ALTERNATIVE FUELS IN DETAIL: COMMERCIALLY AVAILABLE OPTIONS

LIQUEFIED NATURAL GAS (LNG)

GREENVOYAGE 2050

Overview

- Background and key characteristics
- LNG fuel production value chain
- Feedstocks and energy sources
- Production technologies
- Onshore requirements
- Onboard requirements
- Regulations, standards and guidance
- Environmental impact
- Cost overview
- Barriers and risks
- Summary

Background and key characteristics

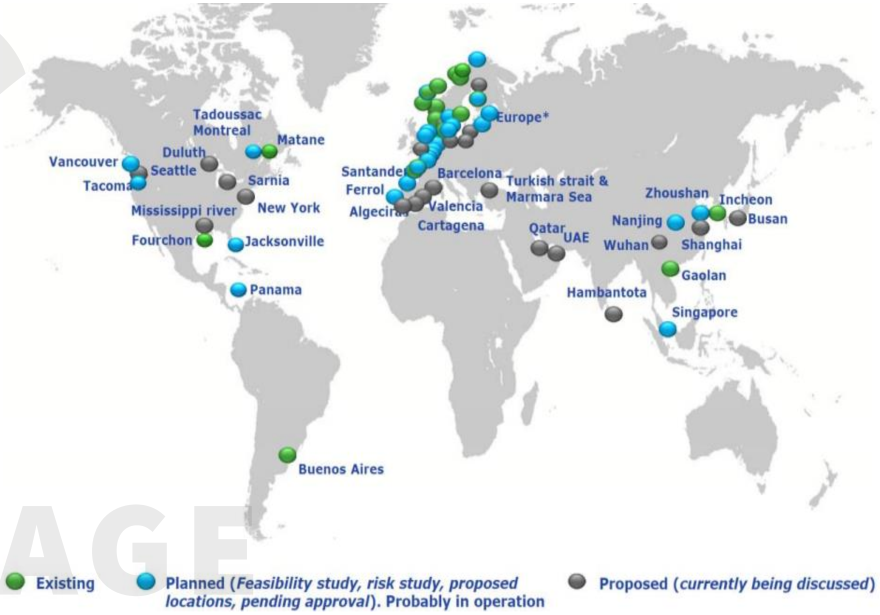
HFO

- Energy density: 42 MJ/kg = 35 MJ/dm^3.
- Flashpoint: 60°C.
- Water solubility: None.
- Most widely-used ship bunker fuel.

LNG (CH_4)

- Energy density (@-162°C): 53.6 MJ/kg = 22.2 MJ/dm^3.
- Liquid at –162°C at atmospheric pressure.
- When liquefied, takes up 600x less space than its gaseous state.
- Volumetric density of LNG is lower than HFO, so volume of ship required to accommodate storage tanks is larger.
- In liquid state, LNG, is non-flammable, non-explosive and non-toxic. Flashpoint in gaseous state is -188°C.
- Commonly used in power generation.

