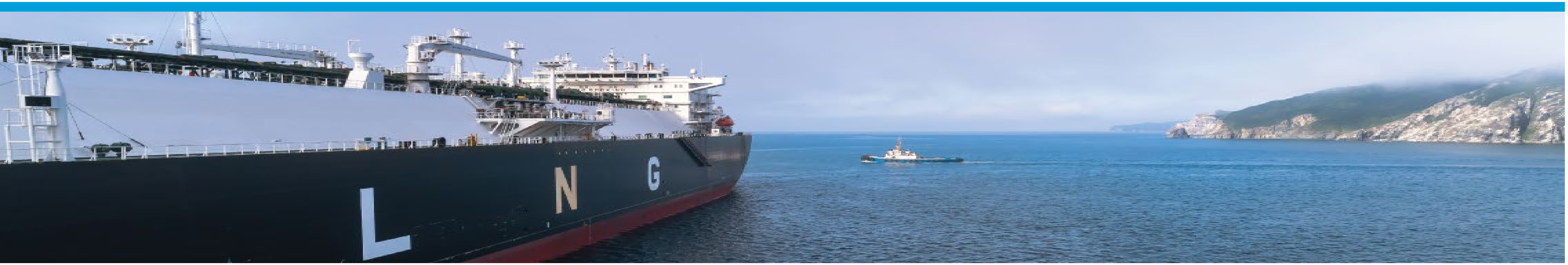
Welcome to LNG Day

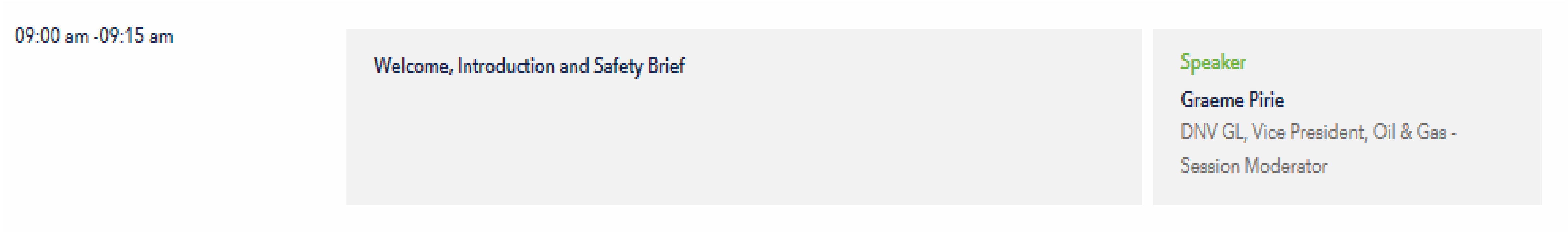
Technology Week 2020

February 26, 2020 Katy, TX



SAFER, SMARTER, GREENER

LNG Day Program Agenda



09:00 am -09:15 am

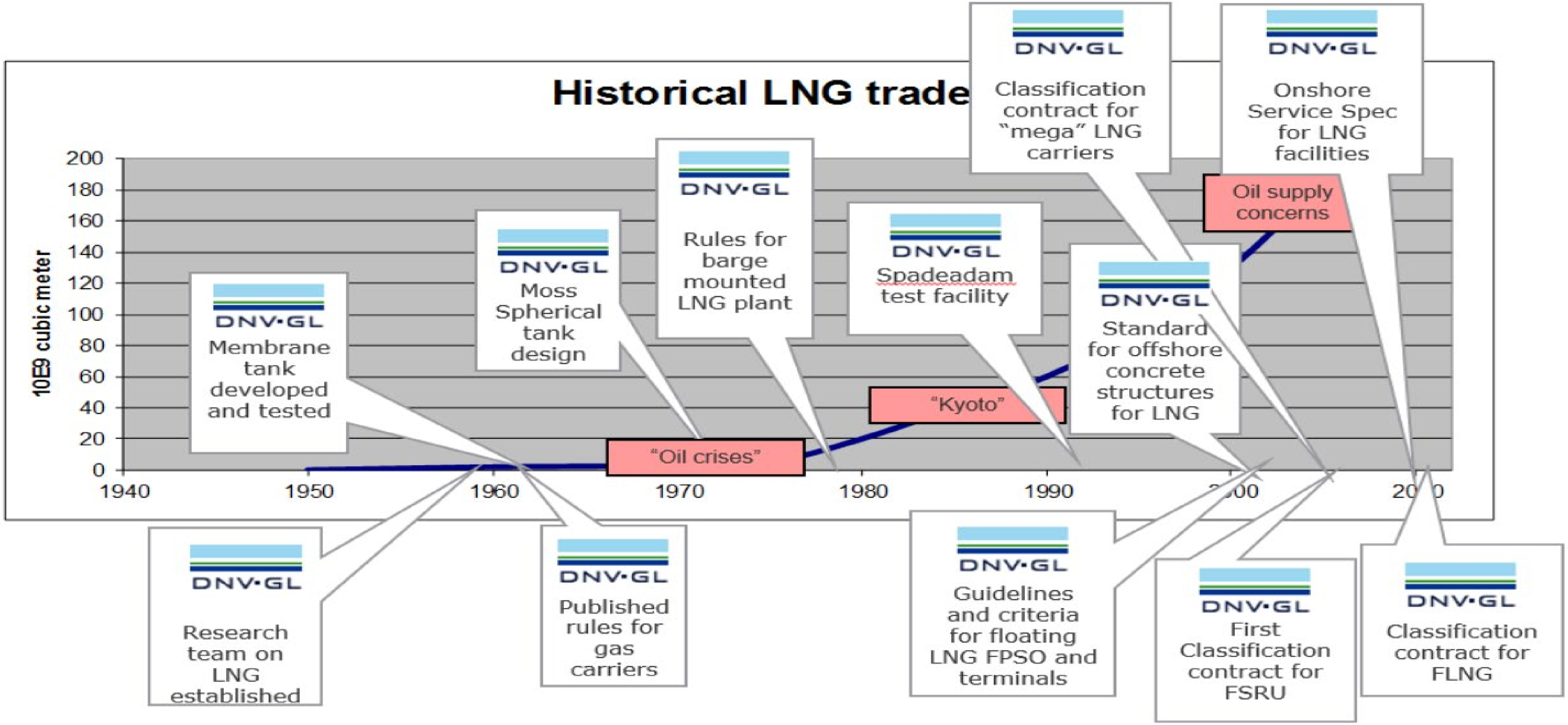
Welcome, Introduction and Safety Brief

Speaker

Graeme Pirie

DNV GL, Vice President, Oil & Gas - Session Moderator

Why is LNG Important to DNV GL - Our Historical Journey



Research team on LNG established

Membrane tank developed and tested

Published rules for gas carriers

Moss Spherical tank design

Rules for barge mounted LNG plant

Spadeadam test facility

Guidelines and criteria for floating LNG FPSO and terminals

Standard for offshore concrete structures for LNG

Classification contract for "mega" LNG carriers

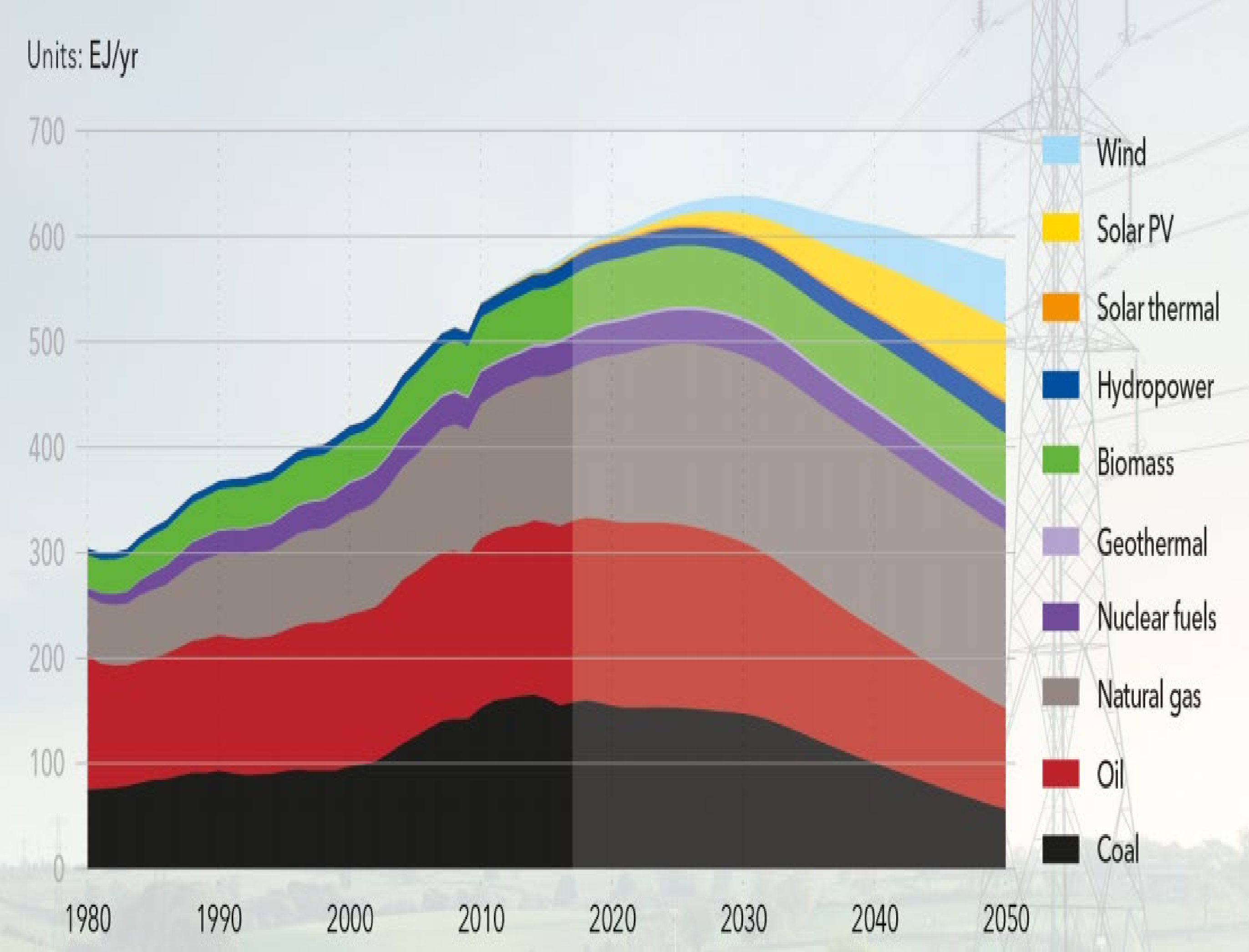
First Classification contract for FSRU

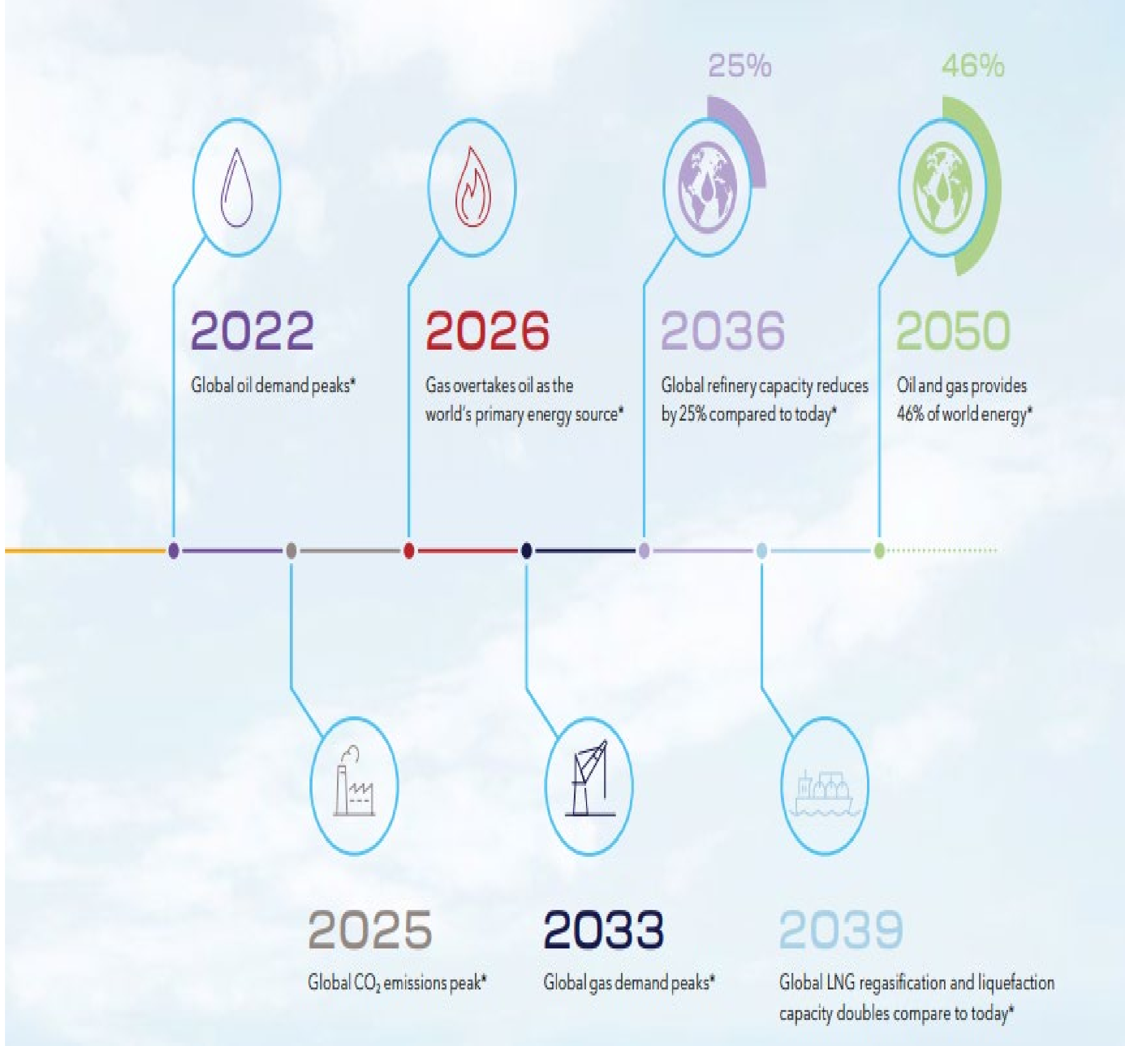
Onshore Service Spec for LNG facilities

Classification contract for FLNG

Our global LNG project experience footprint

Continued Exponential Gas Growth - A Golden Age of Gas is on the Horizon





2022 Global oil demand peaks*

2025 Global CO_2 emissions peak*

2026 Gas overtakes oil as the world's primary energy source*

2033 Global gas demand peaks*

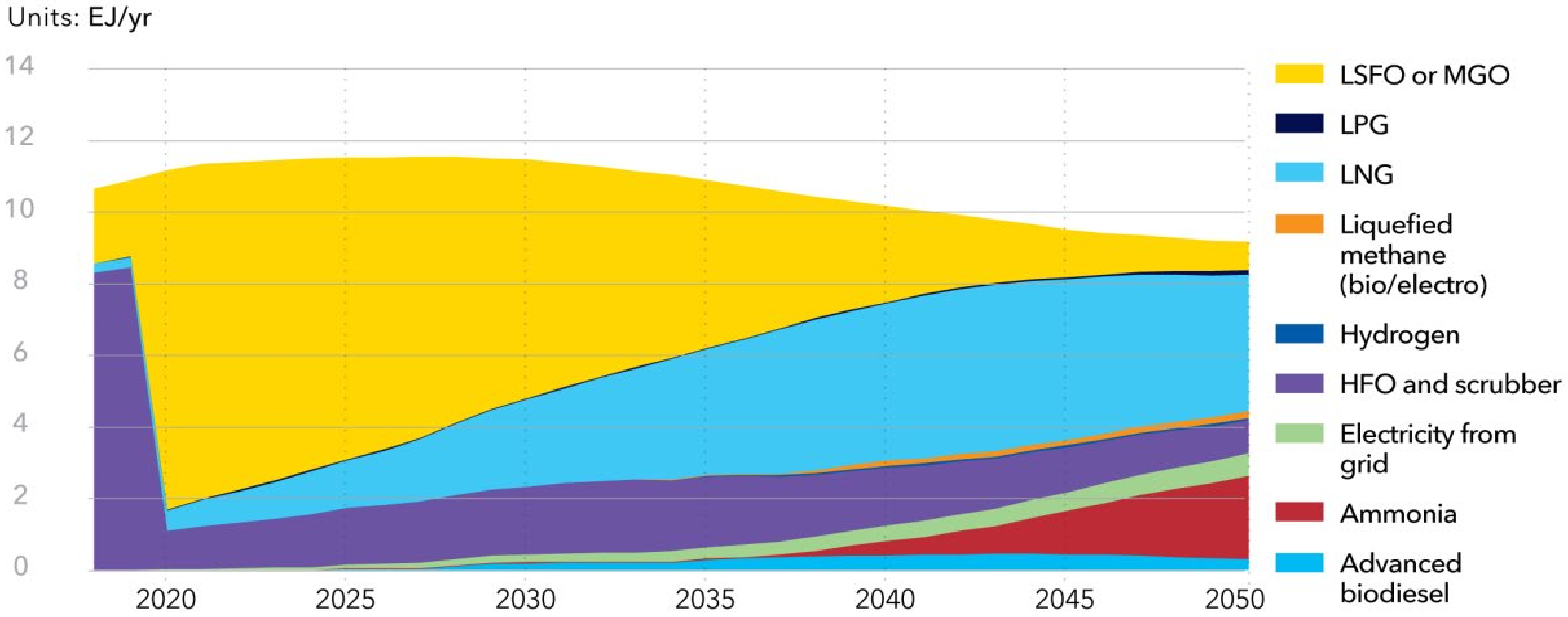
2036 Global refinery capacity reduces by 25% compared to today*

2039 Global LNG regasification and liquefaction capacity doubles compare to today*

2050 Oil and gas provides 46% of world energy*

https://www.dnvgl.com/videos/a-golden-age-of-gas-is-on-the-horizon-140625

Maritime Energy Demand and Fuel Mix Following Similar Trends



Agenda

09:00 – 09:15 : Welcome, Introduction and Safety Brief

09:15 – 10:00 : North America Regulatory Round Up

10:00 – 10:45 : Successful LNG project development

10:45 – 11:00 : COFFEE BREAK

11:00 – 11:45 : Concrete Structures and Geotechnics

11:45 – 13:00 : LUNCH

13:00 – 13:45 : The next wave of FLNG

13:45 – 14:15 : Sulphur Cap 2020 – Are you ready?

