The role of natural gas as fuel and its value chain

http://www.poreen.eu/

Matteo Santolini
Università Politecnica delle Marche

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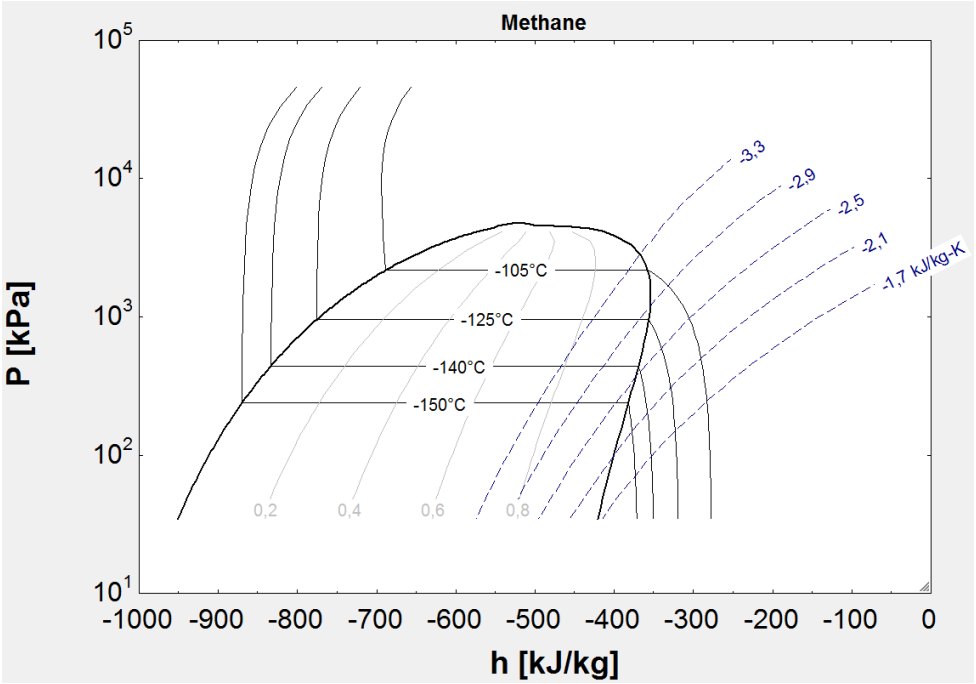
Contents

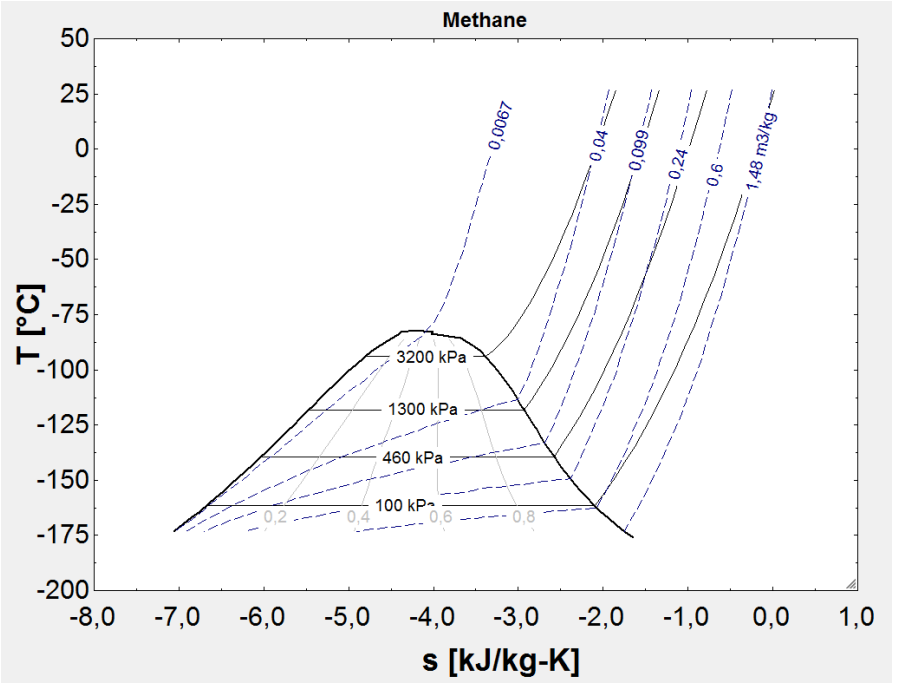
- Natural Gas: chemical and physical properties
- The role of LNG between fossil fuels
- LNG terminology 1:
  - Measure terminology
  - Conversion factor

Chemical and physical properties

- LNG, Liquified Natural Gas, is natural gas converted to liquid for storage or transport.
- Natural Gas in standard condition is in gaseous form, to liquefied it is necessary to cool it down up to -162° C at atmospheric pressure
- Natural gas need an Upgrading process, before being liquefied, in order to eliminate impurities

Chemical and physical properties





Source: EES Software

Chemical and physical properties

- NG is a mixture of hydrocarbons
  - CH4 Methane
  - C2H6 Ethane
  - C3H8 Butane
  - C4H10 Propane
  - C5H12 Pentane
  - C6+ Exane +

  …and other impurities

Source: Snam Rete Gas, 2008

Chemical and physical properties

- Main impurities of Natural Gas
  - N2 Nitrogen, is an inert gas and reduce the heating value
  - CO2 Carbon Dioxide, is corrosive and dangerous for the equipment.
  - H2S Hydrogen Sulfide, is corrosive and caused acid rain
  - He Helium, is an inert gas and reduce the heating value
  - H2O Water, to remove it, should be necessary a dehydration

