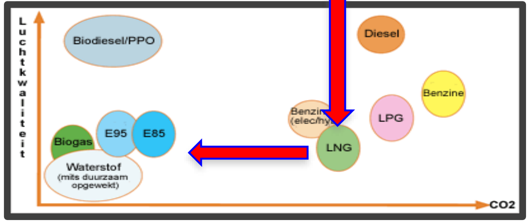
(+) CO_2 emission reduction is 20%
(-) CH_4 is an extreme greenhouse gas than CO_2.

But:

- ✓ It is possible to give LNG fuel a more CO_2 neutral profile through blending with bio-based components and Hydrogen.
- ✓ LNG can be produced from bio-gas.
- ✓ LNG has a high energy content (thermal and combustion wise)



Source: NGVAmerica, Encana Estima , Environmental Protection Agency



LNG fuel supply chain

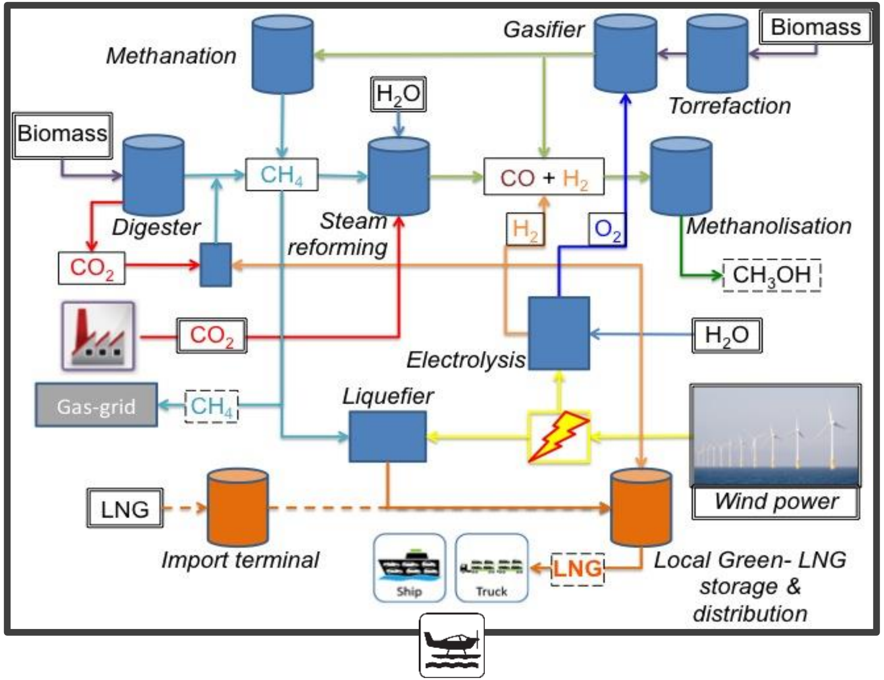
The LNG fuel supply chain challenges.

€ (CAPEX, OPEX and R&D)

- ❑ Cost of the facility in general in comparison with the traditional fuels
- ❑ Storage LNG boil-off typically 0.2-0.5% of the stored volume per day
- ❑ Differences in LNG storage pressure and end-user LNG storage pressure (typically 5bara for ships, 8 or 18bara for trucks; complexity).
- ❑ The cost of safety.
- ❑ The cost of logistics (LNG delivery and retrieval, startup, maintenance).
- ❑ Transfer is more complex than with traditional fuels; cost of transfer
- ❑ Cost for zero-emission design
- ❑ Cost of handling and components

Introducing the renewable LNG fuel supply chain.

- ✓ Sensible use of fossil LNG (price and availability).
- ✓ Does not depend on the upstream LNG quality.
- ✓ Maximum use of bio-based and/or Hydrogen additives.
- ✓ The LNG fuel quality and quality spread is determined by the maximum possible efficiency of combustion.
- ✓ Maximal use of cold energy recovery processes.
- ✓ Towards an energy neutral to produce and to distribute fuel.
- ✓ Towards a CO2 neutral supply chain and combustion technology.
- ✓ Is user friendly and safe.
- ✓ Compliant with environmental targets.