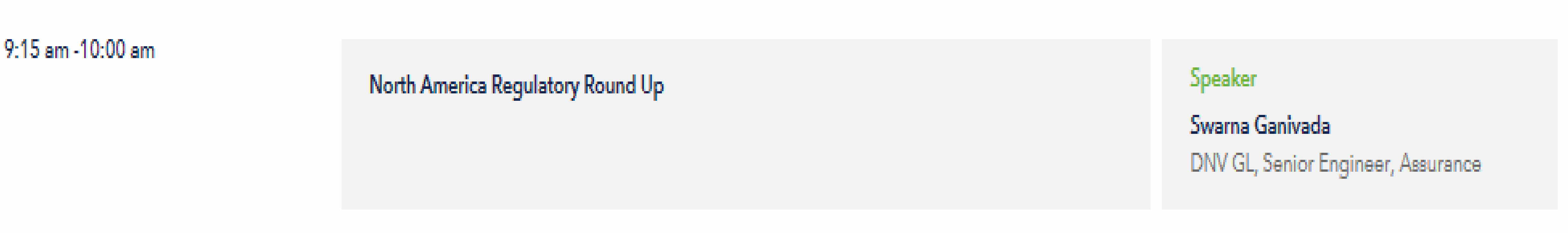
14:15 – 14:30 : COFFEE BREAK

14:30 – 15:15 : Alternative Fuels for the Maritime Industry, what are they?

15:15 – 15:45 : Governments and the Energy sector are getting serious about Hydrogen as a clean energy carrier

15:45 – 16:00 : Session wrap-up / Adjourned

LNG Day Program Agenda



9:15 am -10:00 am

North America Regulatory Round Up

Speaker

Swarna Ganivada

DNV GL, Senior Engineer, Assurance

North America Regulatory Round Up

LNG Facilities

Regulatory Overview of LNG Facilities in BC, Canada

Regulatory Agencies responsible for LNG facilities in BC (Examples)

BC Oil & Gas COMMISSION

National Energy Board
Office national de l'énergie
Canada

Fisheries and Oceans Canada

TECHNICAL SAFETY BC

Transport Canada
Canada

WORK SAFE BC
WORKING TO MAKE A DIFFERENCE

Canadian Environmental Assessment Agency

Regulatory Agencies responsible for LNG facilities in BC

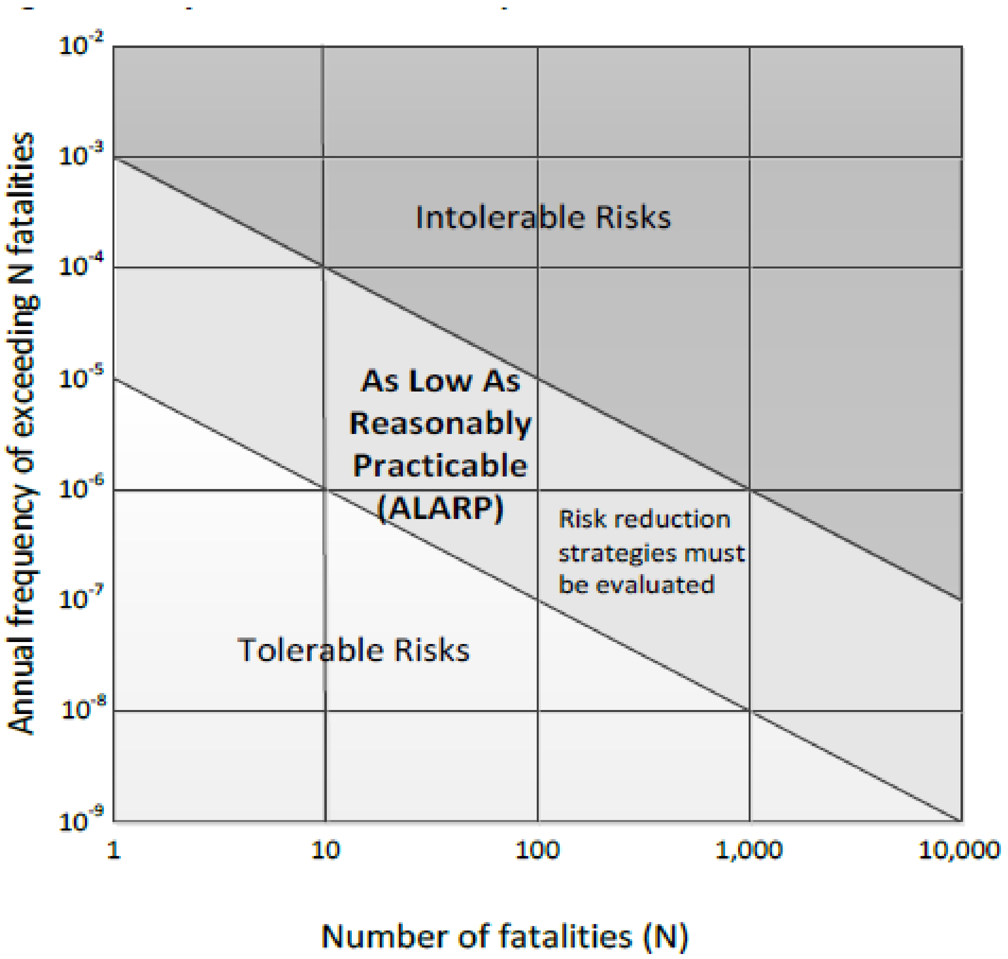
British Columbia Oil & Gas Commission	Technical Safety BC	Worksafe BC	Transport Canada
• Oversees oil and gas operations including exploration, development, pipeline transportation and reclamation • Regulatory responsibility extends from the exploration and development phases, through to facilities operation and ultimately decommissioning	• Oversees the safe installation and operation of technical systems and equipment • Issues permits, licenses and certificates of qualification • Works with industry to reduce safety risks through assessment, education and outreach, enforcement, and research	• Sets and enforces occupational health and safety standards	• Jurisdiction over marine safety, security and pollution prevention

Background: BCOGC – LNG Facility Regulation (LNGFR)

- Follow a process of hazard identification, risk assessment, mitigation and monitoring
- Starts at the application stage of a project with the initial hazard identification study (HAZID)
- Requires various safety and risk assessment studies to be carried out at appropriate stages of the project
  - Section 3 (1) (d) – prior to construction (partial listing)
    - (i) an updated hazard identification study; (ii) a process hazard analysis
    - (iii) a safety integrity level study
  - Section 8 – before operation (partial listing)
    - Safety and loss management program
- Results of the safety and risk assessment studies should be incorporated into the safety case associated with the facility

Safety Case Approach

- The Safety Case:
  - Identifies the hazards and risks
  - Describes how the risks are controlled
  - Describes the safety and loss management system in place to ensure the controls are effectively and consistently applied.
- Produced by the Owner/Operator
- Owner/Operators' responsibility to assess their processes, procedures and systems to identify and evaluate risks and implement the appropriate controls
- Identifies the safety critical aspects of the facility, both technical and managerial



Safety and Loss Management System - Principles

- Systematic Way to identify hazards and control risks, ensuring the controls are effective and continuous
  - Reduction of risk to a level as low as reasonably practicable – as defined in Schedule 2 of the LNGFR
  - A commitment to safety at all levels in the organization
  - Is required by OGC for an LNG Site

- Review and update at least once every 3 years

- Leadership and Accountability
- Risk Management
- Performance Improvement Planning
- Competency, Training and Behaviour
- Communication and Documentation Management
- Facilities Design and Construction
- Operations and Maintenance
- Contract Services and Supplier Management
- Crisis and Emergency Management
- Management of Change
- Performance Measurement and Monitoring
- Incident Reporting, Investigation and Analysis
- Governance and Assurance including Audit
- Management Review

Technical Safety BC – Safety Standards Act

- Regulates Technical Systems - Equipment and Work on the Equipment

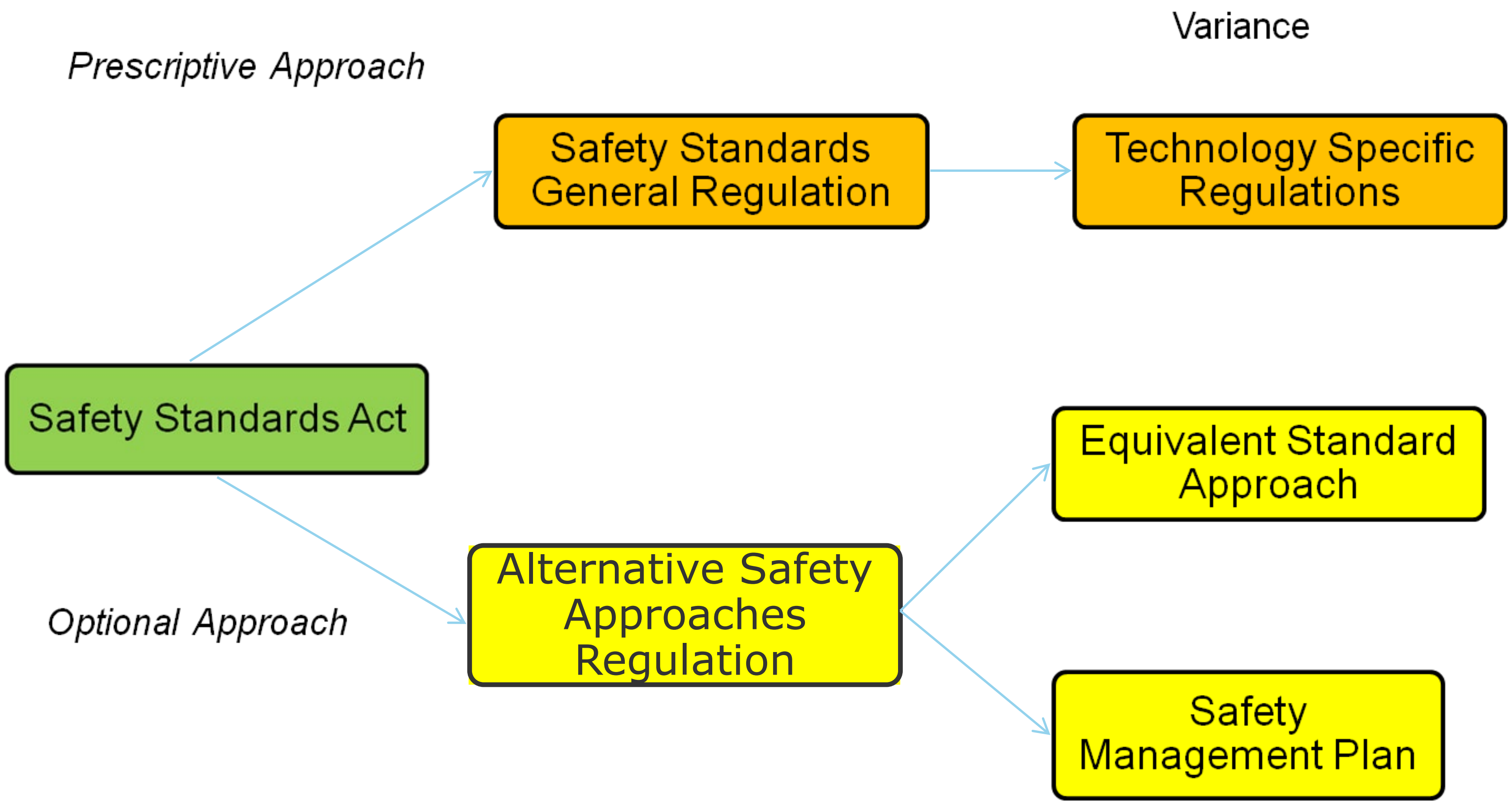
- One Act, One Set of General Regulations and One Technology Specific Regulation for each of the technologies regulated – www.technicalsafetybc.ca

- For an LNG site this means:
  - Electrical Equipment – including Instrumentation
  - Boilers, Pressure Vessels
  - Refrigeration systems and equipment
  - Elevators – if there is one
  - Passenger conveyors, ropeways

Regulations

- Boiler, Pressure Vessel and Refrigeration Safety Regulation
- Electrical Safety Regulation

Background: Safety Standards Act – Regulatory Options



Variance

Prescriptive Approach

Safety Standards General Regulation

Technology Specific Regulations

Safety Standards Act

Equivalent Standard Approach

Optional Approach

Alternative Safety Approaches Regulation

Safety Management Plan

Worker Safety - WorkSafe BC

Work Safe BC OHS Regulations:

- Confined Spaces
- Ladders, Scaffolds and Temporary Work Platforms
- Cranes and Hoists
- Rigging

Modular Units Built Outside Of BC

Section 6 of the LNGFR provides the Commission with the ability to require verification of any modular units built outside of British Columbia by a third party acceptable to the Commission.

The purpose of the verification is to demonstrate that the module’s components have been constructed and tested in accordance with the design and quality assurance program through an audit or review process.