Chemical and physical properties

Chemical composition		Importazione Tarvisio (Gas Russo)	Importazione Passo Gries (Nord Europa)	Importazione Mazara del Vallo (Gas Algerino)	Importazione Gela (Gas Libico)	Importazione Panigaglia (GNL)	Immissione Ravenna Terra (gas Nazionale)	Immissione Falconara (gas Nazionale)	Interconnessione GNL Edison Minerbio	Importazione OLT Livorno (GNL)
Methan	%MOLE	95,890	89,677	85,473	85,029	90,154	99,631	99,412	92,933	89,695
Ethane	%MOLE	2,218	4,315	9,291	5,960	7,808	0,060	0,015	6,680	7,015
Propane	%MOLE	0,589	0,830	1,409	2,232	1,070	0,011	0,001	0,090	1,334
Iso Butane	%MOLE	0,092	0,125	0,124	0,327	0,081	0,005	0,002	0,004	0,121
N Butane	%MOLE	0,093	0,140	0,163	0,513	0,100	0,001	0,002	0,005	0,325
Iso Pentane	%MOLE	0,019	0,039	0,030	0,136	0,002	0,004	0,003	0,003	0,022
Normal Pentane	%MOLE	0,012	0,030	0,025	0,087	0,001	0,004	0,003	0,003	0,002
Hexane +	%MOLE	0,011	0,039	0,035	0,024	0,001	0,002	0,000	0,000	0,000
Nitrogen	%MOLE	0,752	3,357	1,758	4,293	0,698	0,234	0,478	0,257	1,449
Carbon dioxide	%MOLE	0,313	1,413	1,692	1,284	0,000	0,048	0,084	0,001	0,001
Helium	%MOLE	0,011	0,035	0,000	0,115	0,000	0,000	0,000	0,024	0,036
Oxigen	%MOLE	-	-	-	-	0,085	-	-	-	-

Source: Snam Rete Gas, 2014

Chemical and physical properties

Phisical properties		Importazione Tarvisio (Gas Russo)	Importazione Passo Gries (Nord Europa)	Importazione Mazara del Vallo (Gas Algerino)	Importazione Gela (Gas Libico)	Importazione Panigaglia (GNL)	Immissione Ravenna Terra (gas Nazionale)	Immissione Falconara (gas Nazionale)	Interconnessione GNL Edison Minerbio	Importazione OLT Livorno (GNL)
Higher Heating Value	kJ/m3	38549	38025	40289	39594	40483	37715	37584	39650	40386
Lower Heating Value	kJ/m3	34746	34303	36399	35777	36547	33957	33838	35764	36465
Density	kg/m3	0,71199	0,75669	0,78874	0,79965	0,74676	0,68245	0,68358	0,72234	0,75345
Compressibility factor	(Z)	0,99784	0,99774	0,99740	0,99747	0,99756	0,99800	0,99801	0,99771	0,99755
Wobbe index	kJ/m3	50573	48389	50218	49014	51858	50538	50321	51643	51504
Relative density		0,58102	0,61750	0,64366	0,65256	0,60940	0,55692	0,55784	0,58947	0,61486
Molecular weight	kg/kmol	16,80	17,85	18,60	18,86	17,61	16,10	16,13	17,04	17,77
m^3 @ 15 °C, 1.01325 bar (standard condition)										

Source: Snam Rete Gas, 2014

Chemical and physical properties

Chemical composition		Importazione Panigaglia (GNL)	Interconnessione GNL Edison Minerbio	Importazione OLT Livorno (GNL)
Methan	%MOLE	90,154	92,933	89,695
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N Butane	%MOLE	0,100	0,005	0,325
Iso Pentane	%MOLE	0,002	0,003	0,022
Normal Pentane	%MOLE	0,001	0,003	0,002
Hexane +	%MOLE	0,001	0,000	0,000
Nitrogen	%MOLE	0,698	0,257	1,449
Carbon dioxide	%MOLE	0,000	0,001	0,001
Helium	%MOLE	0,000	0,024	0,036
Oxigen	%MOLE	0,085	-	-

Phisical properties		Importazione Panigaglia (GNL)	Interconnessione GNL Edison Minerbio	Importazione OLT Livorno (GNL)
Higher Heating Value	kJ/m3	40483	39650	40386
Lower Heating Value	kJ/m3	36547	35764	36465
Density	kg/m3	0,74676	0,72234	0,75345
Compressibility factor	(Z)	0,99756	0,99771	0,99755
Wobbe index	kJ/m3	51858	51643	51504
Relative density		0,60940	0,58947	0,61486
Molecular weight	kg/kmol	17,61	17,04	17,77
m^3 @ 15 °C, 1.01325 bar (standard condition)				

Source: Snam Rete Gas, 2014

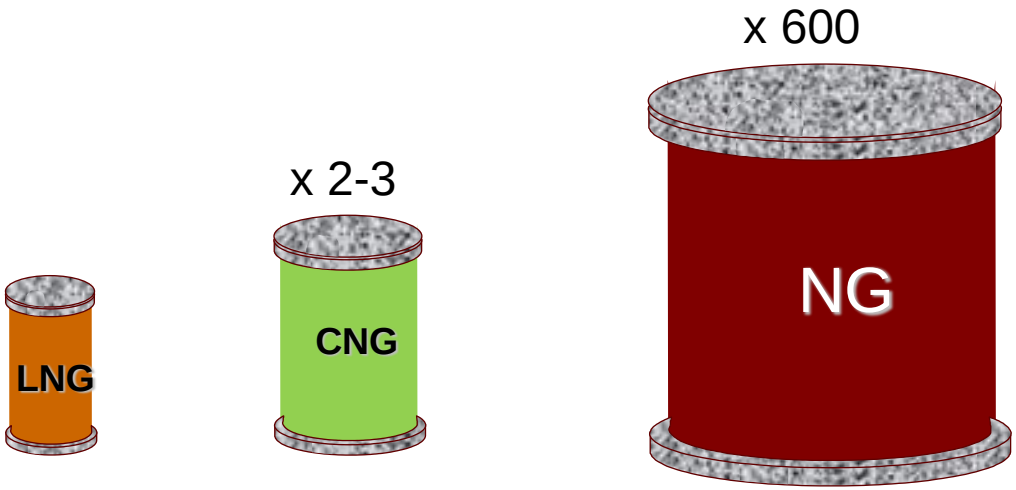
Chemical and physical properties

- Energy density

1 Sm^3 NG (@ 1,01 bar, +15° C)	ρ= 0,680 kg/m^3
1 m^3 CNG (@ 220 bar, +15° C)	ρ= 181,40 kg/m^3
1 m^3 LNG (@ 1,01 bar, -161,5° C)	ρ= 422,36 kg/m^3
1 m^3 Diesel (@ 1,01 bar, +15° C)	ρ= 848 kg/m^3

Chemical and physical properties

- Energy density



The role of LNG between fossil fuels

- Fossil fuels
  - Coal
    - Anthracite, Hard Coal, Coke
  - Petroleum derivates
    - LPG, Gasoline, Diesel, Kerosene, Heavy fuel oil
  - Natural Gas
    - Natural Gas, Liquefied Natural Gas