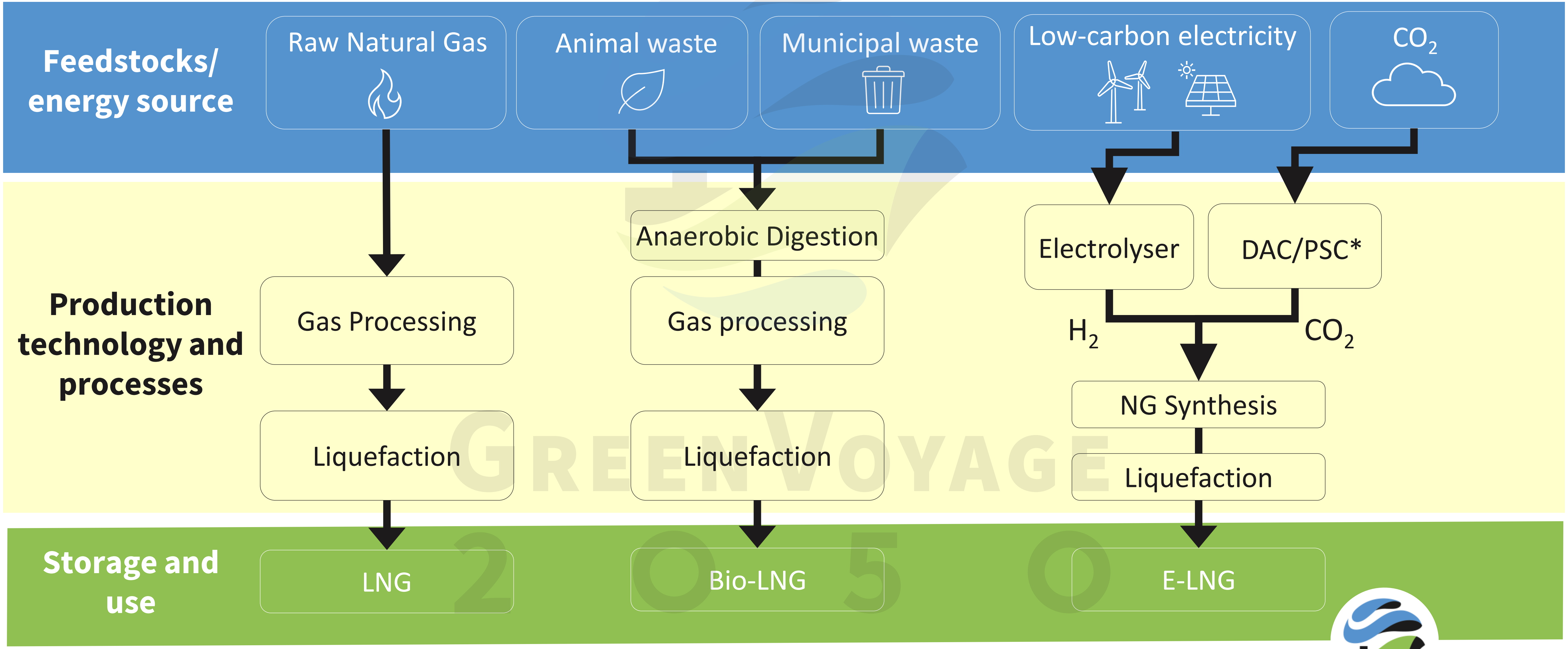
LNG bunkering availability at ports[1]



2019 global supply = 359 million tonnes[2].

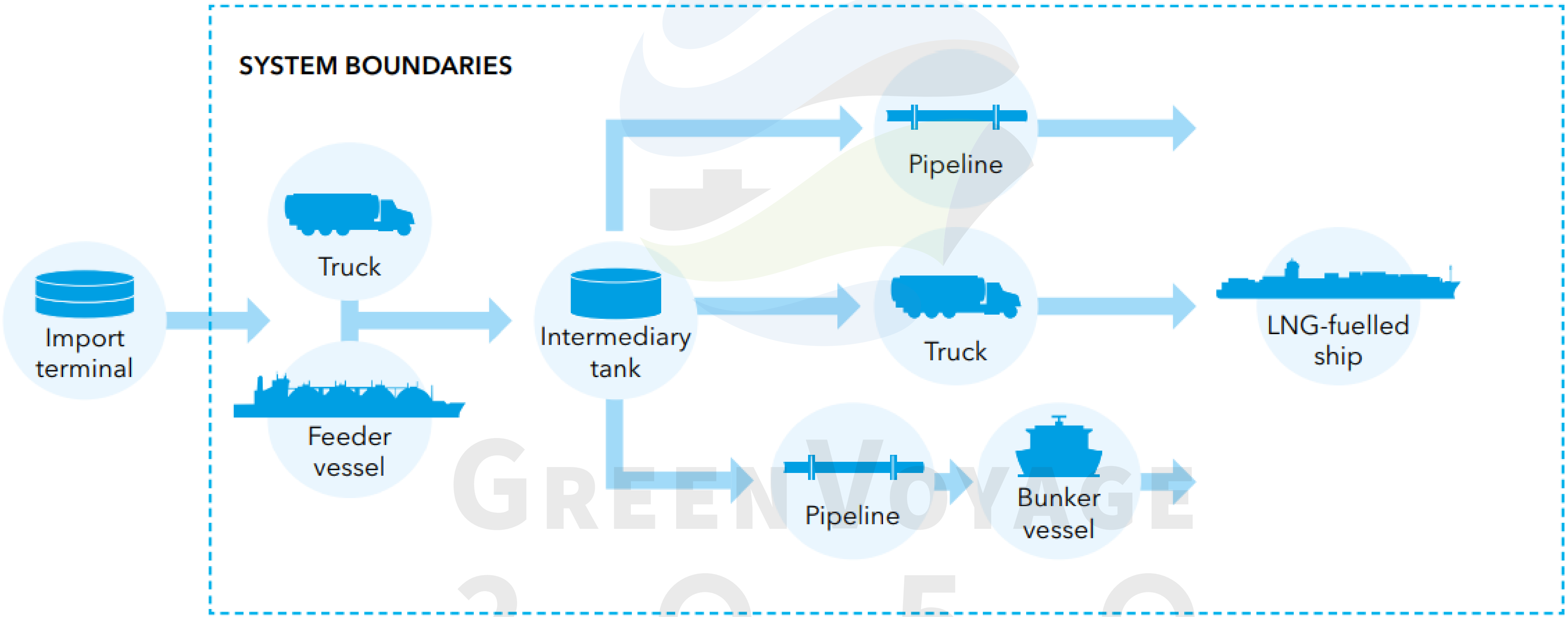
[1] DNV GL. Role of Natural Gas and LNG as Marine Fuel. La Jolla: presented at the XXV La Jolla Energy Conference.
[2] Shell LNG outlook 2020.