CSA EXP276.2:19 – Design requirements for near-shore FLNG facilities

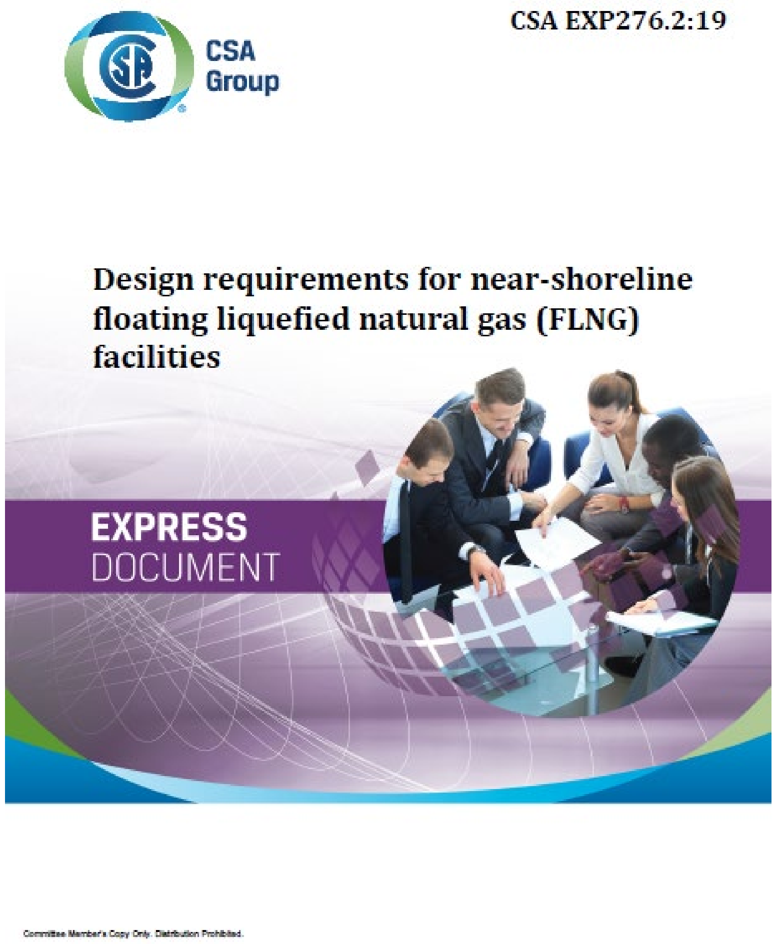
- Applies to FLNG facilities permanently moored to shore
- Risk-based approach to facility design and layout (QRA)
- Demonstrating ALARP is critical to satisfying AHJ

Role of Flag:

- Required during transit – for self-propelled and "wet" tow
- After being permanently moored, not required to maintain flag
- Operator shall however adhere to certain aspects of IMO (IGC, MARPOL, SOLAS)

Role of Class:

- Classification and Verification by an IACS member – practical means to achieve regulatory compliance
- Hull & Marine Systems – Class
- Topside & Safety Systems – Risk based verification - ALARP demonstration based on risk studies (QRA, HAZID, HAZOP, EERA, CRA, FERA, ESSA, SIL)
- Interface between onshore systems and FLNG – Risk based verification



CSA Group

CSA EXP276.2:19

Design requirements for near-shoreline floating liquefied natural gas (FLNG) facilities

EXPRESS DOCUMENT

Committee Member's Copy Only. Distribution Prohibited.

EXP276.1-2015 **Design requirements for marine structures associated with LNG facilities (DRMS)**

- This Express Document is intended to supplement the requirements in CSA Z276, Clause 11.4.

- Establishes minimum engineering requirements for the design of LNG marine facilities in order to minimize risk of structural failure that could result in LNG spills or other releases and to protect the public safety and the environment.

EXP276.1-2015

Design requirements for marine structures associated with LNG facilities (DRMS)

EXPRESS DOCUMENT

Regulatory Overview of LNG Facilities in Mexico

Regulators and Regulations

Agencia de Seguridad, Energía y Ambiente (ASEA)

- Guidelines on Industrial Safety, Operational Safety and Environmental Protection for the Design, Construction, Pre-start, Operation, Maintenance, Closing, Dismantling and Abandonment of Natural Gas Liquefaction Facilities

Comisión Reguladora de Energía (CRE)

- NOM-001-SECRE-2010 – Natural Gas Specifications
- NOM-013-SECRE-2012 – Safety requirements for the design, construction, operation and maintenance of liquefied natural gas storage terminals including reception systems, equipment and facilities

DNV GL Mexico Accreditations

Statutory Verification

Before the reform, the authorities in Mexico used a statutory verification scheme to achieve compliance with the different national standards required by the regulators, (i.e. SENER, CRE, SEMARNAT, STPS…).

DNV GL in Mexico is authorized for the verification of the following national standards:

Natural Gas Facilities:

- NOM-001-SECRE
- NOM-002-SECRE
- NOM-003-SECRE
- NOM-007-SECRE
- NOM-013-SECRE

Pressure Vessels:

- NOM-020-STPS

Electrical Facilities:

- NOM-001-SEDE-2005

LPG Facilities:

- NOM-015-SECRE
- NOM-004-SECRE

Authorized Third Party Scope

→

Design Verification

Construction and Pre-Start Up Verification

Annual Operation and Maintenance Verification

Hierarchy Of Requirements

International Codes and Standards

Official Mexican standards (NOMs)

- **Natural Gas Regulation**
- **ASEA Regulation**
- **Hydrocarbons Regulation**
- **Regulation Activities Article 3. Law of Hydrocarbons**

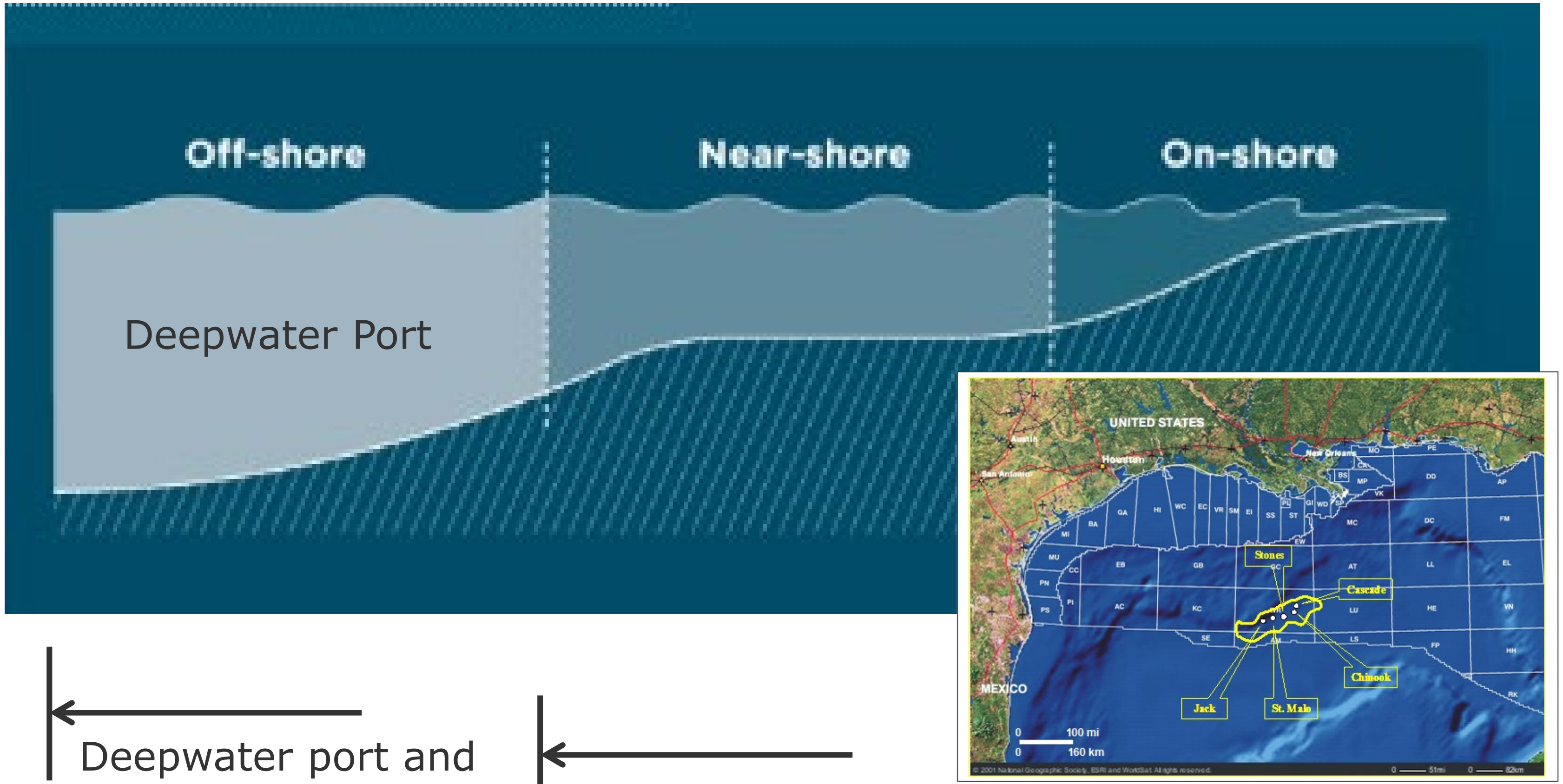
Law of the National Agency of National Security and Protection of the Environment of the Hydrocarbons Sector.

Hydrocarbons Law

Mexican Constitution, Article 27

Regulatory Overview of LNG Facilities in US

North America: Location and Regulation

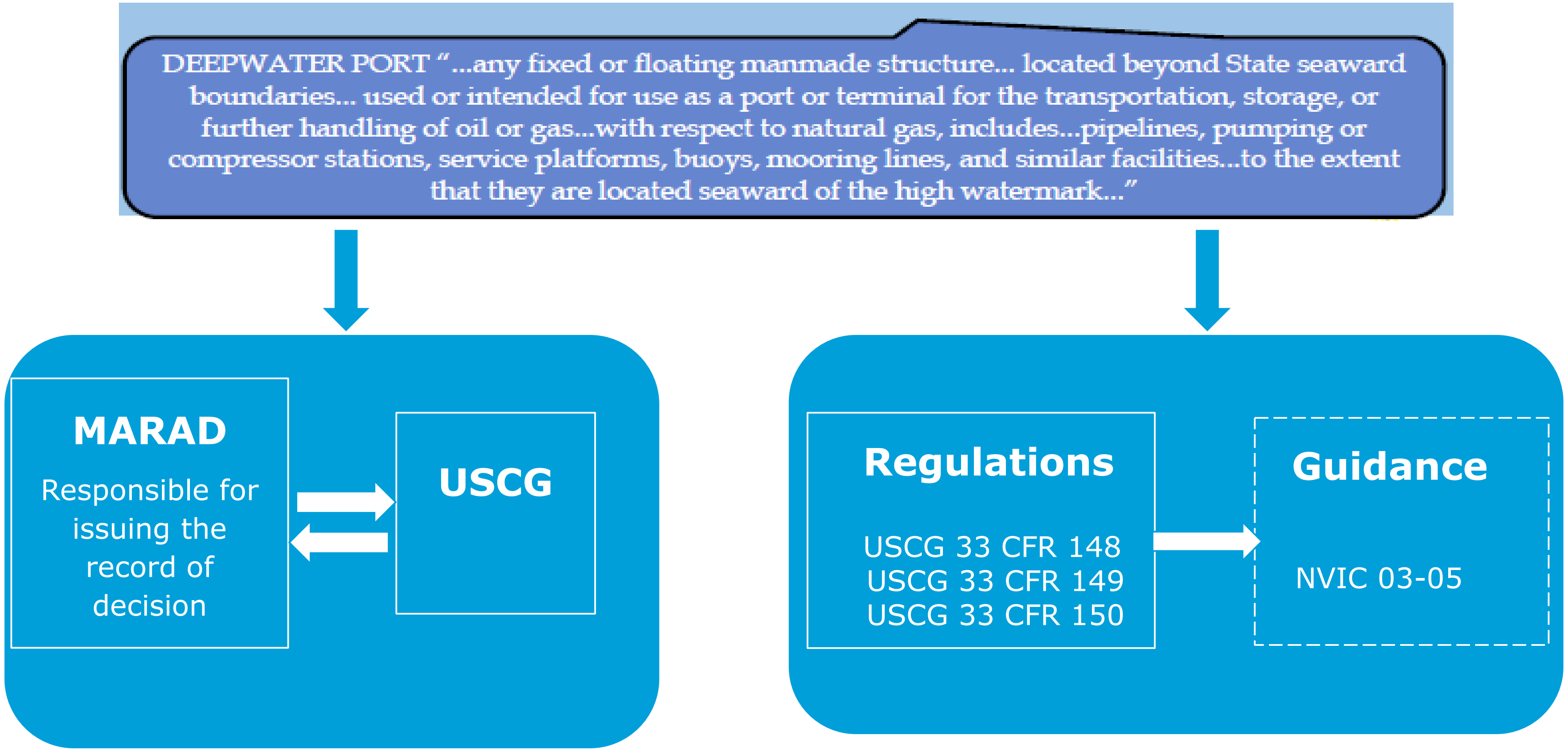


Deepwater port and MARAD/USCG

Within 15NM, FERC is exclusive authority onshore and in state waters

DWP - Regulators and Regulations

Deepwater Port Act of 1974, as amended, 33 U.S.C.1501



DEEPWATER PORT "…any fixed or floating manmade structure… located beyond State seaward boundaries… used or intended for use as a port or terminal for the transportation, storage, or further handling of oil or gas…with respect to natural gas, includes…pipelines, pumping or compressor stations, service platforms, buoys, mooring lines, and similar facilities…to the extent that they are located seaward of the high watermark…"

MARAD

Responsible for issuing the record of decision

USCG

Regulations

USCG 33 CFR 148
USCG 33 CFR 149
USCG 33 CFR 150

Guidance

NVIC 03-05

Certifying Entity (CE) - 33 CFR 148 Licensing Requirements

Nomination of Certifying Entity (CE)

Technical capabilities and experience in design, fabrication, or installation

In-house availability of, or access to, appropriate technology

Ability to perform duties and effectively manage the project

Verification the organization is not owned or controlled by the designer, manufacturer, or supplier of any equipment, material, system, or subsystem.

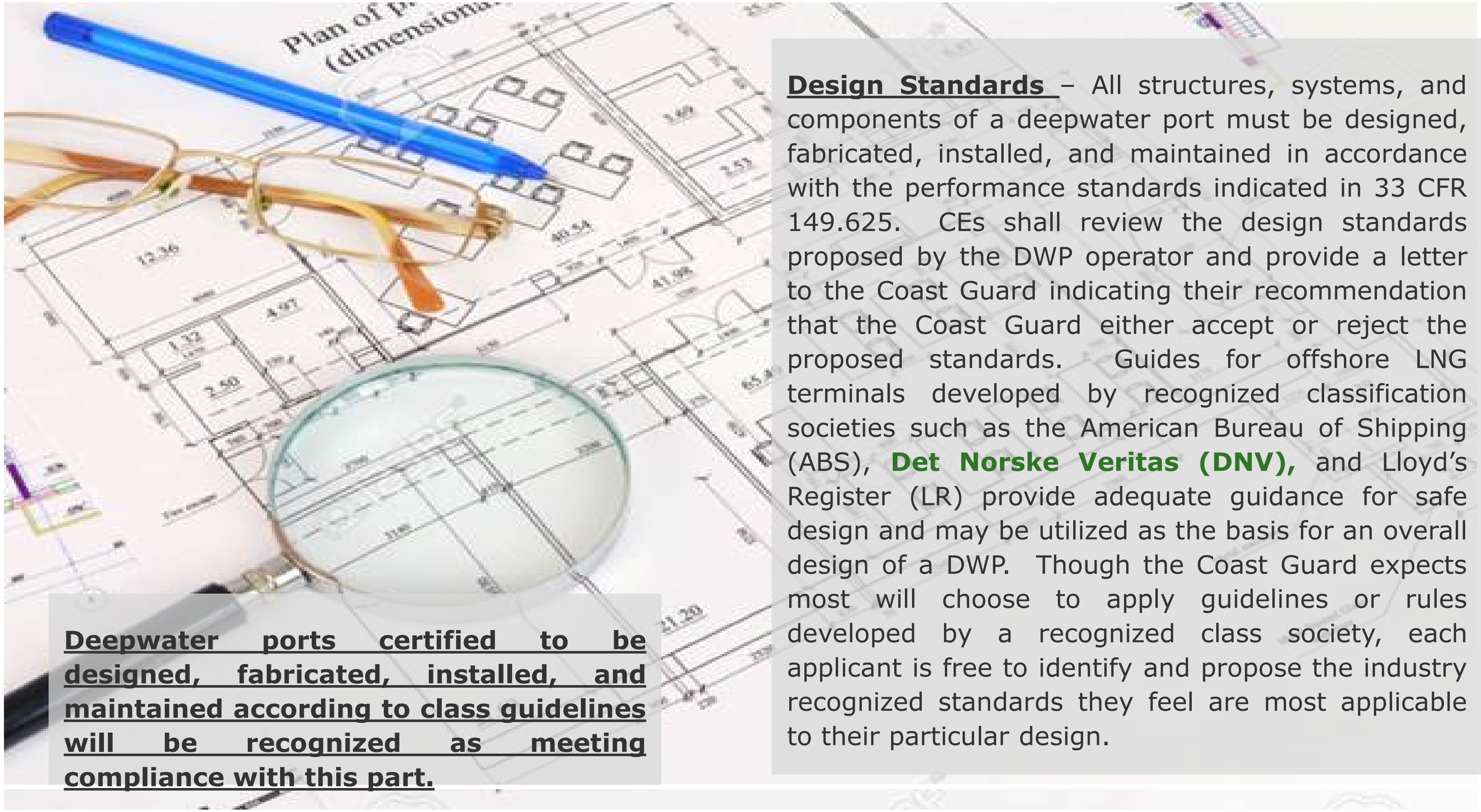
CE must be approved by USCG

NVIC 03-05

USCG Position on 3rd parties:

"We have determined the practice of using 3rd party resources is worthwhile, if not essential, for ensuring DWPs are designed, fabricated, installed, and maintained in accordance with safe engineering practices."