The role of LNG between fossil fuels

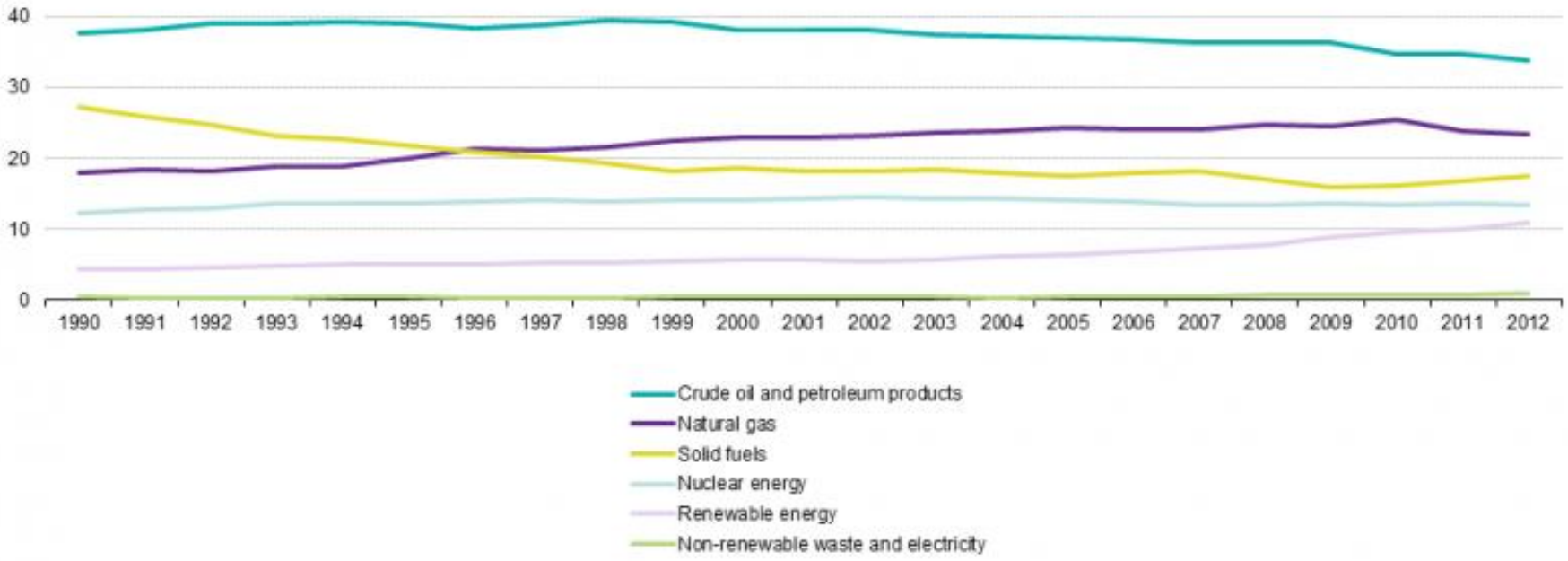
- Heating values for common fossil fuels

Fuel	HHV [MJ/kg]	LHV [MJ/kg]
Methane	55,5	50,0
Natural Gas	52,2	47,1
Kerosene	46,2	43,0
Low-solfur gasoline	45,6	42,5
Diesel	44,8	43,4
Coal (Anthracite)	32,5	

Source: www.ornl.gov; www.nist.gov

The role of LNG between fossil fuels

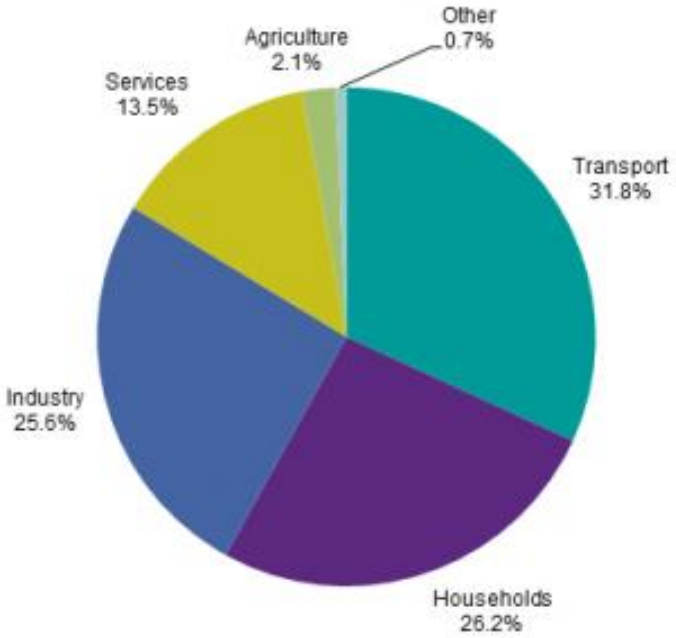
- Gross inland consumption in 2012 (EU-28)
  - % of total consumption



Source: Eurostat (online data code: nrg_100a)

The role of LNG between fossil fuels

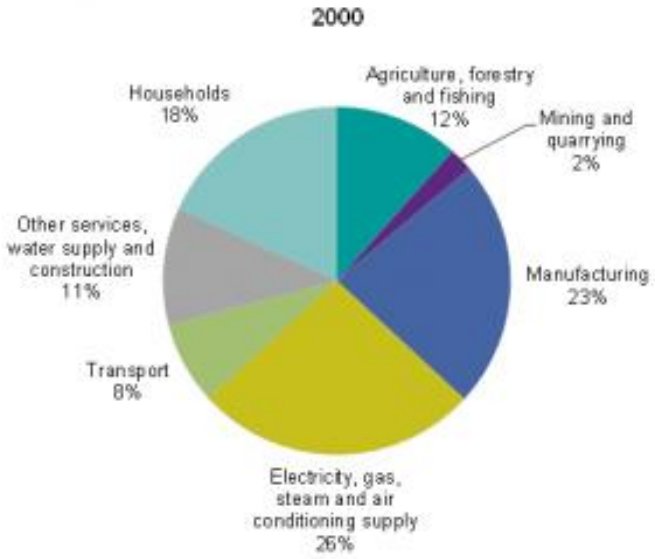
- Sector share in 2012 (EU-28)
  - % of total consumption