LNG thermal energy management.

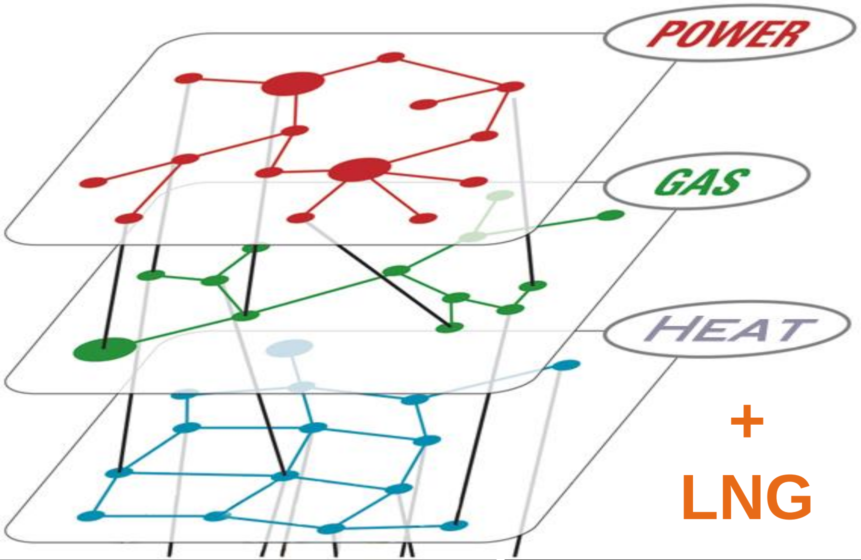
LNG cold utilization

- LNG boil-off gas re-liquefaction utilizing LNG cold storage (100tons/h LNG for processing 15tons/h BOG).
- Cryogenic power generation (direct expansion 26-44kWh/t LNG, 20-37kWh/t LNG for mixed refrigerant Rankin cycle, 35-56kWh/kg in a combination of both).
- Air separation (0.4kWh/m^3 against 0.8kWh/m^3 conventional).
- Production of liquefied CO_2 and dry ice (0.08-0.11kWh/kg CO_2 against 0.2kWh/kg conventional).
- Cold warehouse refrigeration (0.2kWh/kW against 1.3kWh/kW conventional).
- LNG cold for pulverizing waste.
- Sea water desalinization.
- Pre-cooling for the production of liquefied Hydrogen (4-5kWh/kg LHy against, 11.5-13.5kWh/kg LHy conventional).
- Cooling for HTS application as HTS electrical motors.
- Improve the performance of active cycles by using waste heat (cooling water, exhaust heat etc.)

LNG cold energy utilization reduces the CO_2 emissions with 50-75% depending on the application.

The role of LNG other than that of fuel

The Design Strategy of a Flexible, Optimized Hybrid Energy Network.



Couplings through
- ✓ *Conversion*
- ✓ *Storage*
- ✓ *Conditioning*

For
- ✓ *Urban area development*
- ✓ *Waste-to-Energy*
- ✓ *Industrial area development*

Combine

- ➢ Private and Industrial production and use of heat.
- ➢ Existing and new energy network infrastructures in a for energy and economy optimized topology.
- ➢ Multiple network and knowledge providers and industrial partners

By

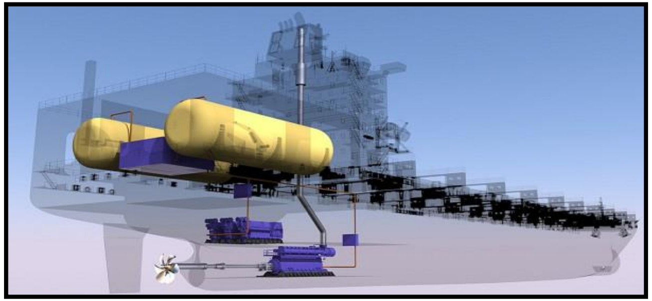
- ✓ Decentralized LNG regasification and cold energy recovery (direct usage and conversion)
- ✓ Distributed pricing and control
- ✓ Energy Hub Interconnectivity
- ✓ Distribution logistics