NVIC 03-05 – Recognized CEs



Design Standards – All structures, systems, and components of a deepwater port must be designed, fabricated, installed, and maintained in accordance with the performance standards indicated in 33 CFR 149.625. CEs shall review the design standards proposed by the DWP operator and provide a letter to the Coast Guard indicating their recommendation that the Coast Guard either accept or reject the proposed standards. Guides for offshore LNG terminals developed by recognized classification societies such as the American Bureau of Shipping (ABS), **Det Norske Veritas (DNV),** and Lloyd's Register (LR) provide adequate guidance for safe design and may be utilized as the basis for an overall design of a DWP. Though the Coast Guard expects most will choose to apply guidelines or rules developed by a recognized class society, each applicant is free to identify and propose the industry recognized standards they feel are most applicable to their particular design.

Deepwater ports certified to be designed, fabricated, installed, and maintained according to class guidelines will be recognized as meeting compliance with this part.

THANK YOU

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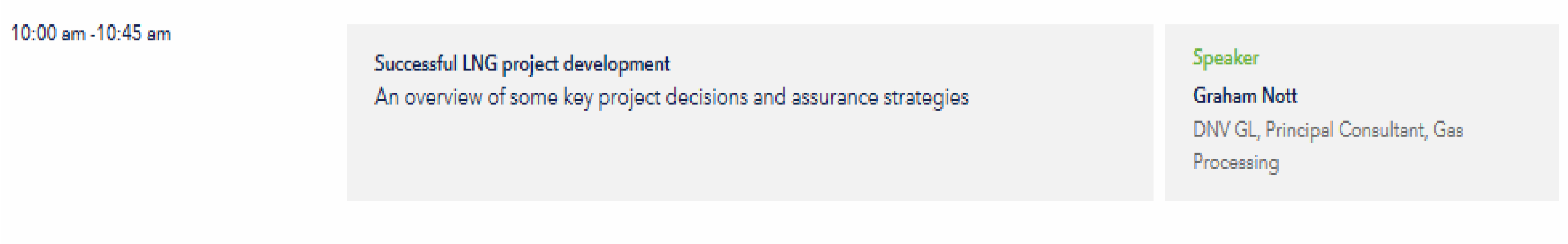
LNG Day Program Agenda



10:00 am -10:45 am

Successful LNG project development

An overview of some key project decisions and assurance strategies

Speaker

Graham Nott

DNV GL, Principal Consultant, Gas Processing

OIL & GAS

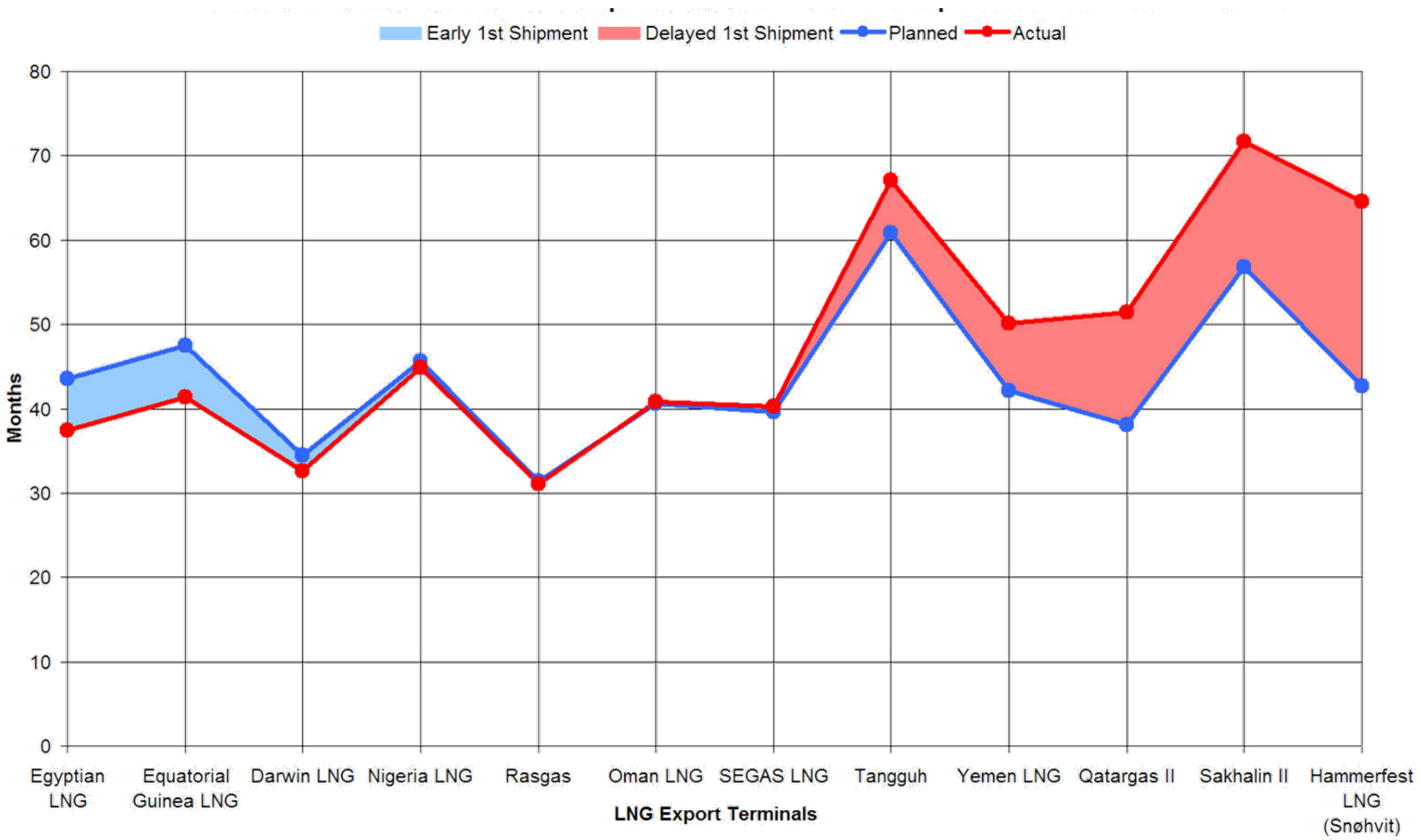
Successful LNG project development –

An overview of some key project decisions and assurance strategies

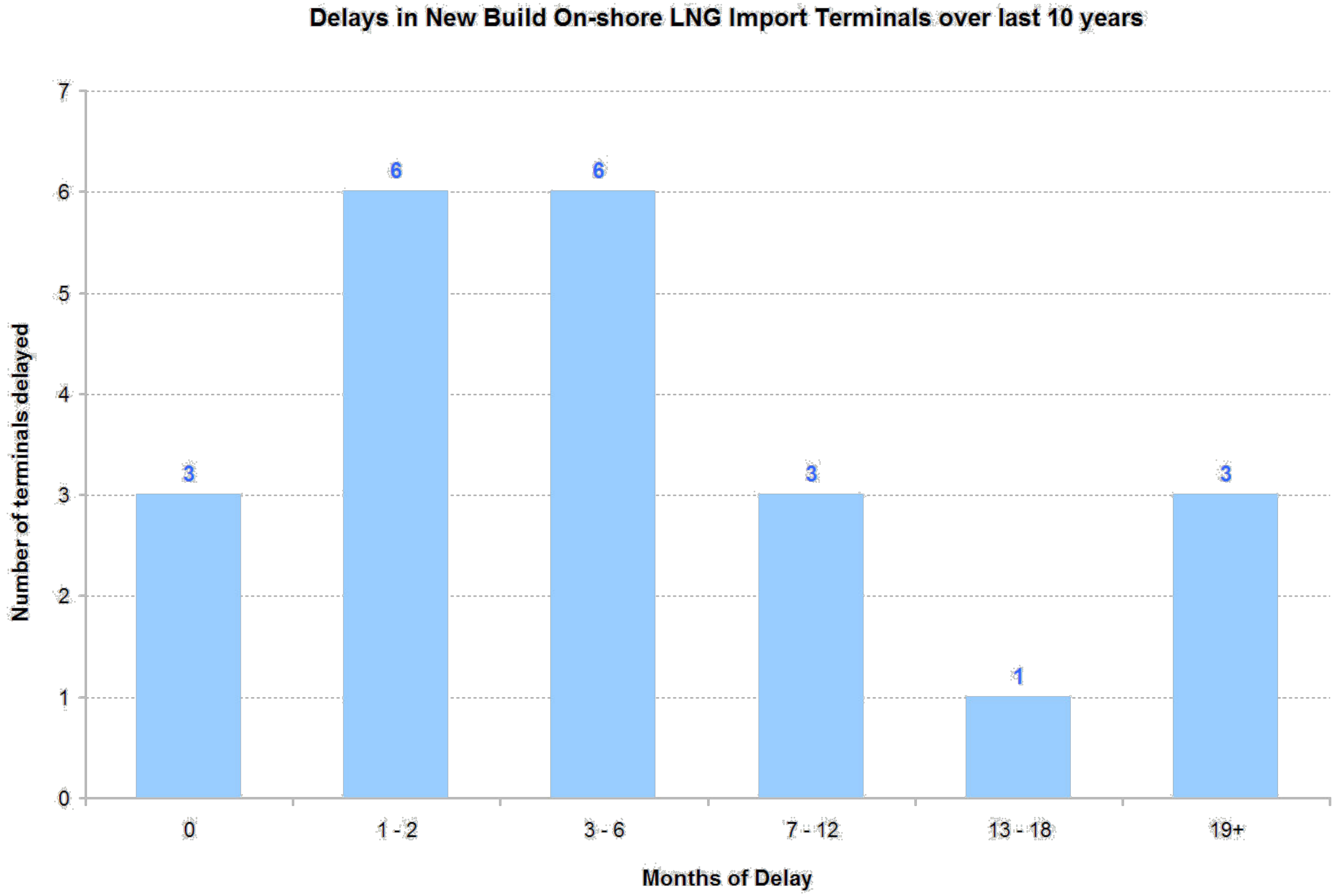
Graham Nott
25 February 2020

LNG Export Terminal Construction

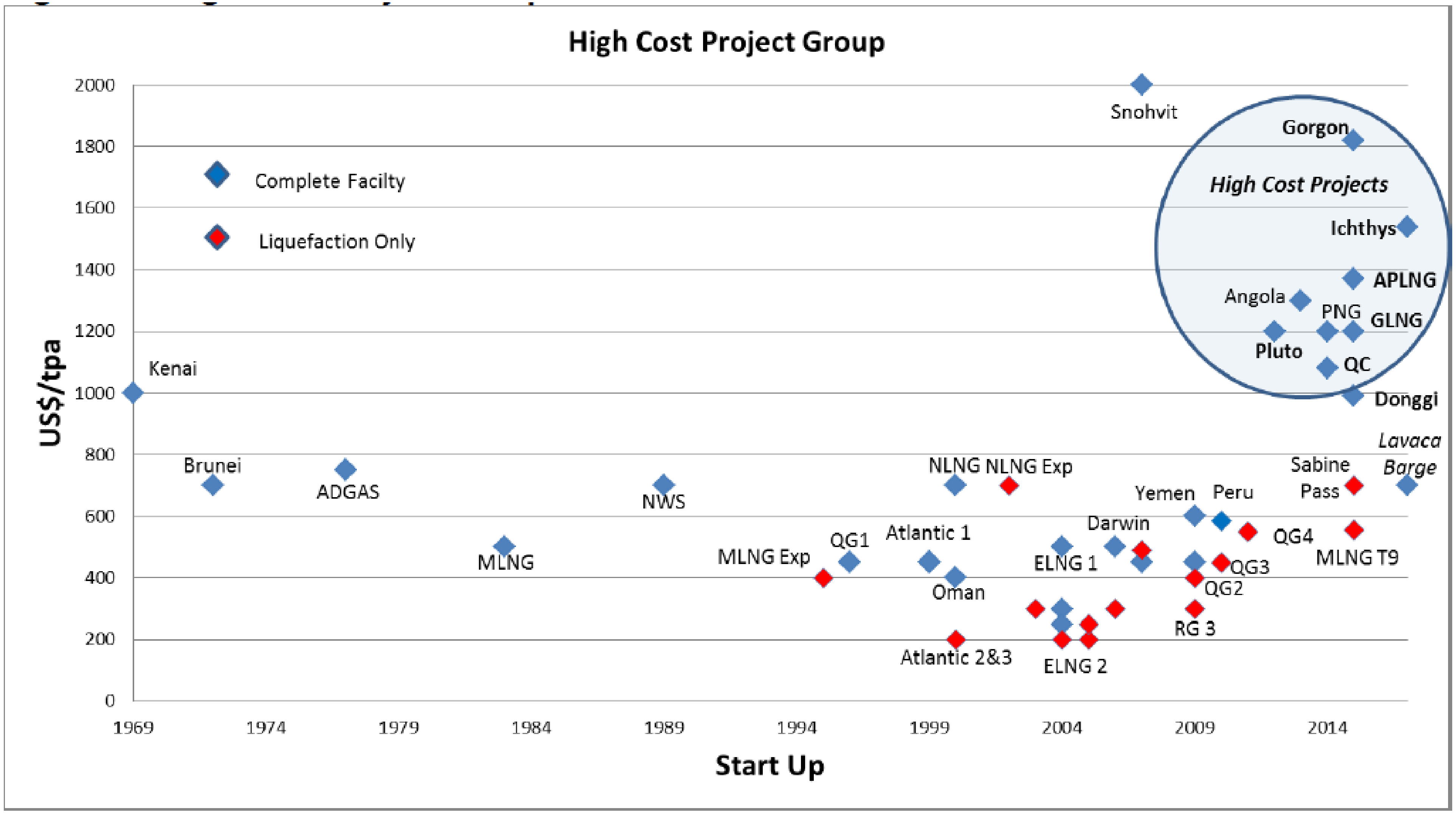
Time from construction to first shipment of LNG for LNG Export terminals built in period 2000 - 2010