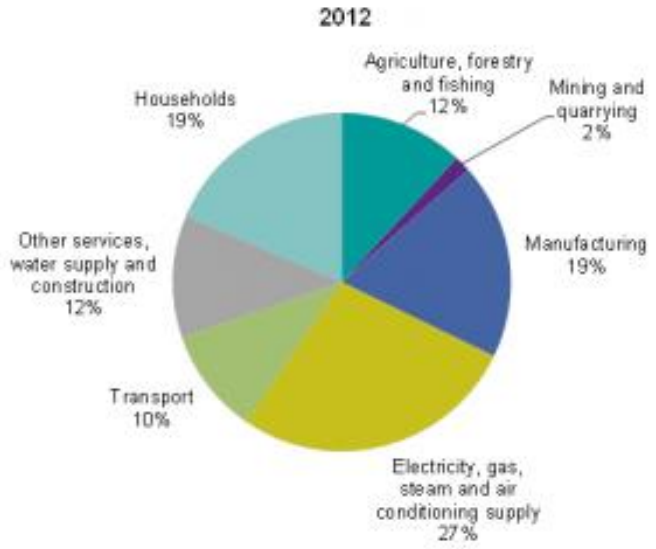


Source: Eurostat (online data code: tsdpc320)

The role of LNG between fossil fuels

- GHG emissions in 2000-2012 (EU-28)
  - % of total emissions





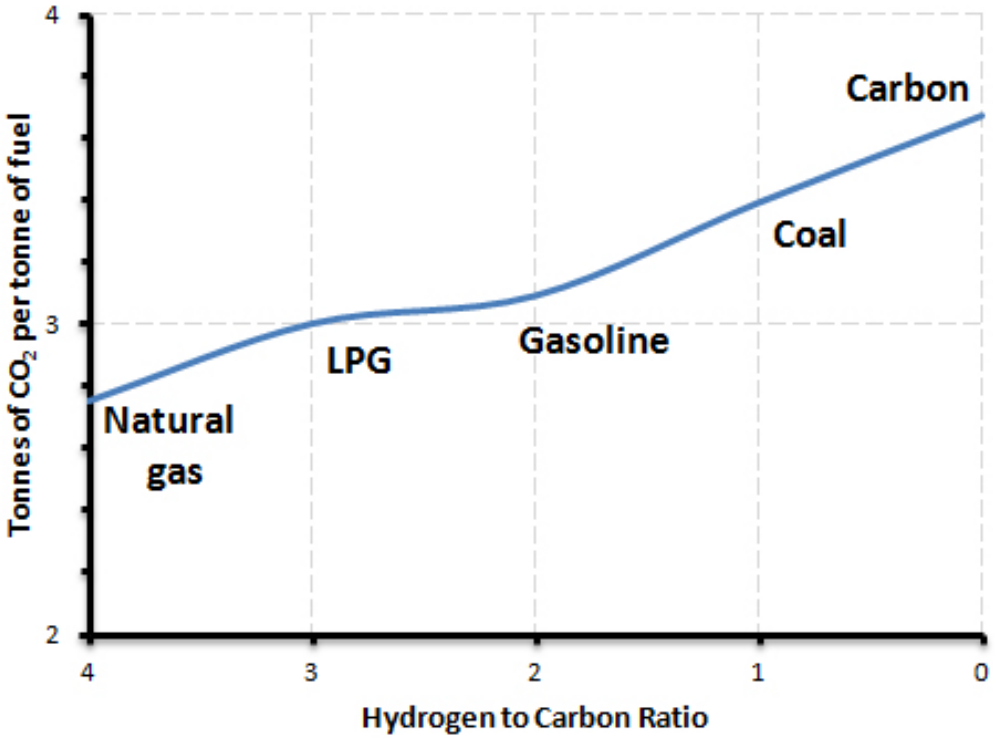
(*) 2012: estimates.
Source: Eurostat (online data codes: env_ac_ainah_r1 and env_ac_ainah_r2)

The role of LNG between fossil fuels

- Main advantages of Natural Gas
  - Enviromental benefits
  - Availability of resources
  - Reduction of dependency on oil
  - Avalaible technology