LNG fuel production value chains



*DAC = Direct air capture / PSC = Point source capture

Small scale LNG distribution value chain



Feedstocks and energy sources

Current availability

- Natural Gas
- Low-Carbon Electricity
- CO_2 (DAC)
- CO_2 (PSC)
- Residual Biomass
- Municipal Waste

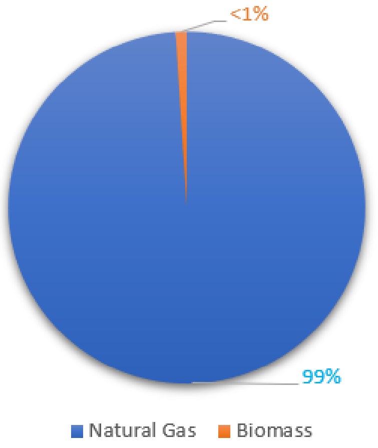
DAC = Direct air capture / PSC = Point source capture

Widely Available | Availability Constrained | Availability Very Restricted

Key Points

- Nearly all LNG is currently produced using fossil natural gas which are widely available.
- Alternative feedstocks currently have supply constraints, but these are expected to reduce over time.
- Ability to produce E-LNG is determined by local availability of renewable power.

Global LNG Production by Feedstock

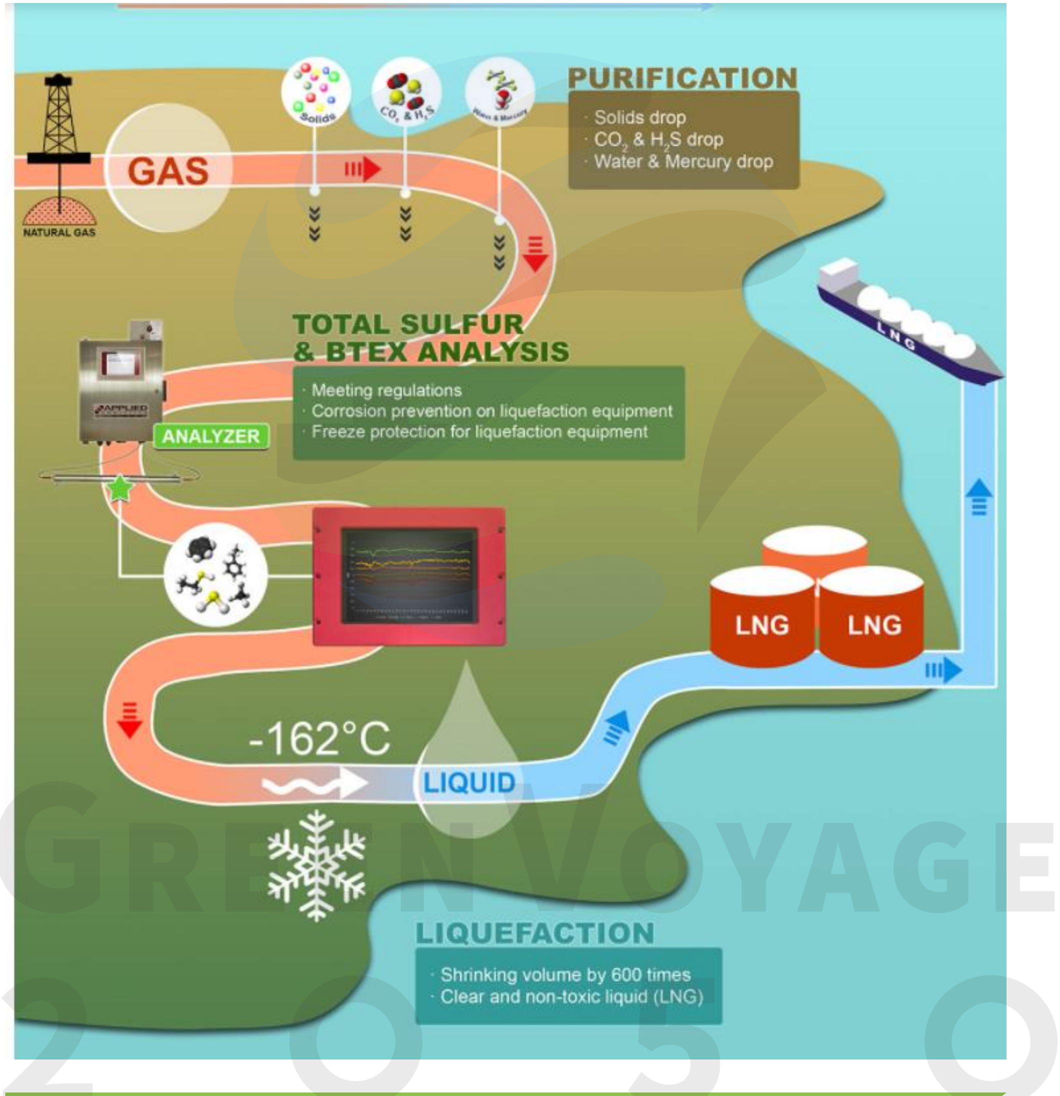


Production technologies

Production technology and processes	Gas Processing → Liquefaction	Anaerobic Digestion → Gas processing → Liquefaction	Electrolyser (H_2) + DAC/PSC* (CO_2) → NG Synthesis → Liquefaction
Readiness	TRL 9	TRL 7 - 8	TRL 6 - 7

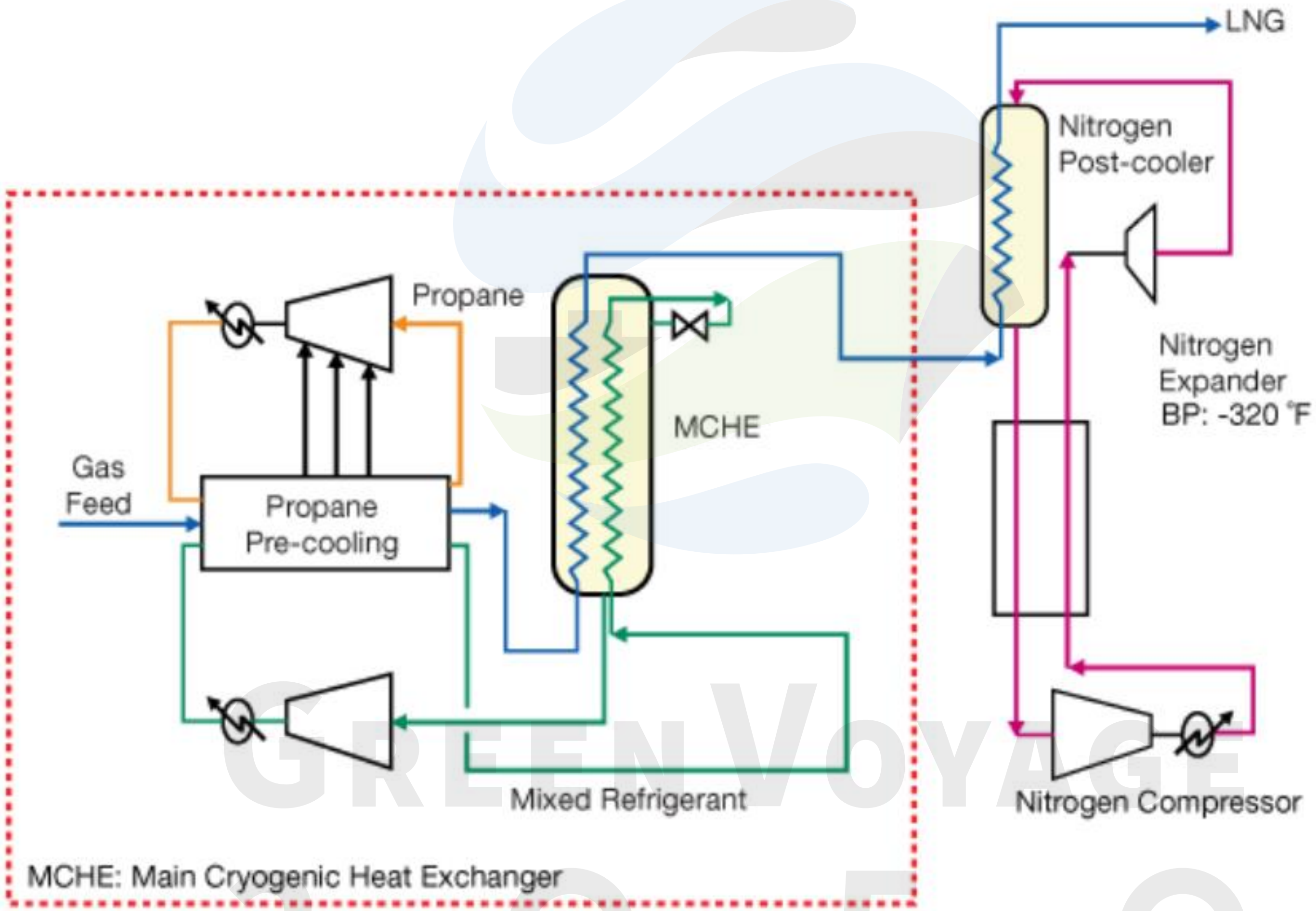
*DAC = Direct air capture / PSC = Point source capture