Hanze – TU/e PhD: Juliana Montoya Cardona

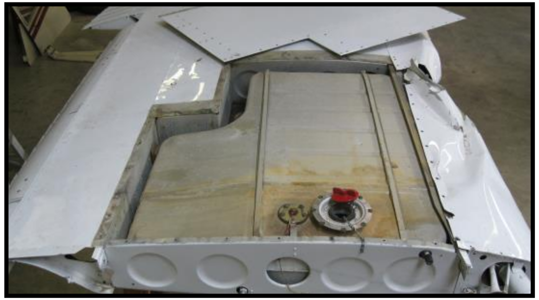
LNG fuel containment systems.

Traditional approach: cylindrical, double-wall, vacuum-MLI isolated, systems.

Truck LNG tank



Ship LNG tank (study)



Wing tank Cessna 172P

- Expensive by design.
- The double wall design makes only one shape possible (aerospace??).
- Heavy, especially at higher pressures (truck up to 18bara, ship up to 6bara, aerospace TBD).
- Maintenance (vacuum).
- Performance under translation, rotation and acceleration loads (sloshing, vapor collapse).
- LNG boil off from 0.2%/day (stationary) up to >> 1% per day under movement.

Hanze – TU/e studies on new, single wall, arbitrary shape, flexible LNG fuel containment systems

LNG applications

Direct LNG fuel injection in combustion engines

Claims

- Combustion energy LNG: 55.2MJ/kg
- Thermal energy LNG: 0.86MJ/kg

} ➢ Possible 1.8% higher fuel efficiency.

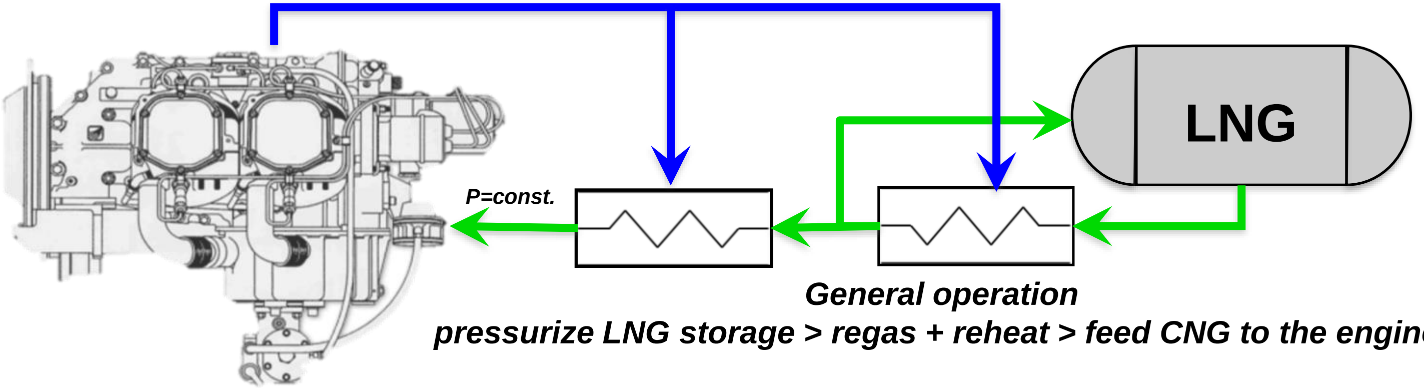
➢ Direct LNG fuel injection will also significantly reduce the LNG fuel system “overhead” which gives a serious cost reduction.

➢ Applicable in any type of converted or new engine; spark-ignited, single and dual-fuel and turbine in any type of transport (truck, ship, airplane).