The role of LNG between fossil fuels

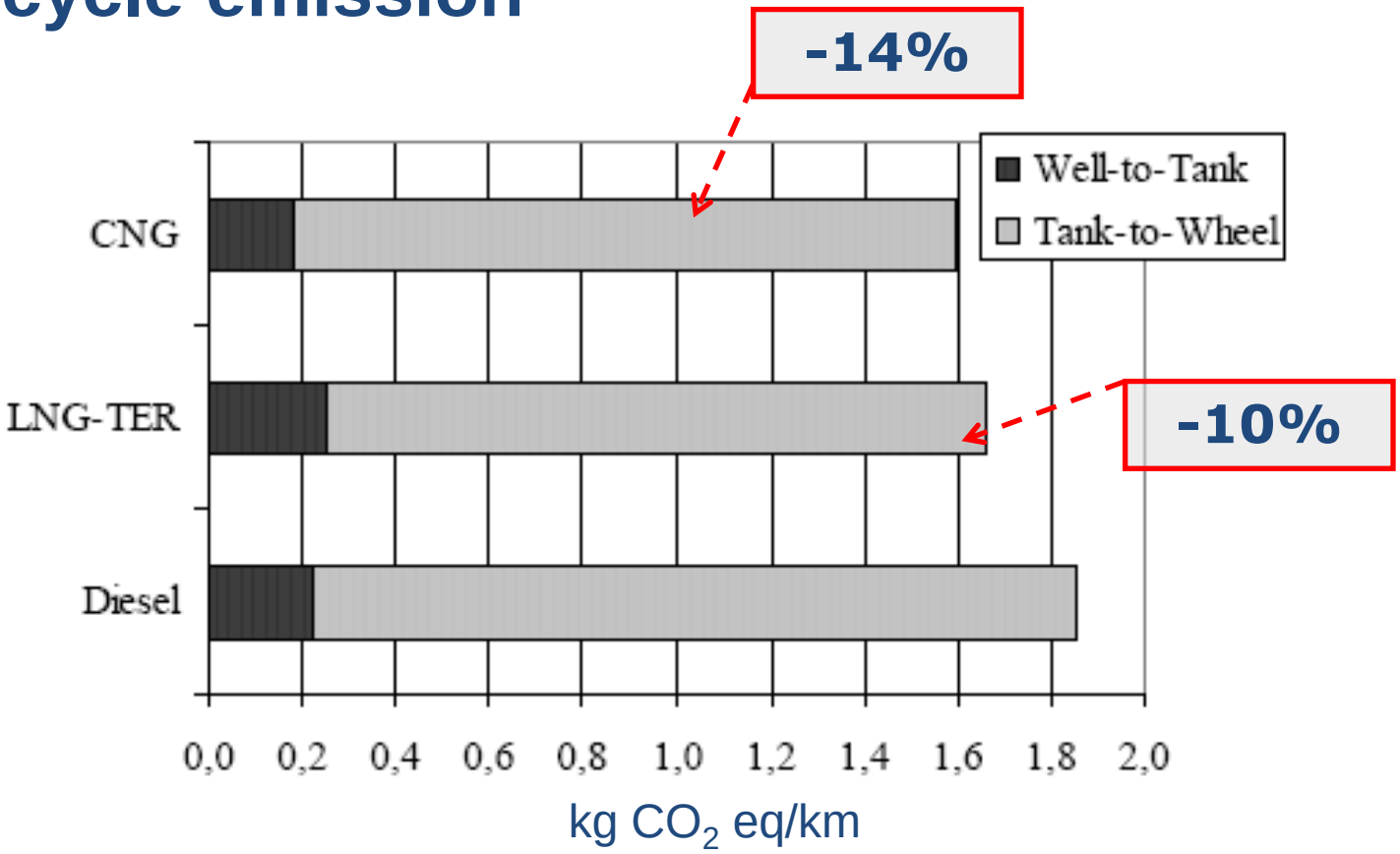
- Enviromental benefits



Source: Small-Mid scale LNG, 2013

The role of LNG between fossil fuels

Life cycle emission

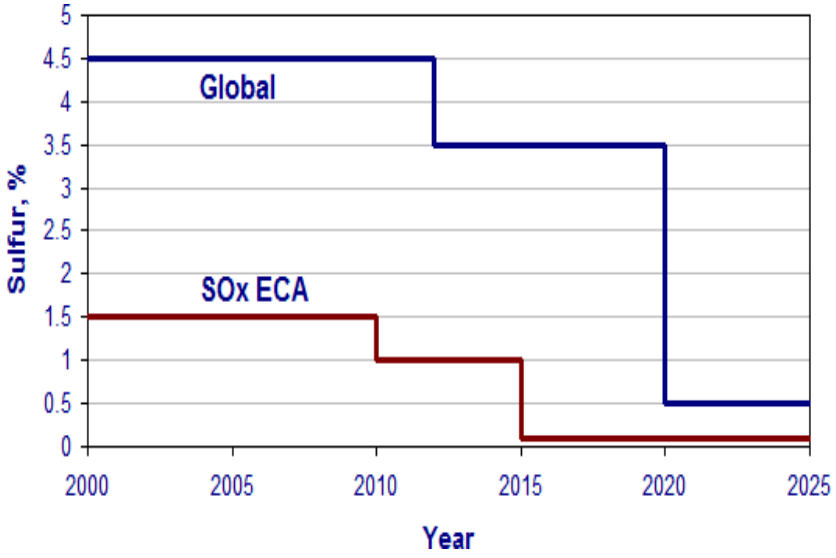


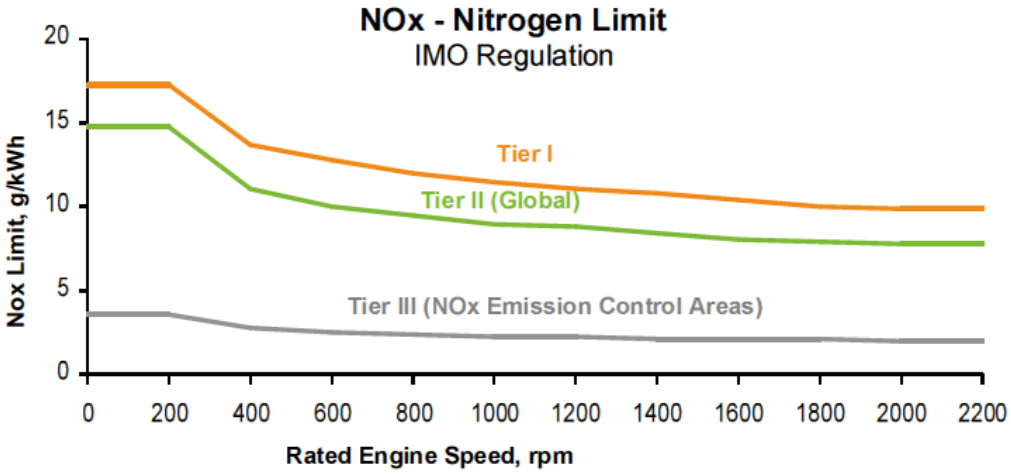
The role of LNG between fossil fuels

- GHG emission reduction with LNG
  - CO_2 -23%;
  - NOx -92%;
  - SOx -100%,
  - Particulate -98/100%

The role of LNG between fossil fuels

Emission Control Area





Source: MARPOL, Annex VI

LNG terminology 1:

- Measure terminology
- Conversion factor

LNG terminology 1:

- unit of measure, International System vs Imperial Units

	SI	Imperial
Weight	kg	pound lb
Volume	m^3	gallon gal
Temperature	K	Fahrenheit °F
Pressure	Bar	Pounds per square inch psi
Energy	J	British thermal unit Btu

LNG terminology 1:

- Typical NG unit of measure
  - Smc standard cubic meter, mass of NG contained in a cubic meter at the temperature of 15°C and at the pressure of 1 bar
  - Nmc normal cubic meter, mass of NG contained in a cubic meter at the temperature of 0°C and at the pressure of 1 bar, ~1,05 Smc
  - Scf standard cubic foot, mass of NG contained in a cubic meter at the temperature of 60°F and at the pressure of 14,73 psi
  - TOE, tonn of oil equivalent, equal to 41,9 GJ

LNG terminology 1:

- unit of measure convertion

SI	Imperial	Convertion factor
kg	pound lb	1 lb =0,4536 kg
m^3	gallon gal	1 gal = 0,0037854 m^3
K	Fahrenheit °F	T(°F)=T(°C)*9/5+32
Bar	Pounds per square inch psi	1 bar = 14,5 psi
J	British thermal unit Btu	1 Btu = 1055,1 J

LNG terminology 1:

- Practical unit of measure convertion

unit	Convertion
Smc	0,7 kg
Scf	1/35,3 Smc
kWh	3600 kJ
Btu	1/3412 kWh

Fuel value chain

MATTEO SANTOLINI
Università degli Studi eCampus
11-12/06/2015

LNG chain

- LNG Regasification Terminal

- **LNG liquefaction plant from pipeline or stranded well**

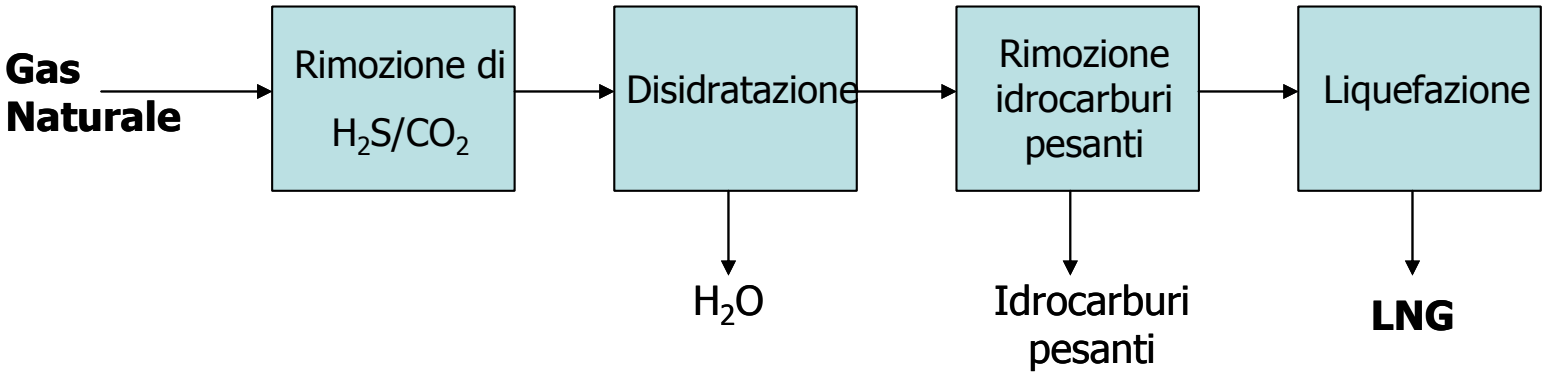
LNG chain

- LNG plant scale
  - Micro scale
  - Small scale
  - Baseload plant

- LNG liquefaction process (baseload plant)
  - MFCP Cycle
  - ACPI cycle
  - Cascade cycle
  - DMR cycle
  - Linde cycle