LNG Import Terminals - delays



OIES estimate of project and liquefaction plant costs



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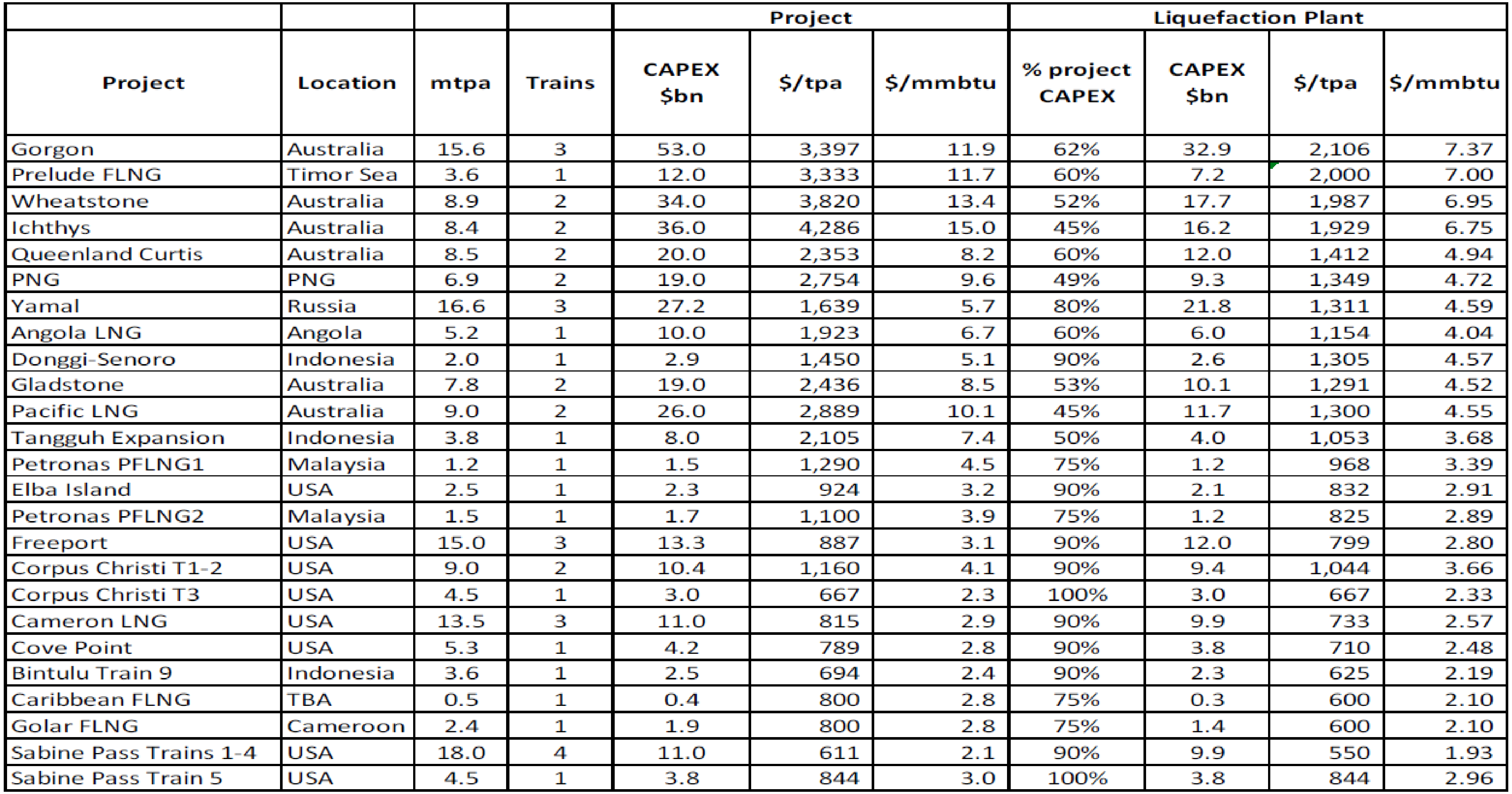
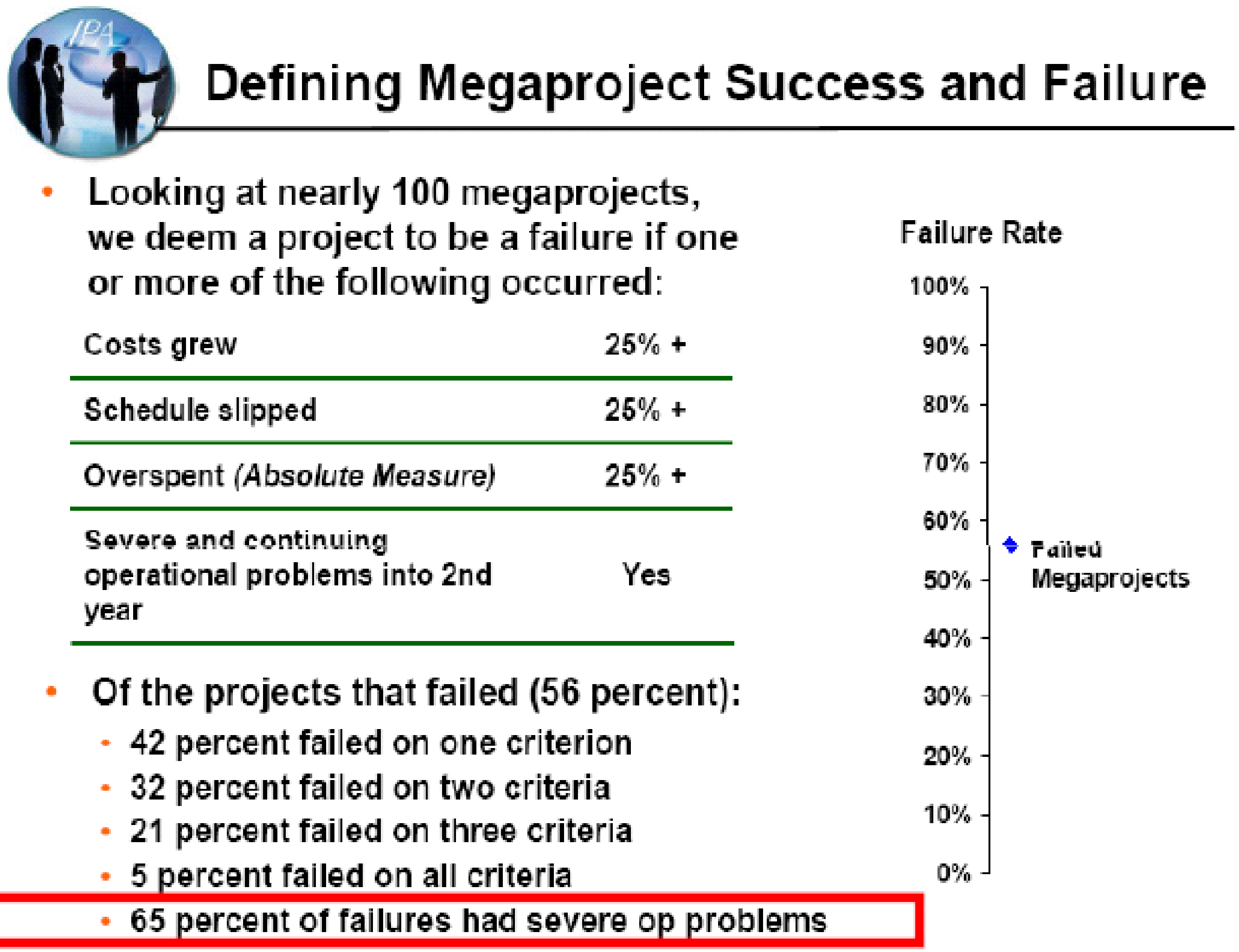


				Project			Liquefaction Plant			
Project	**Location**	**mtpa**	**Trains**	**CAPEX $bn**	**$/tpa**	**$/mmbtu**	**% project CAPEX**	**CAPEX $bn**	**$/tpa**	**$/mmbtu**
Gorgon	Australia	15.6	3	53.0	3,397	11.9	62%	32.9	2,106	7.37
Prelude FLNG	Timor Sea	3.6	1	12.0	3,333	11.7	60%	7.2	2,000	7.00
Wheatstone	Australia	8.9	2	34.0	3,820	13.4	52%	17.7	1,987	6.95
Ichthys	Australia	8.4	2	36.0	4,286	15.0	45%	16.2	1,929	6.75
Queenland Curtis	Australia	8.5	2	20.0	2,353	8.2	60%	12.0	1,412	4.94
PNG	PNG	6.9	2	19.0	2,754	9.6	49%	9.3	1,349	4.72
Yamal	Russia	16.6	3	27.2	1,639	5.7	80%	21.8	1,311	4.59
Angola LNG	Angola	5.2	1	10.0	1,923	6.7	60%	6.0	1,154	4.04
Donggi-Senoro	Indonesia	2.0	1	2.9	1,450	5.1	90%	2.6	1,305	4.57
Gladstone	Australia	7.8	2	19.0	2,436	8.5	53%	10.1	1,291	4.52
Pacific LNG	Australia	9.0	2	26.0	2,889	10.1	45%	11.7	1,300	4.55
Tangguh Expansion	Indonesia	3.8	1	8.0	2,105	7.4	50%	4.0	1,053	3.68
Petronas PFLNG1	Malaysia	1.2	1	1.5	1,290	4.5	75%	1.2	968	3.39
Elba Island	USA	2.5	1	2.3	924	3.2	90%	2.1	832	2.91
Petronas PFLNG2	Malaysia	1.5	1	1.7	1,100	3.9	75%	1.2	825	2.89
Freeport	USA	15.0	3	13.3	887	3.1	90%	12.0	799	2.80
Corpus Christi T1-2	USA	9.0	2	10.4	1,160	4.1	90%	9.4	1,044	3.66
Corpus Christi T3	USA	4.5	1	3.0	667	2.3	100%	3.0	667	2.33
Cameron LNG	USA	13.5	3	11.0	815	2.9	90%	9.9	733	2.57
Cove Point	USA	5.3	1	4.2	789	2.8	90%	3.8	710	2.48
Bintulu Train 9	Indonesia	3.6	1	2.5	694	2.4	90%	2.3	625	2.19
Caribbean FLNG	TBA	0.5	1	0.4	800	2.8	75%	0.3	600	2.10
Golar FLNG	Cameroon	2.4	1	1.9	800	2.8	75%	1.4	600	2.10
Sabine Pass Trains 1-4	USA	18.0	4	11.0	611	2.1	90%	9.9	550	1.93
Sabine Pass Train 5	USA	4.5	1	3.8	844	3.0	100%	3.8	844	2.96

The Operators View



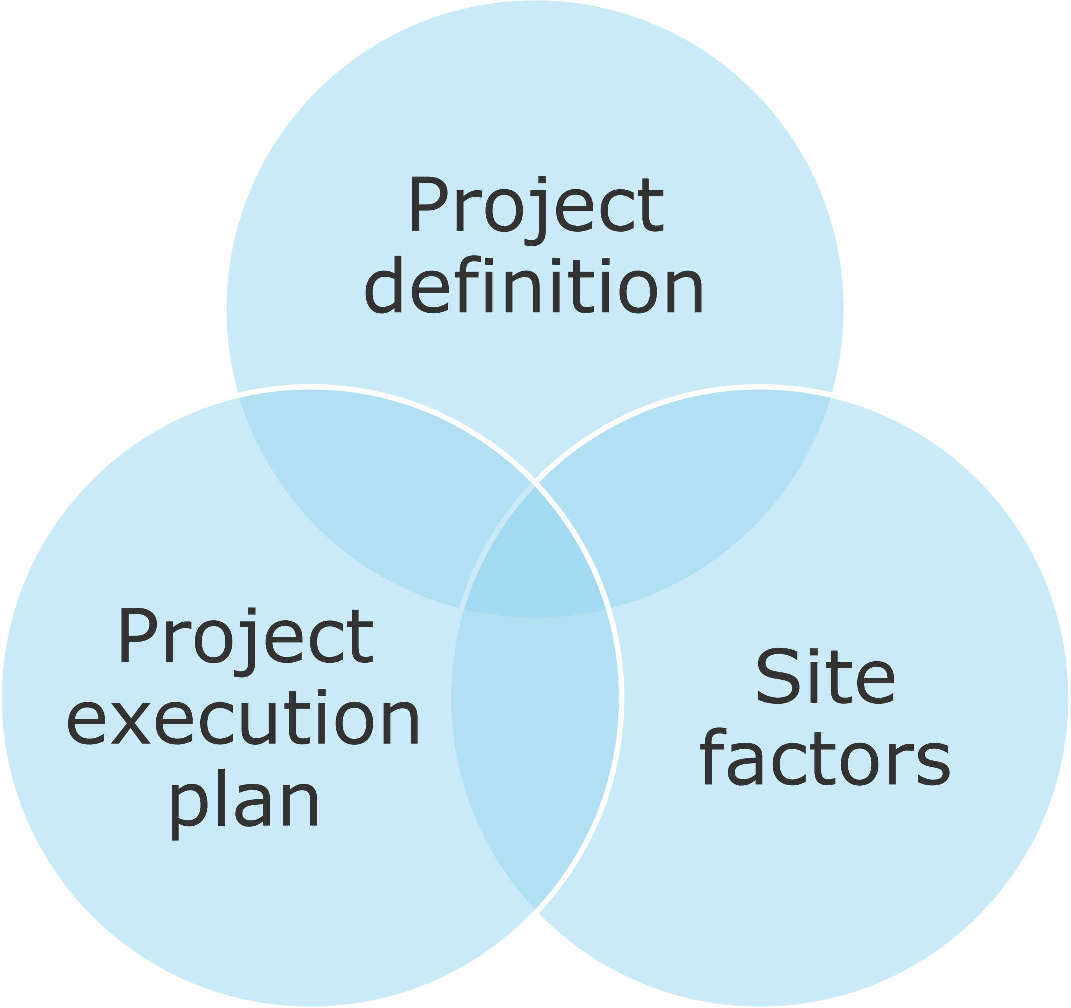
Defining Megaproject Success and Failure

- Looking at nearly 100 megaprojects, we deem a project to be a failure if one or more of the following occurred:

Costs grew	25% +
Schedule slipped	25% +
Overspent *(Absolute Measure)*	25% +
Severe and continuing operational problems into 2nd year	Yes

- Of the projects that failed (56 percent):
  - 42 percent failed on one criterion
  - 32 percent failed on two criteria
  - 21 percent failed on three criteria
  - 5 percent failed on all criteria
  - 65 percent of failures had severe op problems

Key success criterion



Project definition

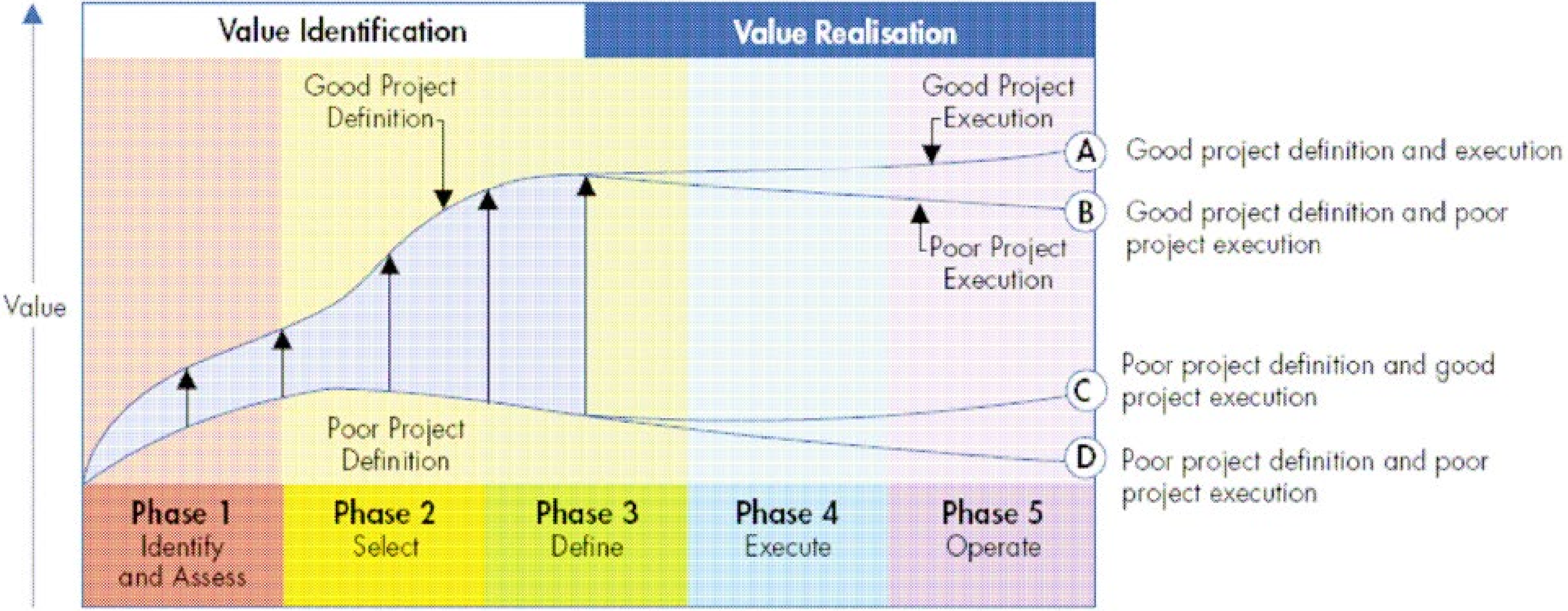
Project execution plan

Site factors

Typical USA LNG project development glide path

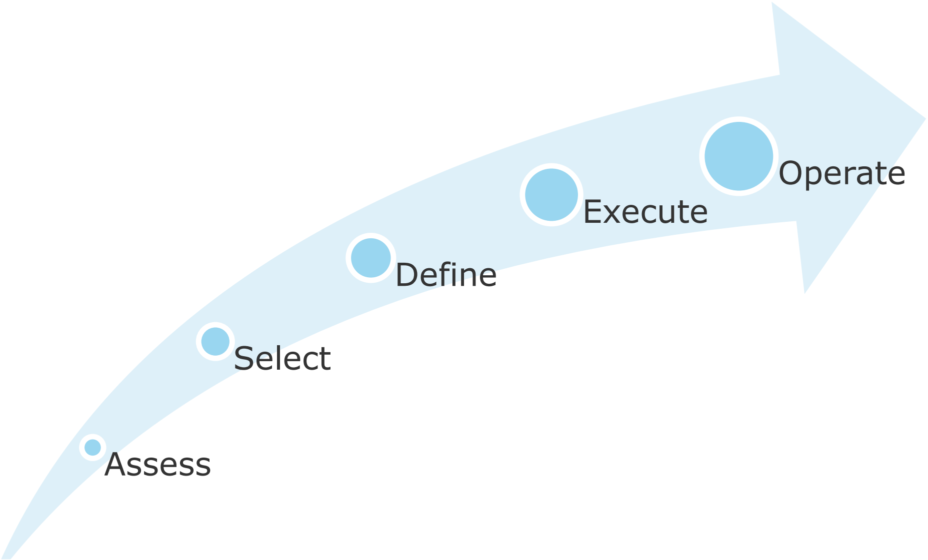
	Assess	Select	Define	Execute	Operate
WHO	**Business team**	**Consultants / Engineers**	**EPC contractor**	**EPC contractor**	**Owner**
WHAT	Concept study	Pre-FEED	FEED	EPC	TUA
HOW	Reimbursable	Reimbursable	Fixed fee	LSTK	Cost plus
WHY	Evaluate potential value	Formulate investment case + FERC pre-filing	FERC approval + fix costs	Turn investment into asset	Turn asset into cash stream
	< $1MM	Tens $ MM	Hundreds $ MM	Billions $	
	3 – 6 Months	6 – 12 Months	12 – 18 Months	30 – 40 Months	