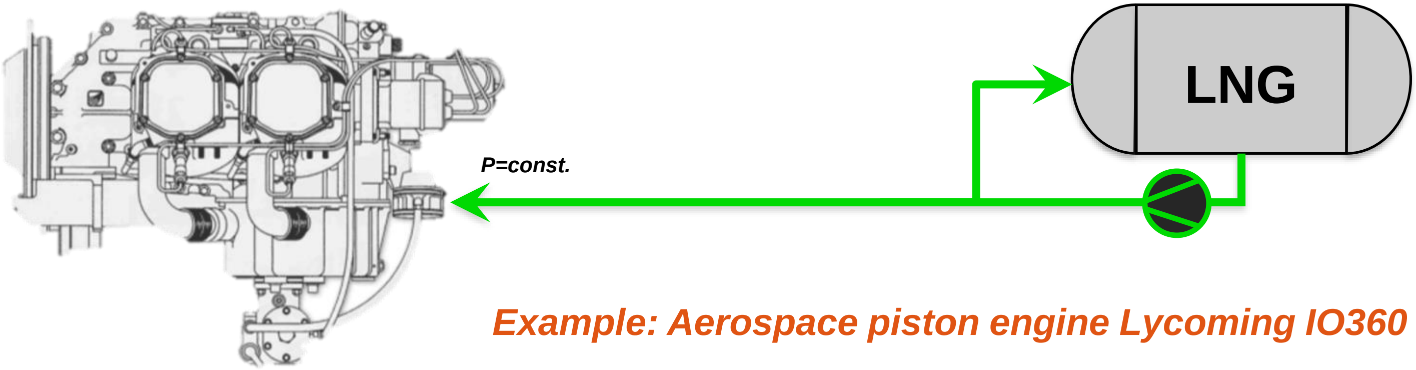
➢ Speeds-up de use of LNG as preferred fuel.

➢ Lowers emission and possibly the route to prevent Methane slip.

Direct LNG fuel injection in combustion engines



General operation
pressurize LNG storage > regas + reheat > feed CNG to the engine.



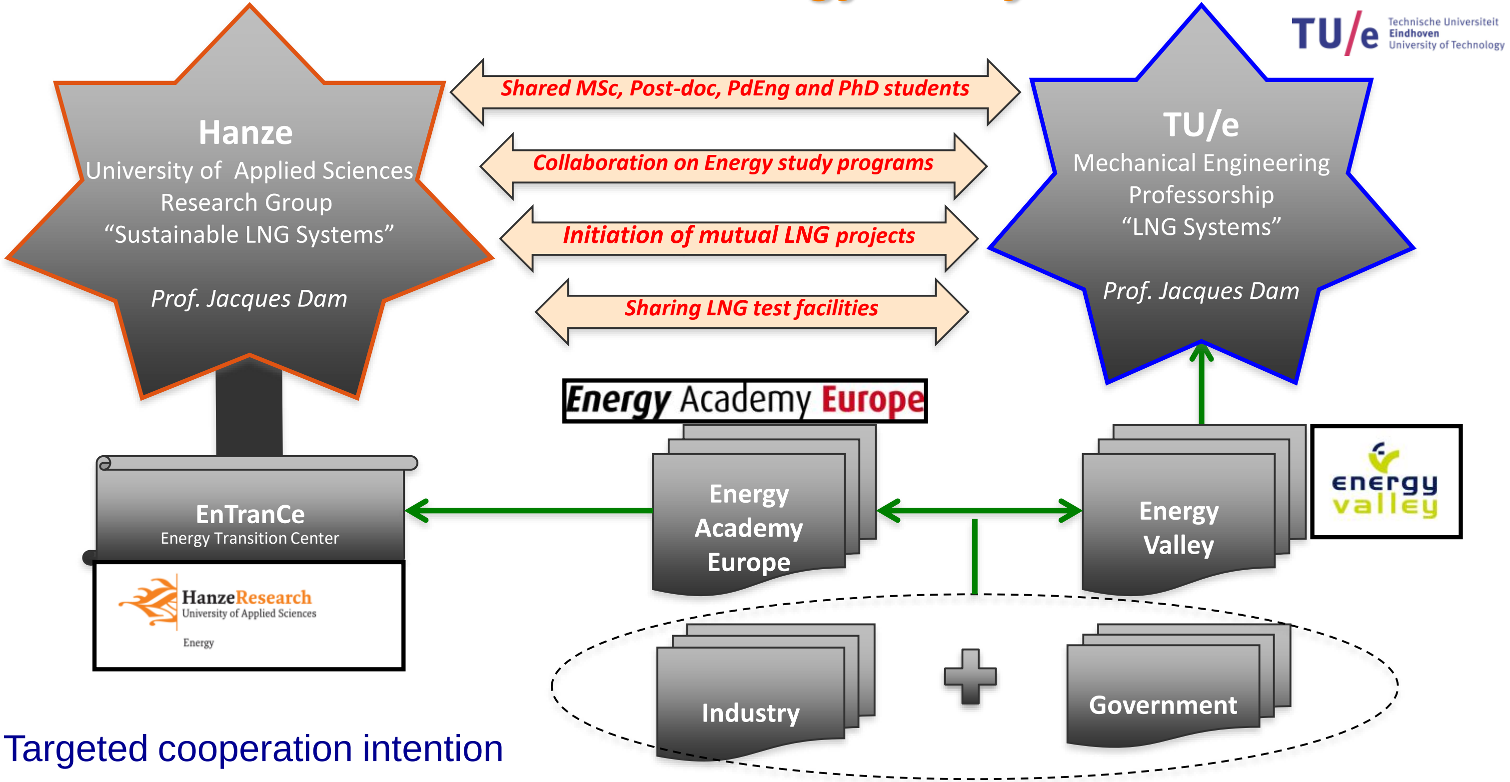
Example: Aerospace piston engine Lycoming IO360