LNG chain

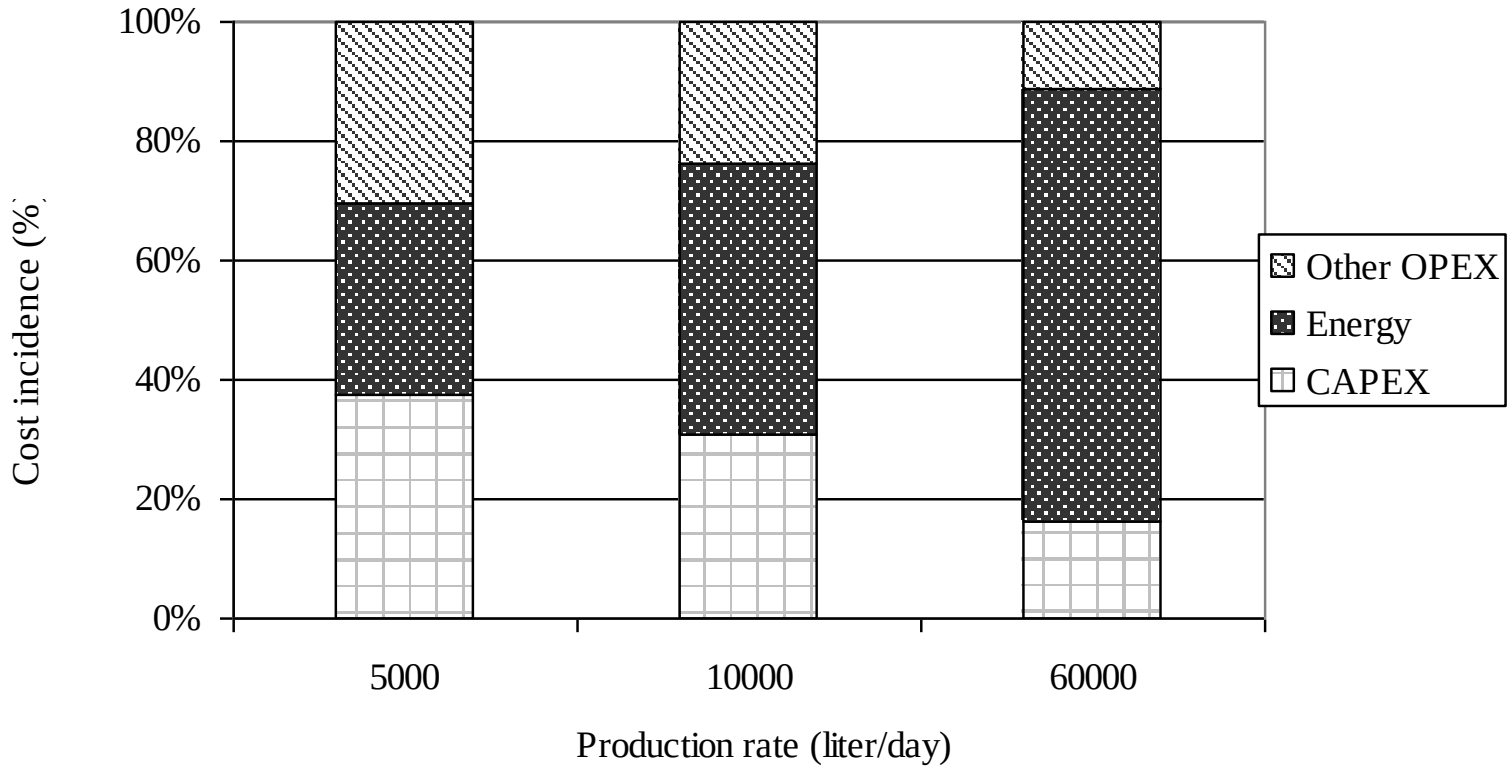
- LNG liquefaction process



Source: Arteconi et al., ICR 2011

LNG chain

- LNG Plant size effect liquefaction cost



Source: Arteconi et al., 2011 – ICR2011

LNG chain

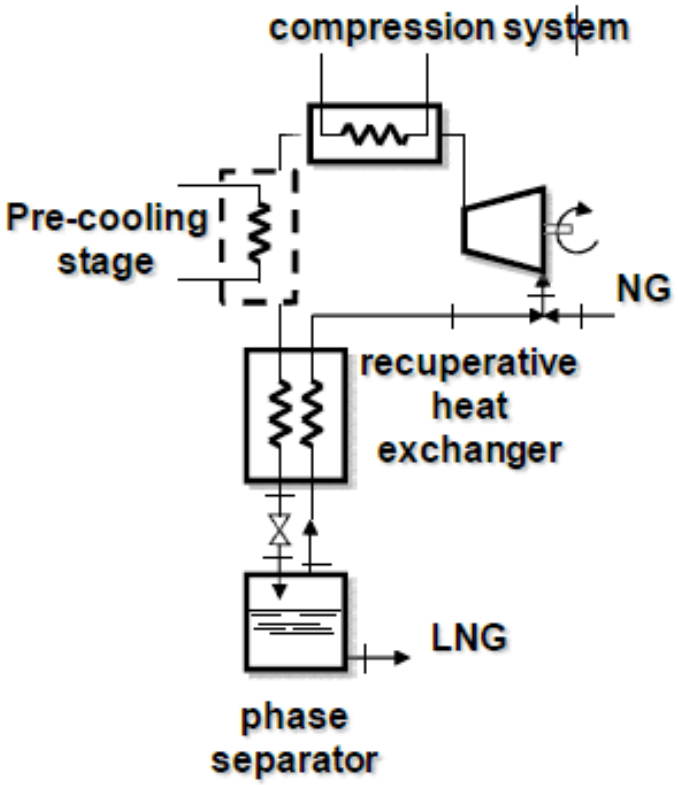
- LNG liquefaction small scale process
  - High efficiency and reliability
  - Low CAPEX and, as possible, OPEX
  - Off the shelf components
  - Flexibility at various operating condition

LNG chain

- LNG liquefaction process for micro-scale plant (<20 tpd)
  - Linde cycle, 1 or more pressure drop, P_{max}= 200 bar
  - Claude cycle, P_{max}= 50 bar
  - Let-down plant, on pipeline pressure reducing station
  - Nitrogen plant

LNG chain

- Linde cycle



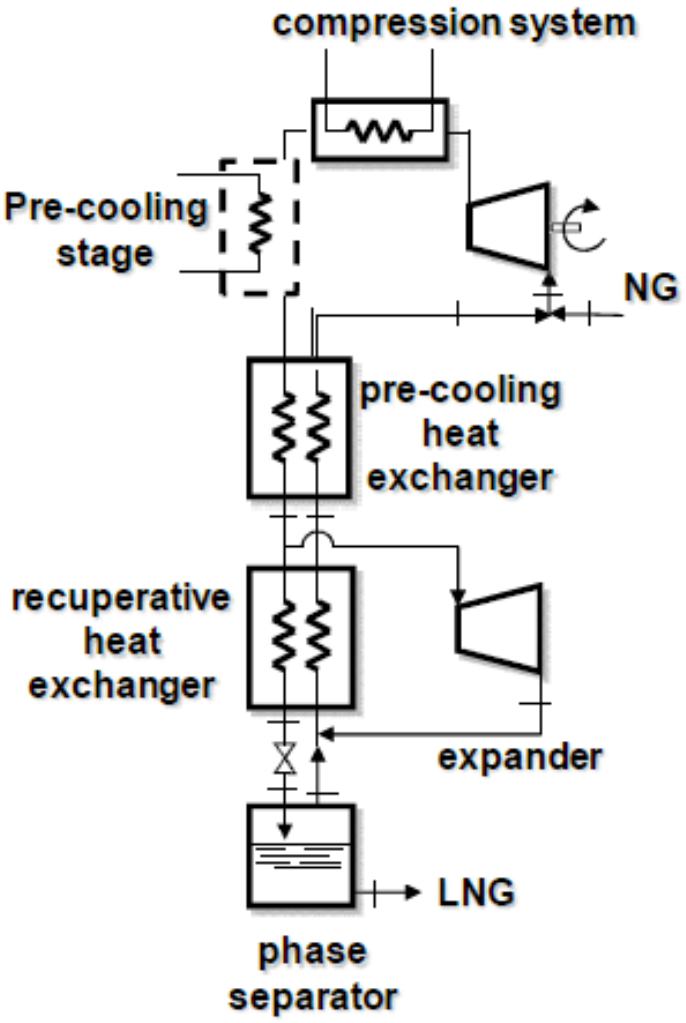
Source: Arteconi et al. 2011

LNG chain

- Linde plant
  - Joule-Thomson valve
  - High pressure, up to 200 bar
  - Pre-cooling needed
  - Low efficiency
  - Low CAPEX cost
  - Multiple pressure drop increase efficency and cost

LNG chain

- Claude cycle



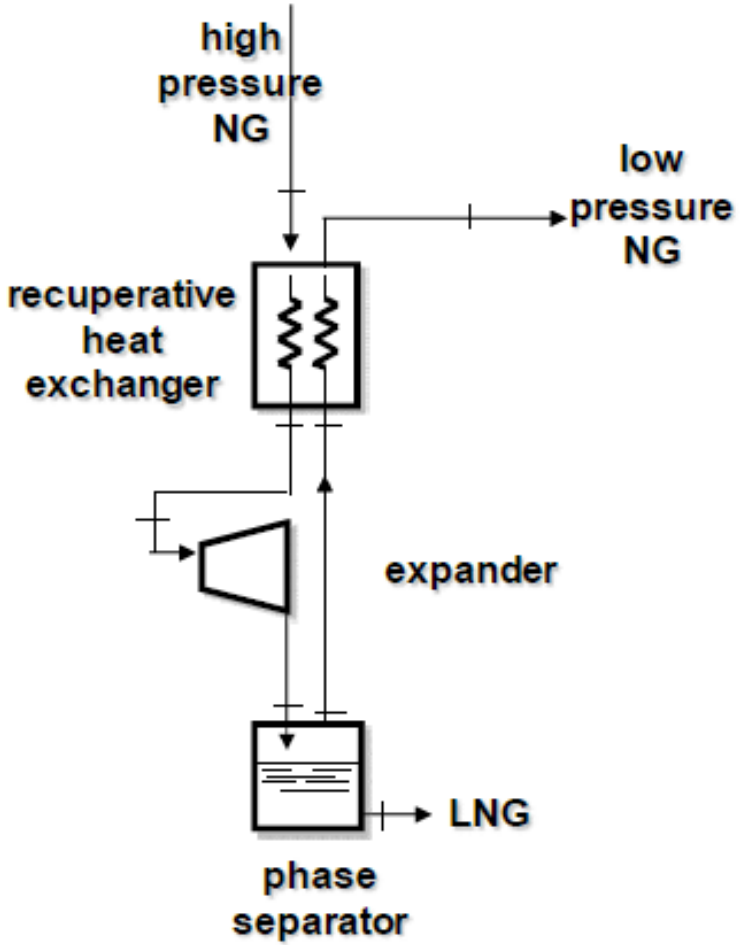
Source: Arteconi et al. 2011

LNG chain

- Claude plant
  - cryoexpander
  - High efficiency
  - High cost
  - No pre-cooling needed
  - Medium pressure, 50-70 bar