Doing the right project v's doing the project right



Source: Hutchinson & Wabeke (2006)

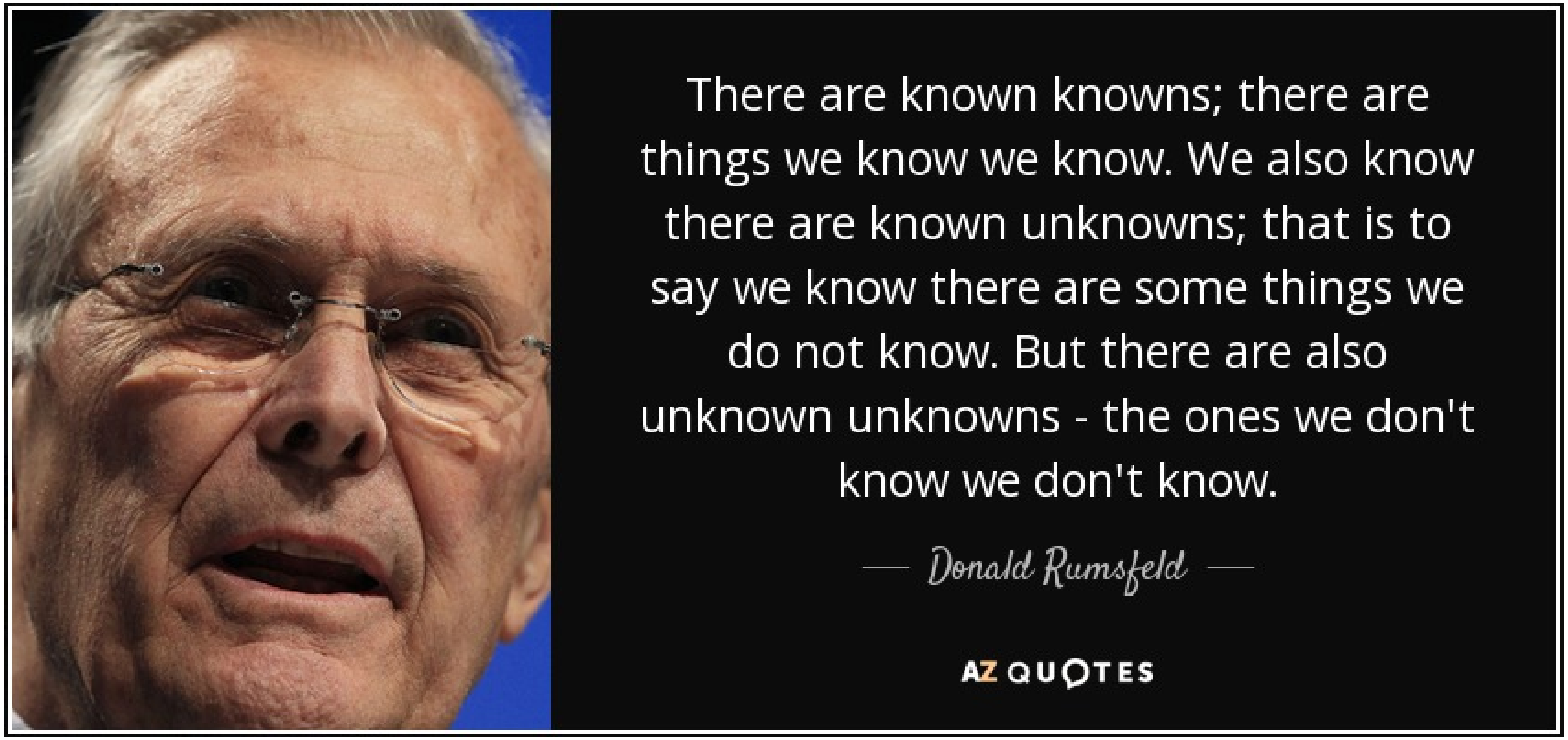
Early value improvement practices have greatest influence



Assess	Select	Define	Execute	Operate
Lessons learned	Technology selection	Reliability modelling	Customised standards	Predictive maintenance
Pre-project planning	Process simplification	Value engineering	Change & dispute management	Ready for operations
	Energy optimisation	Design margins	Alignment	
	Constructability review	Constructability review	Ready for start-up	
		Team building	Materials management	

Peer / cold eyes review

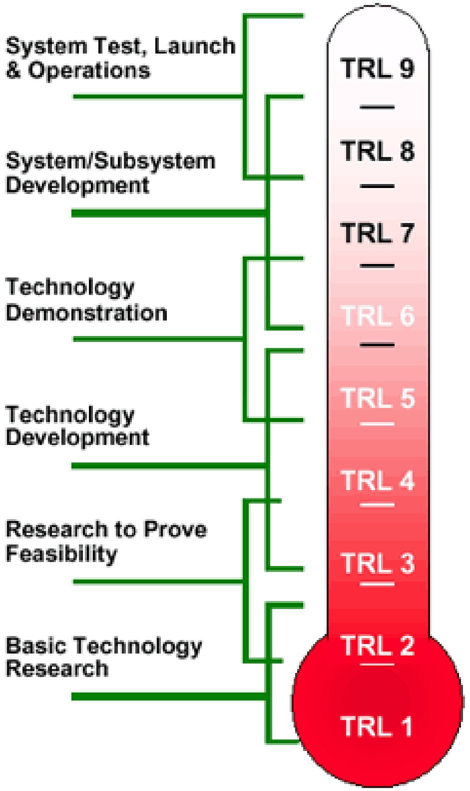

Assess
Select
Define
Execute
Operate


There are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns - the ones we don't know we don't know.

— Donald Rumsfeld —

AZ QUOTES

Technology qualification



Early outline QRA and process hazard analysis

Assess

Select

Define

Execute

Operate

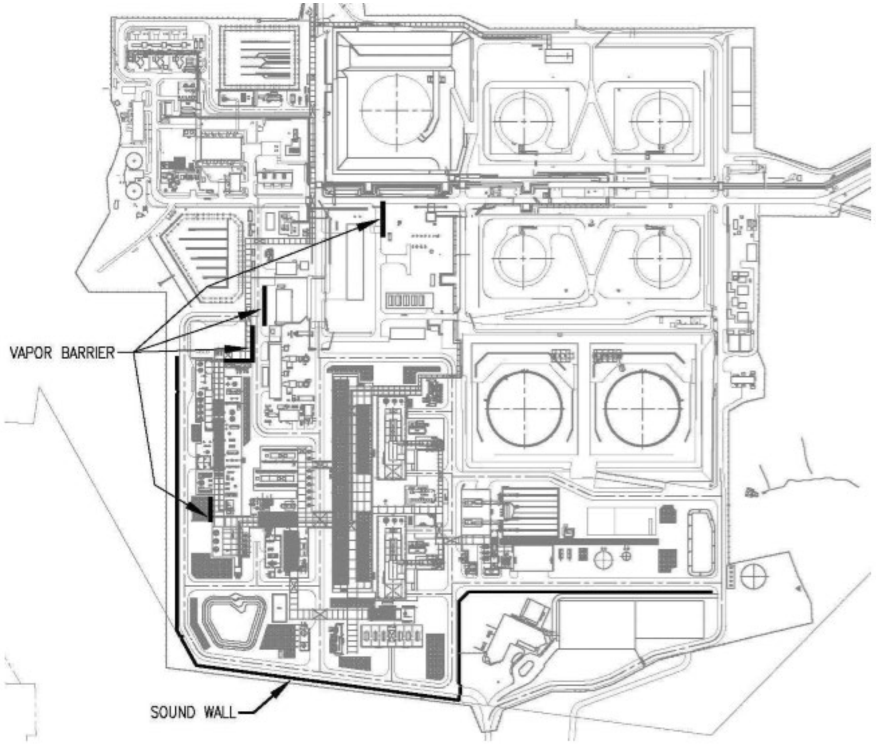
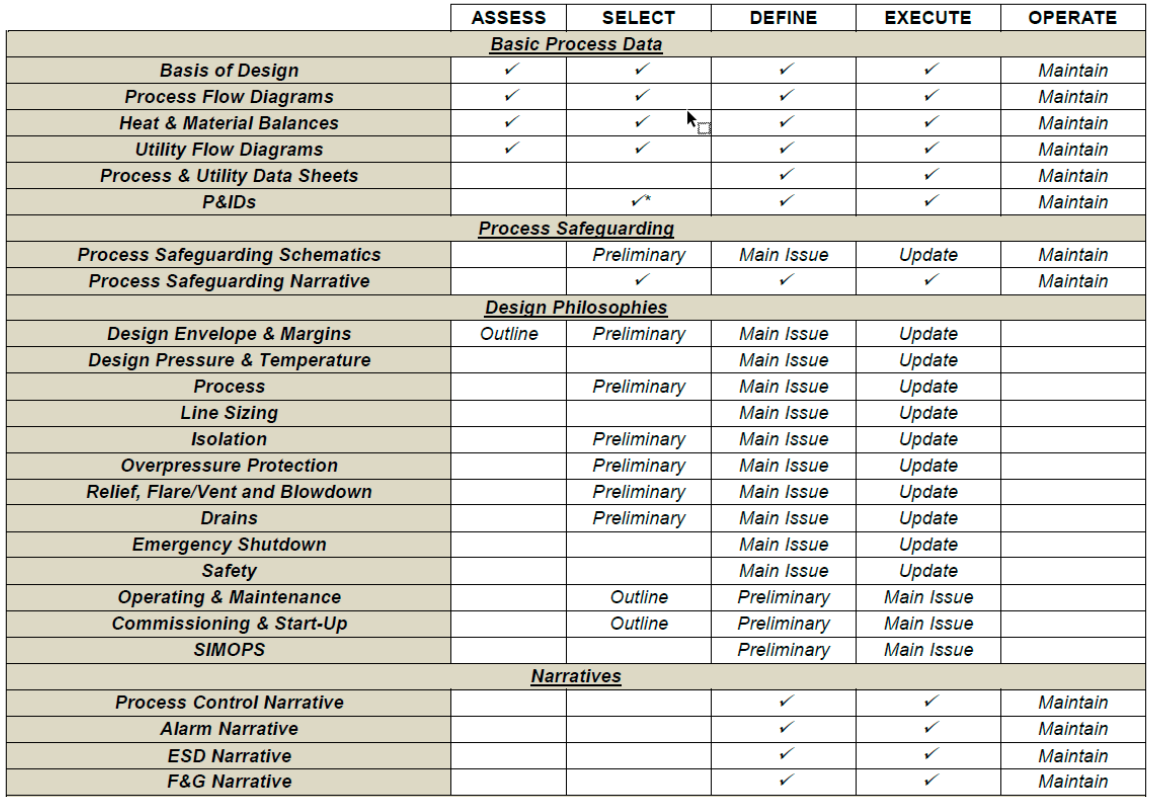