Education Research Testing

Hanzehogeschool Groningen

Education, research and testing*) on LNG

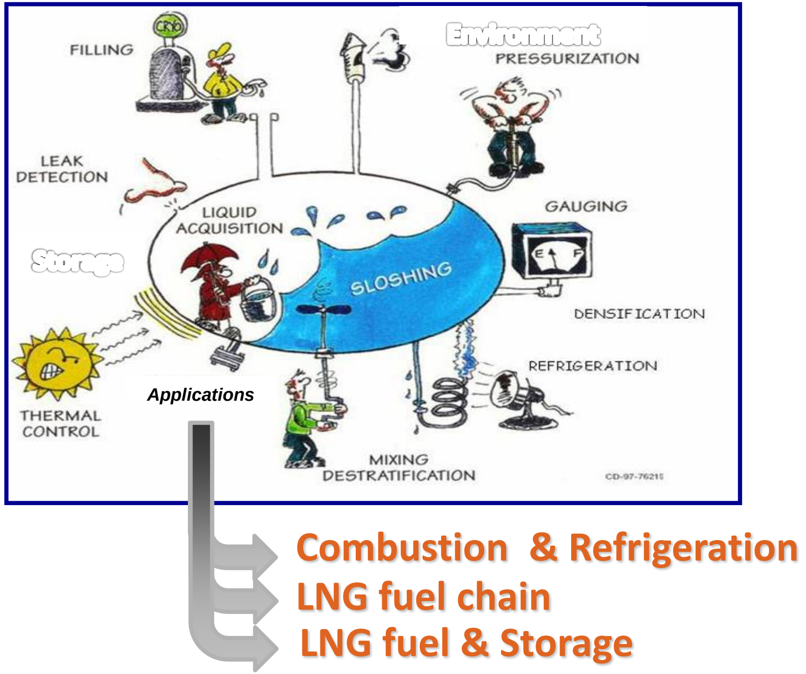
Hanze + EnTranCe + TU/e + Energy Valley



*) Targeted cooperation intention

LNG research and education opportunities at the Hanzehogeschool, summary

1. LNG storage systems
   - For the transport sector (Truck, Ship, Airplane)
2. LNG fuel usage, LNG fuel quality.
   - **Methane slip**
   - LNG fuel composition inclusive Hydrogen
   - LNG densification
   - Direct LNG injection in engines
3. The role of LNG in Hybrid Energy Networks
4. New LNG Markets
   - Decentralized LNG regasification.
   - Integration with bio-fuel chain.
   - Aviation.
5. LNG education, research and test facilities in The Netherlands.
   - Combining the Hanze and TU/e test and research facilities
   - Merging of the 3TU SET and EUREC Master SFS educational programs



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Zo gezegd, zo gedaan.

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