LNG chain

- Let-down cycle



Source: Arteconi et al. 2011

LNG chain

- Let-down plant
  - Need to be located on reducing pressure station
  - Logistical issue, related to high pressure pipeline
  - Low cost, better efficiency

LNG chain

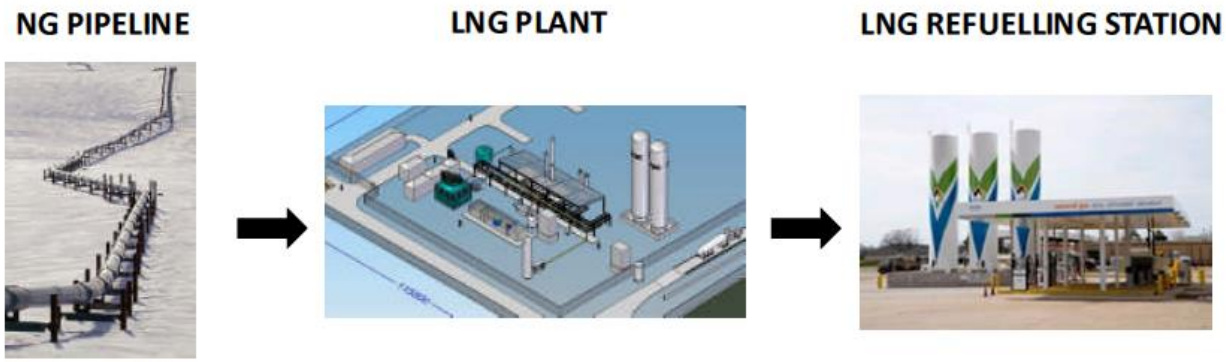
- Nitrogen plant
  - Use liquid nitrogen to liquefying LNG
  - Nitrogen should be
    - created with a local plant
    - Supply by large industrial plant, good avalaibility
  - Low pressure needed
  - Low efficiency compared
  - Low CAPEX cost

LNG chain

Ciclo	Consumo kWh/kg	Costo di produzione LNG €/l
Linde TP	0,7-0,8	0,40
Claude	0,6-0,7	0,41
Let down	-	0,33
Nitrogen	1,0-1,1	0,43

LNG chain

- LNG liquefaction plant from pipeline



Hyphotesis:

- Plant production 10 t/day
- Plant efficiency 0,6 kWh/kg
- ~~Natural gas price 0.39 €/m3 (0.24€/liter)~~

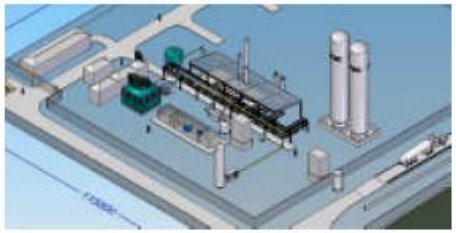
LNG chain

- LNG liquefaction plant from pipeline

NG PIPELINE

+ NG pipeline price

LNG PLANT



+ liquefaction costs
+ plant operator mark up

LNG REFUELLING STATION

+ station operative costs (labour, maintenance, energy, plant amortization)
+ station operator mark up

0,45 €/liter

0.24 €/l → 0.1772 €/l → + 0.0317 €/l = 0.45 €/l

LNG chain

- Small scale LNG liquefaction plant from S.TRA.TE.G.I.E.

Characteristic:

- Plant production 2,5 t/day
- Plant efficiency 1,1 kWh/kg
- Claude-Linde hybrid cycle
- ICE for off-grid application

LNG regasification

- LNG should be used for
  - Terrestrial transport (Heavy duty vehicle)
  - Maritime propulsion
  - Supply local grid without pipeline
  - Supply costumer without pipeline
  - Ease transport and storage (the LNG would be regasified and insert into pipeline)

LNG regasification

- LNG regasification unit
  - LNG terminal for regasification
  - FSRU floating storage refrigeration unit
  - LCNG station for CNG production
  - Regasification onboard for direct use
    - BOG
    - LNG

LNG regasification

on-shore

Panigaglia (SP)

Cameron, La

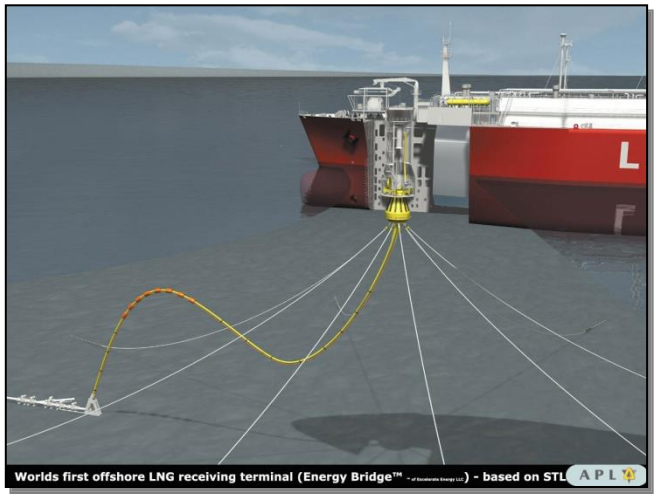
off-shore GBS (Gravity Based Structure)

Porto Viro (RO)

LNG regasification

off-shore FSRU (Floating Storage Regassification Unit)

Livorno



LNG regasification

- Regasification Process
  - ORV open rack
  - SCV submerged combustion
  - STV shell and tube
  - IFV intermediate fluid
  - AAV ambient air

LNG regasification

- Regasification Process
  - ORV open rack
  - SCV submerged combustion
  - STV shell and tube
  - IFV intermediate fluid
  - AAV ambient air

LNG regasification

- LCNG Station
  - LNG storage
  - Cryogenic pump
  - LNG vaporizer
  - Double refilling station CNG and LNG
  - Should be located away from pipeline, close to the customer

LNG terminology 2:

- LNG production plant
  - Methane upgrading
  - Mole sieve
  - J-T valve
  - Expander
  - Vapor-liquid separator

LNG terminology 2:

- LNG storage
  - Self supporting tanks
  - Membrane
  - Boil off gas
  - Roll-over