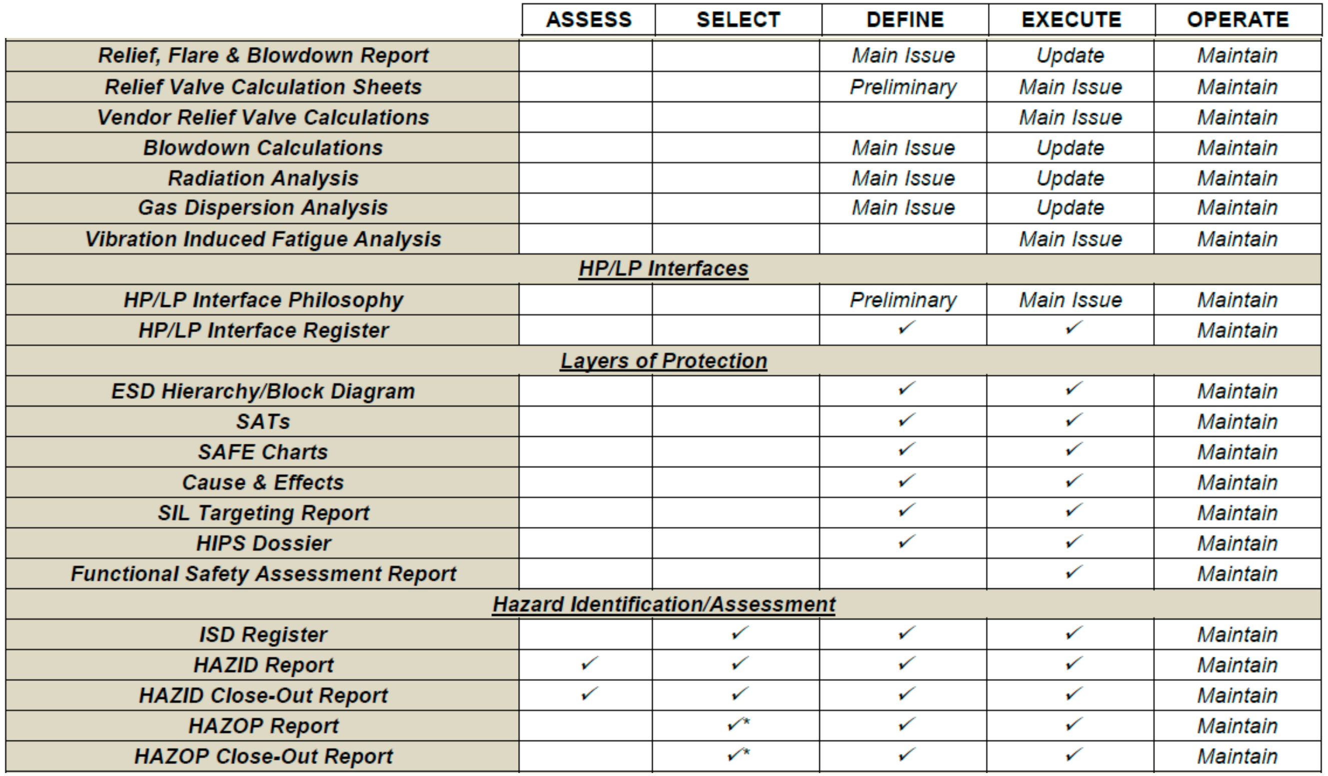
Figure 2.8.6-1

Vapor and Sound Barrier Locations

Process Safety in Design Review

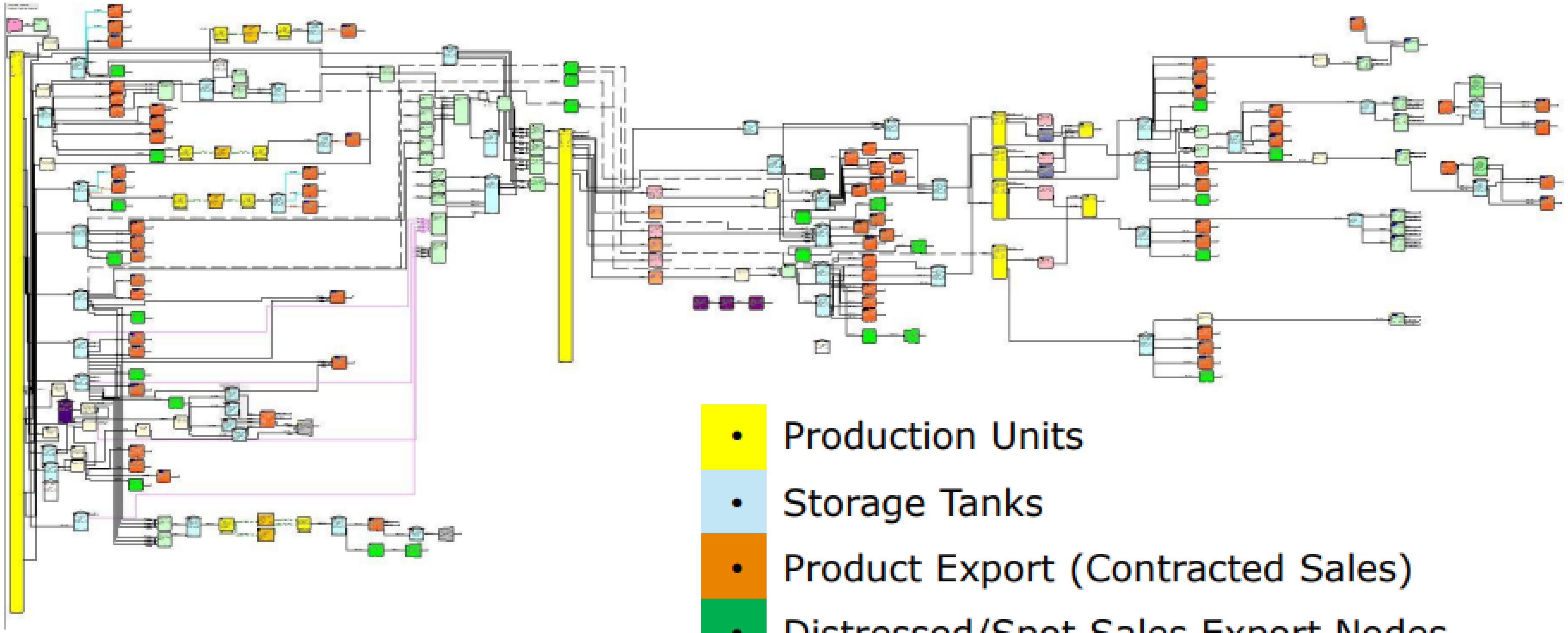


	ASSESS	SELECT	DEFINE	EXECUTE	OPERATE
Basic Process Data					
Basis of Design	✓	✓	✓	✓	*Maintain*
Process Flow Diagrams	✓	✓	✓	✓	*Maintain*
Heat & Material Balances	✓	✓	✓	✓	*Maintain*
Utility Flow Diagrams	✓	✓	✓	✓	*Maintain*
Process & Utility Data Sheets			✓	✓	*Maintain*
P&IDs		✓*	✓	✓	*Maintain*
Process Safeguarding					
Process Safeguarding Schematics		*Preliminary*	*Main Issue*	*Update*	*Maintain*
Process Safeguarding Narrative		✓	✓	✓	*Maintain*
Design Philosophies					
Design Envelope & Margins	*Outline*	*Preliminary*	*Main Issue*	*Update*	
Design Pressure & Temperature			*Main Issue*	*Update*	
Process		*Preliminary*	*Main Issue*	*Update*	
Line Sizing			*Main Issue*	*Update*	
Isolation		*Preliminary*	*Main Issue*	*Update*	
Overpressure Protection		*Preliminary*	*Main Issue*	*Update*	
Relief, Flare/Vent and Blowdown		*Preliminary*	*Main Issue*	*Update*	
Drains		*Preliminary*	*Main Issue*	*Update*	
Emergency Shutdown			*Main Issue*	*Update*	
Safety			*Main Issue*	*Update*	
Operating & Maintenance		*Outline*	*Preliminary*	*Main Issue*	
Commissioning & Start-Up		*Outline*	*Preliminary*	*Main Issue*	
SIMOPS			*Preliminary*	*Main Issue*	
Narratives					
Process Control Narrative			✓	✓	*Maintain*
Alarm Narrative			✓	✓	*Maintain*
ESD Narrative			✓	✓	*Maintain*
F&G Narrative			✓	✓	*Maintain*



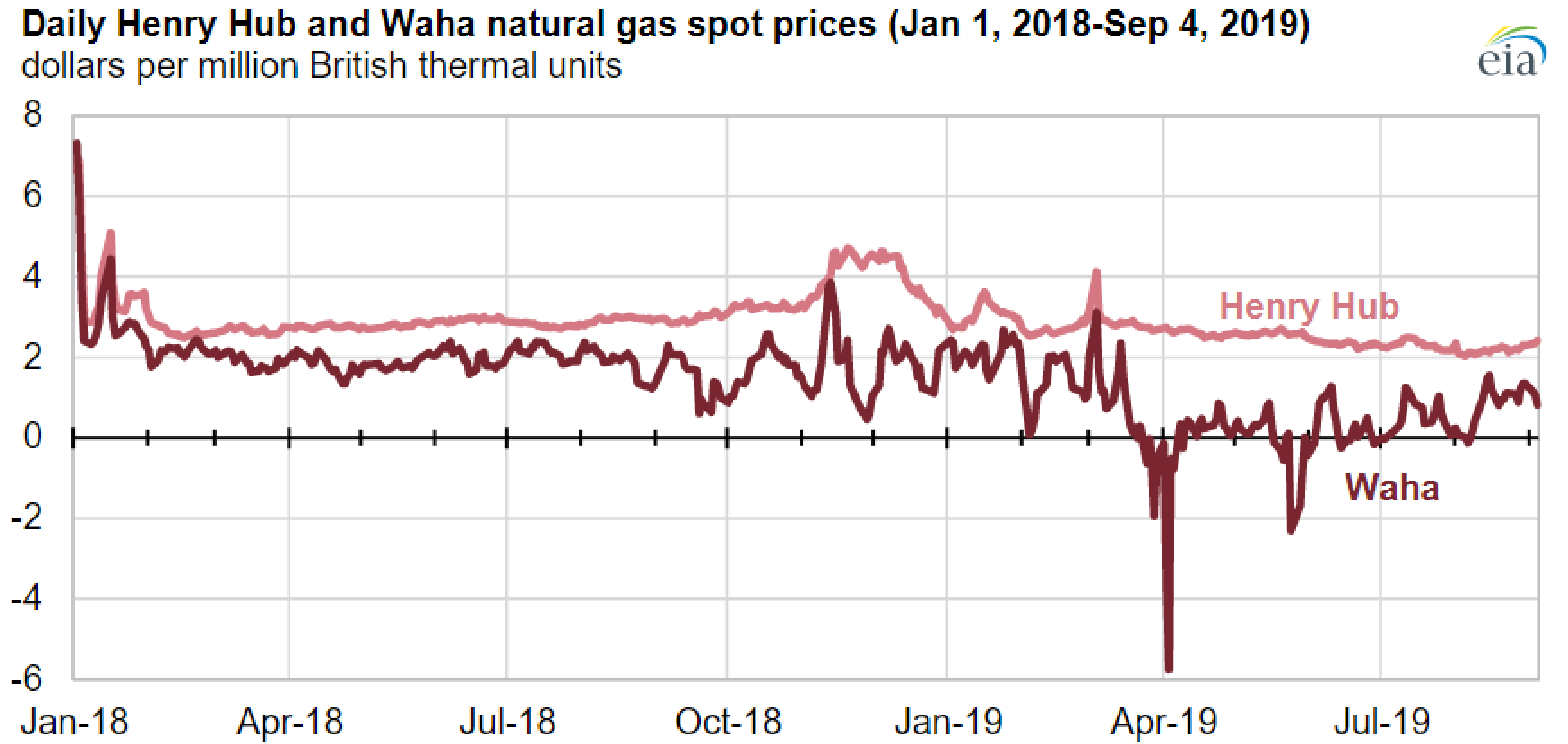
	ASSESS	SELECT	DEFINE	EXECUTE	OPERATE
Relief, Flare & Blowdown Report			*Main Issue*	*Update*	*Maintain*
Relief Valve Calculation Sheets			*Preliminary*	*Main Issue*	*Maintain*
Vendor Relief Valve Calculations				*Main Issue*	*Maintain*
Blowdown Calculations			*Main Issue*	*Update*	*Maintain*
Radiation Analysis			*Main Issue*	*Update*	*Maintain*
Gas Dispersion Analysis			*Main Issue*	*Update*	*Maintain*
Vibration Induced Fatigue Analysis				*Main Issue*	*Maintain*
HP/LP Interfaces					
HP/LP Interface Philosophy			*Preliminary*	*Main Issue*	*Maintain*
HP/LP Interface Register			✓	✓	*Maintain*
Layers of Protection					
ESD Hierarchy/Block Diagram			✓	✓	*Maintain*
SATs			✓	✓	*Maintain*
SAFE Charts			✓	✓	*Maintain*
Cause & Effects			✓	✓	*Maintain*
SIL Targeting Report			✓	✓	*Maintain*
HIPS Dossier			✓	✓	*Maintain*
Functional Safety Assessment Report				✓	*Maintain*
Hazard Identification/Assessment					
ISD Register		✓	✓	✓	*Maintain*
HAZID Report	✓	✓	✓	✓	*Maintain*
HAZID Close-Out Report	✓	✓	✓	✓	*Maintain*
HAZOP Report		✓*	✓	✓	*Maintain*
HAZOP Close-Out Report		✓*	✓	✓	*Maintain*

Production forecasting (RAM Modelling)



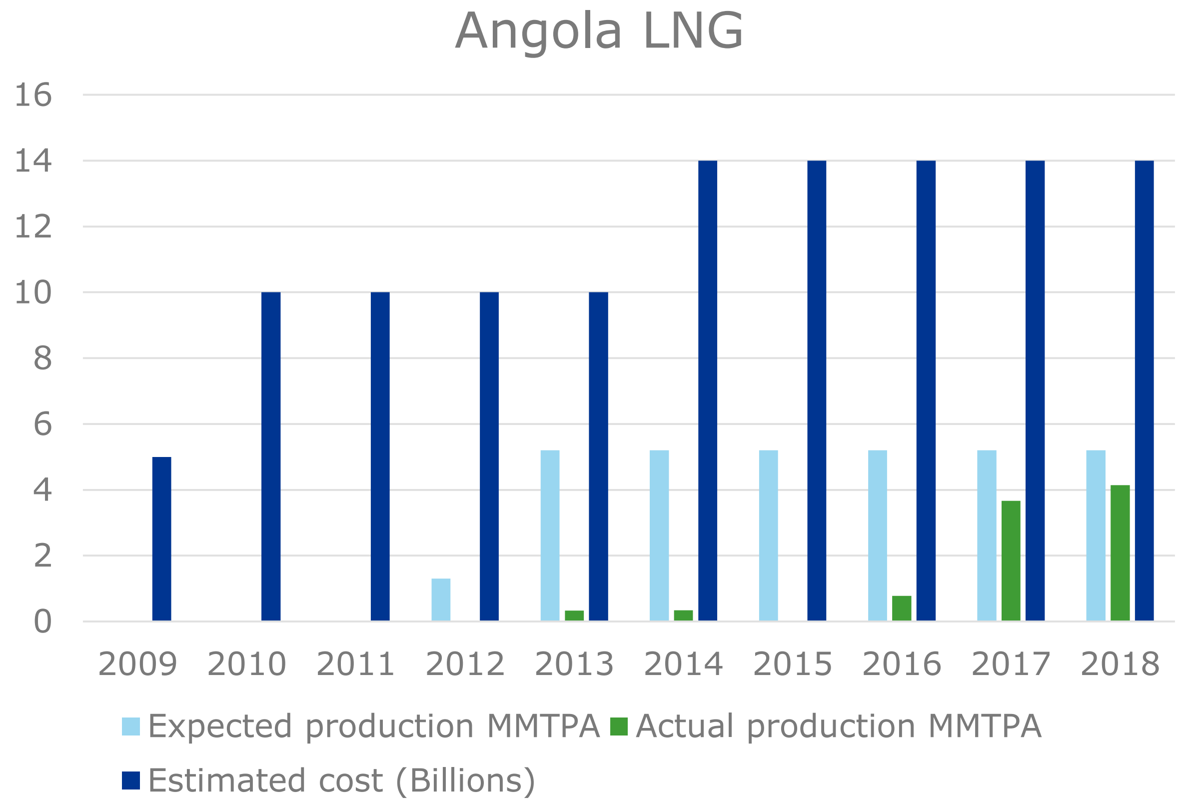
- 🟨 Production Units
- 🟦 Storage Tanks
- 🟧 Product Export (Contracted Sales)
- 🟩 Distressed/Spot Sales Export Nodes

Value of end to end RAM



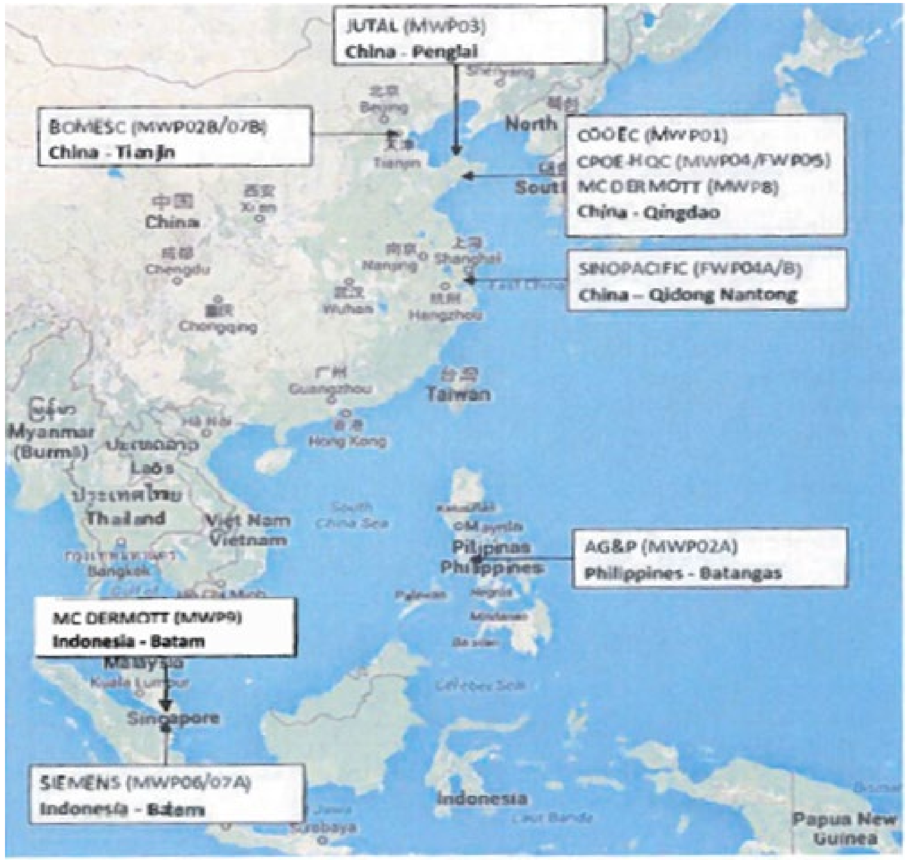
Source: U.S. Energy Information Administration, based on Natural Gas Intelligence

Owner’s independent QA framework review



- FID taken 12/2007 at $4-5 BN
- First production expected Q1/2012
- Damages for liquid surges at start-up (8 Mo.)
- Initial low production rates (<50% nameplate)
- Piping failures in vent & relief incident of 10 April 2014 ceased all production until 6 June 2016.