Production technologies



LNG Production

Production technologies - Liquefaction



LNG AP-X Liquefaction Process

Onshore requirements

Storage and use | LNG

Storage

- Existing storage infrastructure is widespread – many ports already have existing LNG storage facilities particularly where strong natural gas markets exist.
- Storage tanks must be insulated to minimise heat loss and prevent the LNG from vaporising. Any vapour, or Boil Off Gas (BOG), must be managed to avoid over-pressurisation of the tank.
- LNG may be kept at atmospheric pressure in flat bottom tanks or pressurised in spherical or cylindrical tanks.

Transportation

- LNG is currently widely transported globally by ship, truck, pipelines and rail.
- There is widespread familiarity with loading and unloading LNG as a bulk product.

Onshore requirements

Storage and use

LNG

Bunkering

- Ship-to-ship bunkering, terminal to ship and truck to ship bunkering are all available.
- LNG bunkering infrastructure is currently offered at 96 ports with a further 55 ports in the process of developing facilities.[1]
- LNG bunkering vessels continue to grow in numbers.
- LNG bunker vessels are costly compared to methanol and LPG storage due to the requirement to store LNG at cryogenic temperatures.
- More infrastructure required in Southern Hemisphere in future, majority of current ports with LNG bunkering infrastructure are in Northern Hemisphere.

[1] Sea-LNG (sea-lng.org)

Onboard requirements

Storage

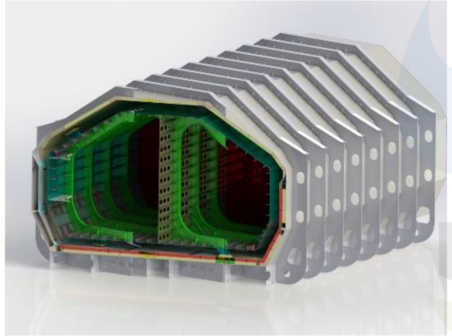
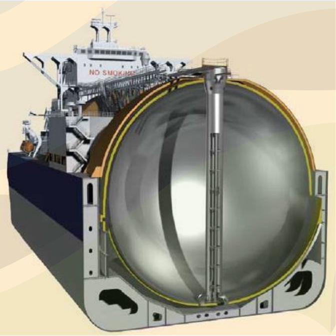
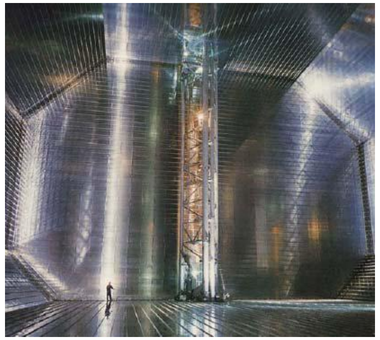
- Double walled pipes required as a low flash point fuel.
- LNG stored in cryogenic insulated tanks to minimise Boil Off Gas (BOG).
- Tanks need to be of a material which is suitable for use with a cryogenic liquid.
- Larger tanks (2.3x) are required for equivalent energy content of HFO/MGO (due to lower volumetric energy density).

Handling

- LNG is widely handled as a bulk cargo and the risks are therefore well understood.
- Handling of LNG as a fuel is covered by the IMO's IGF code and requires additional crew training in accordance with established international standards and codes.

Storage and use | LNG

Onboard LNG Storage Technologies

IMO Classification:	Type A	Type B	Type C	Membrane
				
Pressure	Atmospheric	Atmospheric	Pressurised	Atmospheric
Secondary Barrier	Full	Partial	None	Full
Typical Capacity	>5,000m^3	>5,000m^3	Up to 1,000m^3	>5,000m^3
Cost	High	High	Medium	High
Space Efficiency	Medium	Medium	Low	High

Onboard requirements

Propulsion

- LNG combustion engines already commercially available (including dual-fuel model).
- Retrofit Internal Combustion Engine (ICE) conversions are possible. Adaptations include modifying the fuel injection system.
- Purging system required (N_2 or other inert gas) to enable safe maintenance.
- Low and high pressure 2-stroke ICE and low pressure 4-stroke ICE are widely available.
- LNG based fuel cells are in an earlier development stage but could provide higher efficiency than combustion engines, if commercialised.
- Unburnt methane in the exhaust gas is referred to as “methane slip” which will have an adverse effect on GHG emissions. Methane slip is a key issue in low-pressure engines where lifecycle carbon equivalent emissions can, in some cases, exceed that of MGO or HFO[1][2].

Storage and use | LNG

[1] *The climate implications of using LNG as a marine fuel - Working Paper 2020-02, The International Council on Clean Transportation, 2020*
[2] *Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel,* Thinkstep, 2019

LNG propulsion options

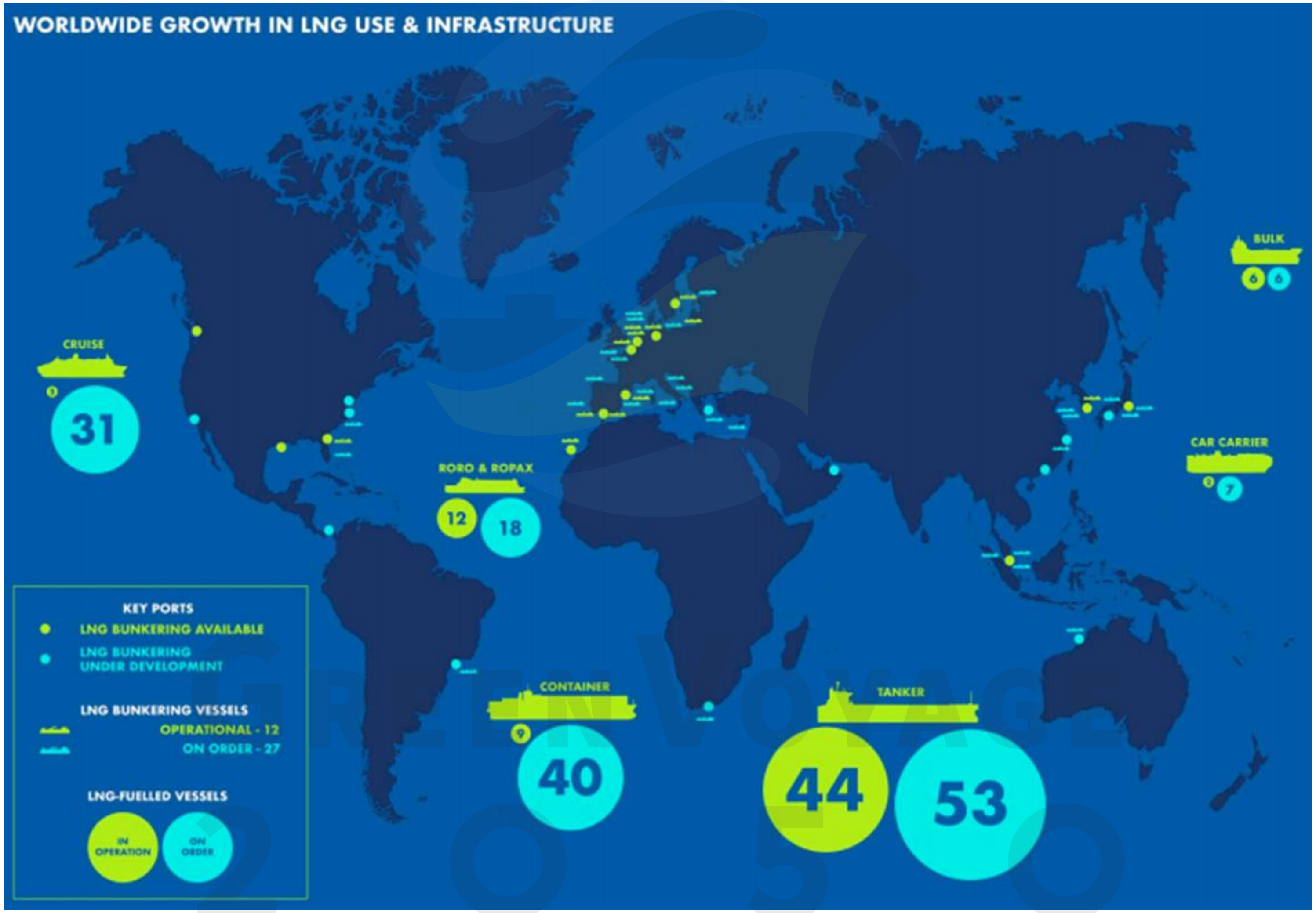
Option	Existing engine retrofit conversion	LNG-ready combustion engine	Fuel cell
Readiness	TRL 9 (commercially available)	TRL 9 (commercially available)	TRL 7 (Under development)
Capital cost (including required changes to ancillary onboard systems e.g. fuel supply)	Highly project specific Estimated ~410 USD/kW [1],[2]	Estimated ~190 USD/kW [1]	Highly project specific
Efficiency (at shaft)	<47% (project specific)	~47%	~60%

[1] LNG Supply Chains and the Development of LNG as a Shipping Fuel in Northern Europe, The Oxford Institute for Energy Studies, 2019
[2] LNG as Ship Fuel, DNV GL Report, 2014

Regulations, standards and guidance

Body/Organisation	Documentation	Status/Comment
IMO	IMO IGF Code (The International Code of Safety for Ships using Gases or other Low-flashpoint), adjunct to SOLAS. IGF code was proposed to the Marine Safety Committee (MSC) of IMO in 2004 and contains requirements for using LNG as a Fuel.	Available
	IMO STCW (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers) contains requirements for crew training and qualification on ships subject to IGF code.	Available
ISO	ISO Standard 23306:2020 Specifies the quality requirements for LNG as a fuel for Marine Applications	Available
Class Society	Use of LNG as a ship's fuel is regulated by Class Rules and Regulations.	Class Rules Available
SGMF	Society for Gas as a Marine Fuel is a Non-Governmental Organisation which produces guidelines for LNG Fuelled vessel operations.	Guidelines produced on a regular basis.
Supplier	Supplier's standards	Available from supplier

LNG powered vessels



[1] *LNG as a marine fuel, SEA-LNG report, 2020*

Examples of LNG vessels and related infrastructure

Vessels

Examples of LNG fuelled vessels

- Glutra: First LNG Fuelled Ferry, built in 2000 at Langsten Yard, Norway. Operating in Norwegian Fjords.
- Fjord1 (Norwegian Ferry Company): operating approximately 12 LNG fuelled ferries on Norwegian Fjords.
- El Coquí & Taíno (ConRo vessels): delivered in 2018 and on dedicated service between Jacksonville and San Juan
- HSC Francisco (High speed craft): operated by Buquebus between Buenos Aires & Montevideo. Delivered 2014 from Incat.
- Siem Confucius & Siem Aristotle (Car Carriers): delivered in 2018/2019 from Xiamen Shipyard in China and chartered to Volkswagen group for trade Europe to USA/Mexico.

Viking Queen, LNG powered PSV

Glutra, LNG powered Ferry

Examples of LNG vessels and related infrastructure

STS LNG Bunkering in Zeebrugge

Source: Port of Zeebrugge

Bunkering and infrastructure

- In 2017, the world's first sea-going large LNG bunker vessel, M.V. Green Zeebrugge, entered operation based in Zeebrugge. This vessel has a capacity of 5,100 m^3 and is owned and operated by NYK.
- The Gate LNG import terminal in the port of Rotterdam has also provided the infrastructure to accommodate smaller vessels for LNG Bunkering and feeder vessels to supply locations throughout Europe. Several LNG bunkering vessels now operate from here including Shells M.V. Cardissa and inland waterways barges.

Environmental impacts

	LNG	Bio-LNG	E-LNG
Emission reduction drivers	• Reducing methane slip** • Source of energy for production & transportation	• Reducing methane slip** • Source of energy for production & transportation • Nature of feedstock (e.g. farmed/waste)	• Reducing methane slip** • Source of energy used for production and transportation
Reduction in GHG emissions*	**up to 15%** [2]	**Potential for high savings*** **	**Potential for high savings*** **

*vs MGO well-to-wake emissions

Emission reductions[1]

SOx	PM	NOx
~-100%	~-100%	~-80%

**Methane slip will reduce as the Engine Technology advances. Methane slip causes increase in overall GHG emissions.

***For Bio-LNG and E-LNG, the CO_2 released when the fuel is burnt derived from CO_2 absorbed in plant growth (for bioLNG) or captured (for E-LNG). E-LNG likely to have greater potential for emissions reduction than Bio-LNG.

[1] *LNG fuel and the ship emissions debate, Riviera 2018*, (https://www.rivieramm.com/opinion/opinion/lng-fuel-and-the-ship-emissions-debate-23849)

[2] *The climate implications of using LNG as a marine fuel, The ICCT, 2020 – Note: maximum life-cycle GHG benefit of LNG compared to MGO over 100-year GWP.*

Fuel cost overview

Production route	LNG	Bio-LNG	E-LNG
Key drivers (Expected trend: positive/negative/either)	• Natural gas price	• Biomass feedstock cost and supply	• Green electricity price
Current cost (per GJ fuel)	7-10 USD [1]	8.5 – 28.5 USD [2]	23 – 110 USD [2]
Current cost vs. HFO market price (per GJ fuel)[1]	~=	Additional 2 – 16 USD[1]	Additional 17 – 98 USD[1]
Potential for cost reduction vs current cost	Low	Medium	High

Current LNG market price vs HFO market price[3]

+1 to -2 USD/GJ

[1] Based on HFO market price of 250-500 USD/tonne & LNG market price of 375 to 550 USD/tonne

[2] Availability and average costs of liquified bio-and synthetic methane, CE Delft, 2020

Barriers and risks

Category	Barrier / Risk	Rating
Policy	Low uptake of LNG technology due to uncertainty in future policy.	High – vessel owners may seek other low(er)-carbon solutions.
Commercial	Cost of engine replacement/conversion.	High/medium – increasing commercial offering of Dual Fuel LNG engines.
	Low volumetric energy density leads to loss of space for cargo or passengers.	High/medium – (application specific).
Infrastructure	Availability of bunkering infrastructure.	Medium – increasing development of bunkering infrastructure globally.
Sustainability	Methane slip is a concern.	High – depends on engine technology.
	Lock-in by fossil LNG which does not meet targets	High - locked in to lower carbon methods to produce LNG which may not be most economic/scalable, to reach targets

LNG summary

Key points

- LNG is safe to use, fully compliant and readily available as a marine transport fuel.
- Engine retrofit conversion possible, but availability of off-the-shelf Dual Fuel engines is increasing.
- Onshore infrastructure and equipment for storage and transportation of LNG is well understood.
- Cost comparisons show that while LNG is currently less expensive than MGO and HFO, lower volumetric energy density demands more fuel tank space.
- LNG is cleaner burning with up to 20% lower GHG emissions than HFO/MGO fuels. However, methane slip can offset this benefit.
- 20% is unlikely to be a long term compatible solution, so non-fossil production pathways will have to be used (i.e only interim fuel solution but locking in engine and storage technology, as well as infrastructure)
- Bio-LNG can bring large well-to-wake GHG reductions (although these can be offset by methane slip), but at present is limited.
- E-LNG is currently expensive but could bring even higher well-to-wake GHG reductions.