Enforced consistent quality control

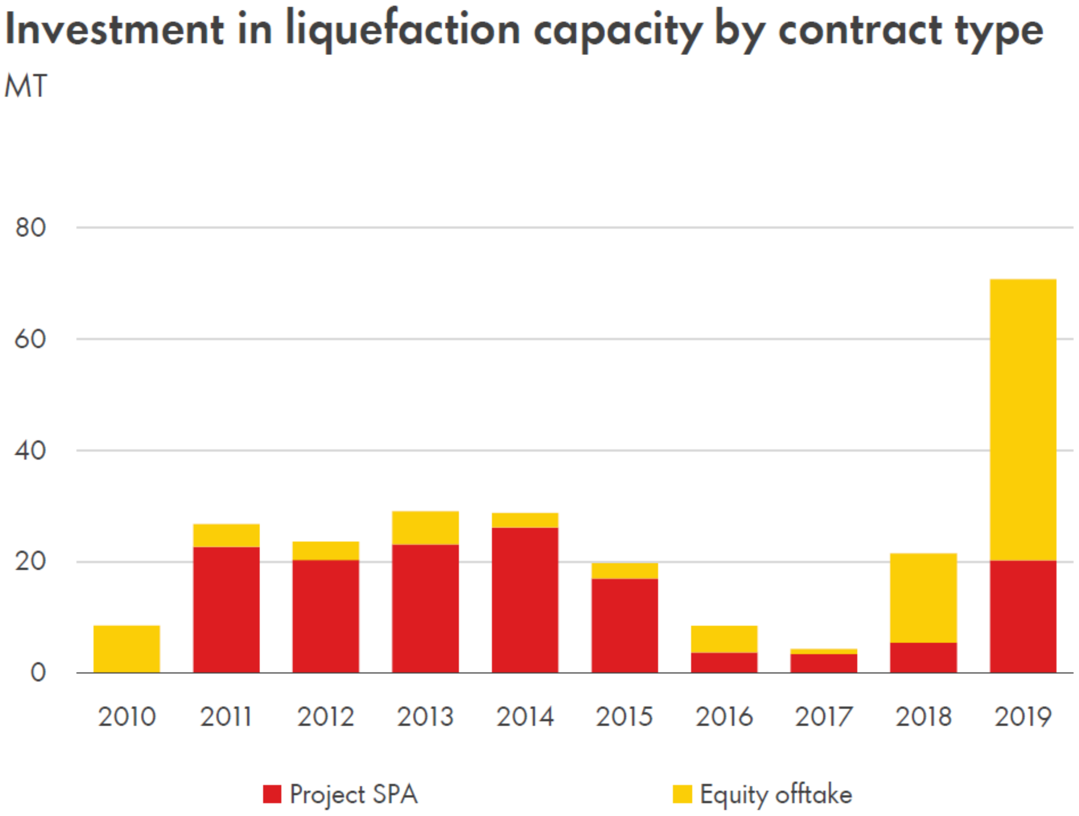


YAMAL LNG is a large scale LNG project constructed in a harsh arctic environment. More than 150 prefabricated modules plus pipe-racks were being fabricated in 6 yards in China and 3 yards in Batam, Indonesia. Quality, competence and consistency of QA/QC practices for building such scale and complex LNG models in China and Indonesia were top concerns from YAMGAZ and other investment stakeholders.

VALUE DELIVERED

- ✓ Audit and spot testing of structure, piping, painting, insulation, electrical, passive fire proofing and cold spill proofing activities.
- ✓ Spot testing of painting DFT, passive fire proofing DFT and cold spill proofing DFT.
- ✓ Spot testing of ultrasonic test, magnetic particle test, penetrant test, radiography test and phase array ultrasonic test.
- ✓ Retest of destructive test for bolt+nut, blasting abrasive, coating adhesion test, passive fire proofing adhesion test and cold spill proofing adhesion test

Independent risk based verification and certification of assets


Investment in liquefaction capacity by contract type

Level	Risk Characteristics	Verification Involvement
LOW	▪ Risks to the asset are lower than average, low consequences of failure. ▪ Proven designs, located in congenial conditions, manufacturing and installation by experienced contractors.	▪ Review of general principles during design and construction phases. ▪ Review of principal documents. ▪ Site attendance only during system testing.
MEDIUM	▪ Asset in a moderate or well controlled environment. ▪ Plans with a moderate degree of novelty. ▪ Medium consequences of failure.	▪ Review of general principles during design and construction. ▪ Detailed review of selected principal documents. ▪ Partial attendance during construction.
HIGH	▪ Innovative designs and plants with high degree of novelty or large leaps in technology. ▪ Extreme environmental conditions. ▪ Contractors with limited experience. ▪ Very high consequences of failure.	▪ Review of general principles during design and construction. ▪ Detailed review of most documents with independent analyses. ▪ Full time attendance at site for most activities.

Pre start-up safety review

Assess

Select

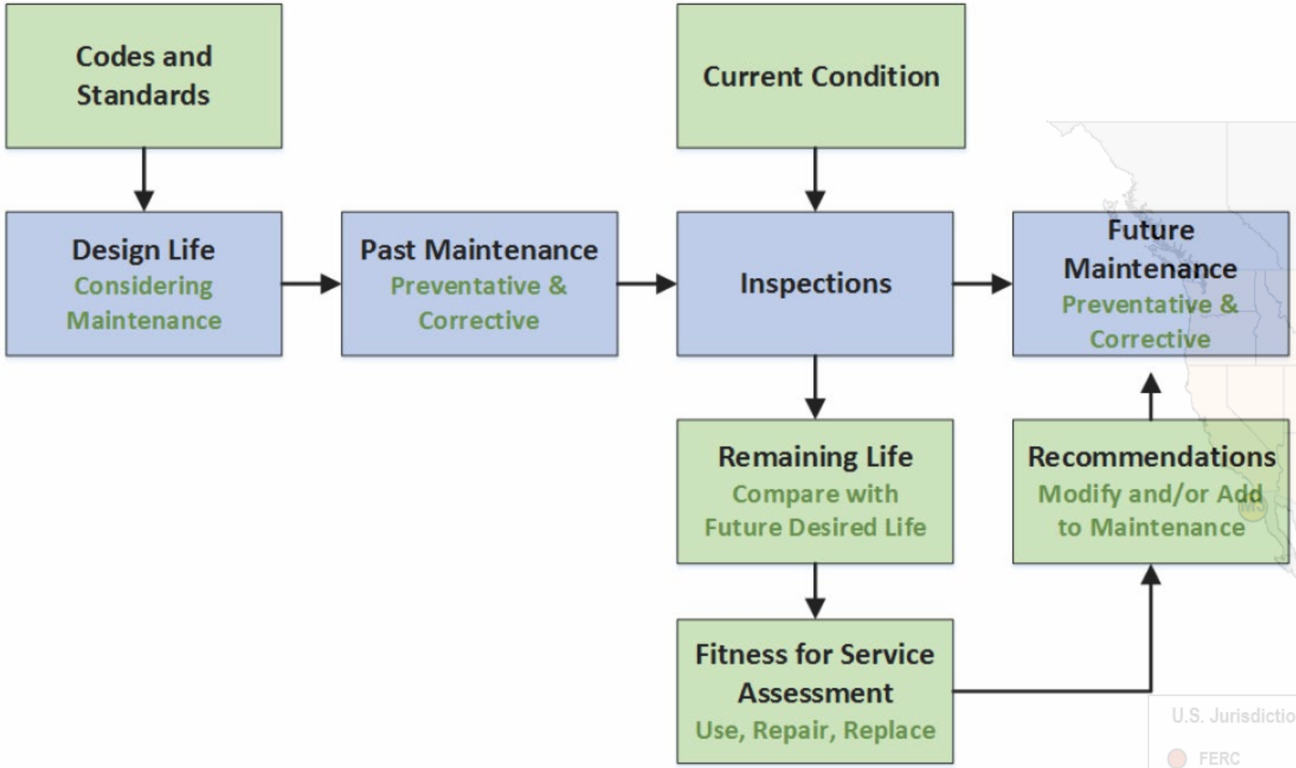
Define

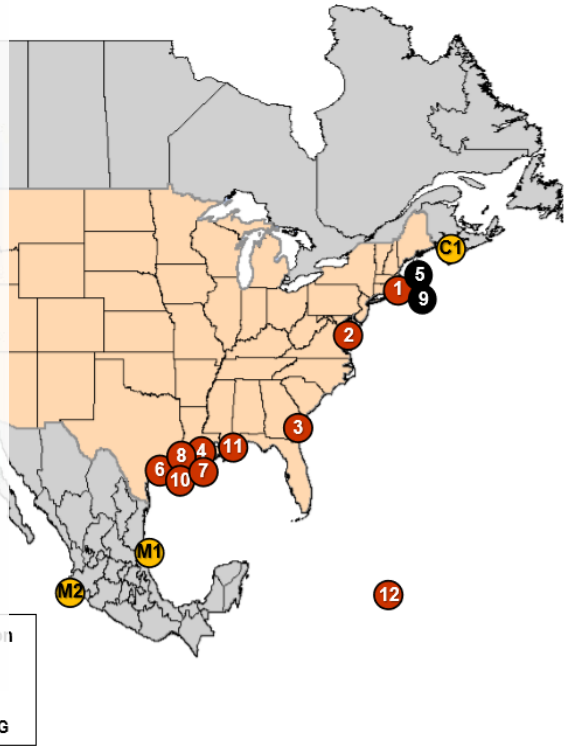
Execute

Operate

In service Risk Based Inspection (RBI) and Fitness For Service (FFS) review

Assess → Select → Define → Execute → Operate





Import Terminals

UNITED STATES
1. Everett, MA: 1.035 Bcfd (GDF SUEZ - DOMAC)
2. Cove Point, MD: 1.8 Bcfd (Dominion - Cove Point LNG)
3. Elba Island, GA: 1.6 Bcfd (El Paso - Southern LNG)
4. Lake Charles, LA: 2.1 Bcfd (Southern Union – Corpus Christi LNG) ★
5. Offshore MA: 0.8 Bcfd (Excelerate Energy – Northeast Gateway)
6. Freeport, TX: 1.5 Bcfd (Cheniere/Freeport LNG Dev.) ★
7. Sabine, LA: 4.0 Bcfd (Cheniere/Sabine Pass LNG) ★
8. Hackberry, LA: 1.8 Bcfd (Sempra - Cameron LNG)
9. Offshore MA: 0.4 Bcfd (GDF SUEZ – Neptune LNG)
10. Sabine Pass, TX: 2.0 Bcfd (ExxonMobil – Golden Pass) (Phase I & II)
11. Pascagoula, MS: 1.5 Bcfd (El Paso/Crest/Sonangol - Gulf LNG Energy)
12. Peñuelas, PR: 0.3 Bcfd (EcoElectrica)

CANADA
C1. Saint John, NB: 1.0 Bcfd (Repsol/Fort Reliance - Canaport LNG)

MEXICO
M1. Altamira, Tamulipas: 0.7 Bcfd (Shell/Total/Mitsui – Altamira LNG)
M2. Baja California, MX: 1.0 Bcfd (Sempra – Energia Costa Azul)
M3. Manzanillo, MX: 0.5 Bcfd (KMS GNL de Manzanillo)

★ Authorized to re-export delivered LNG

Conclusions


Assess
Select
Define
Execute
Operate

- It is not what we do not know that is of detriment, it is what we do not know we do not know.
- A little (risk based) targeted project assurance can go a long way.
- “There are only two things in life than do no harm: verification and chicken soup”.

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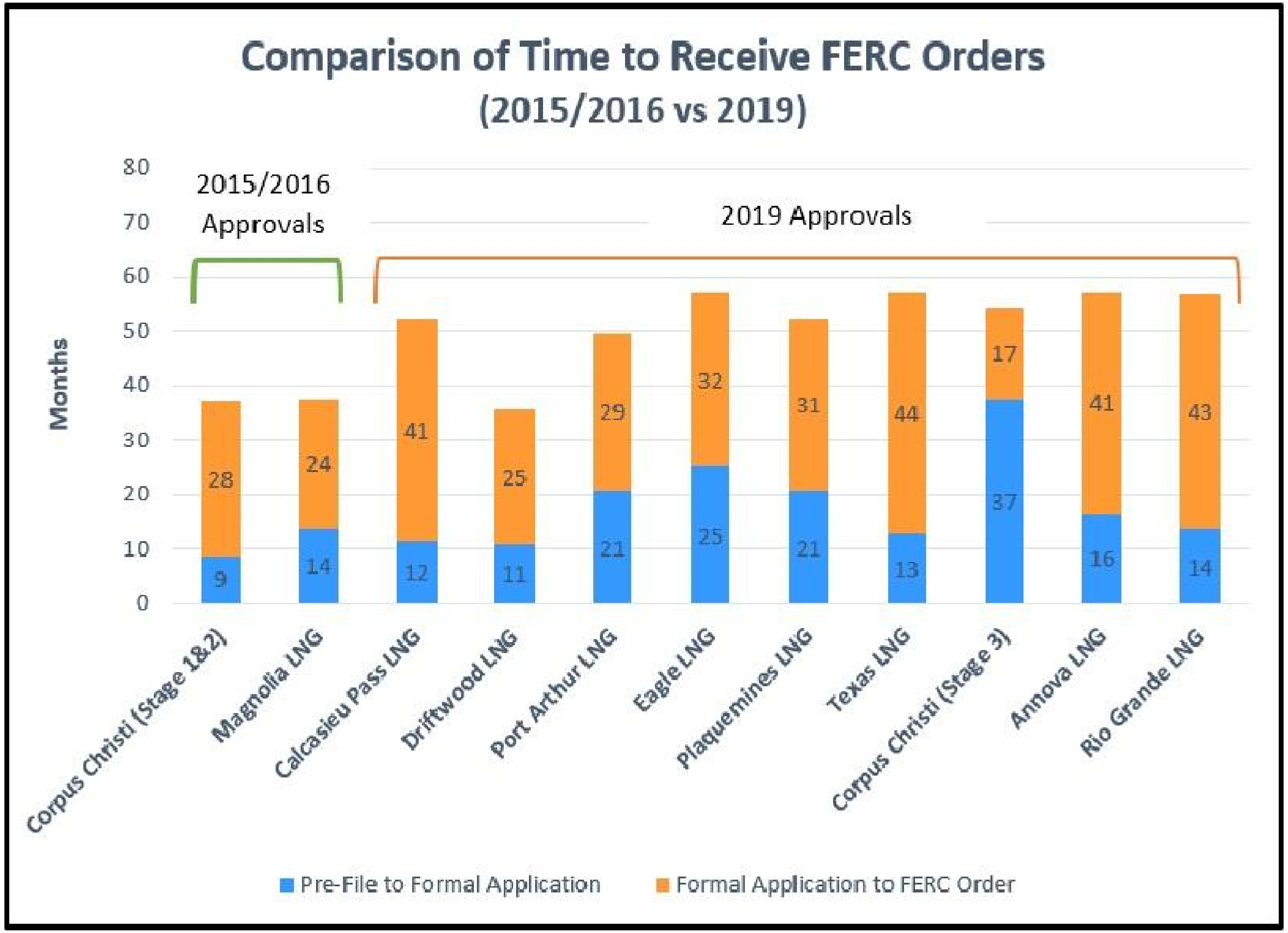
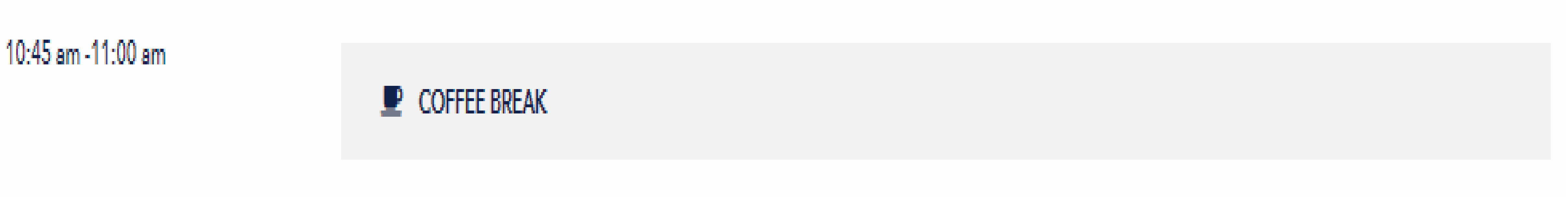
SAFER, SMARTER, GREENER

FERC consultation and determination



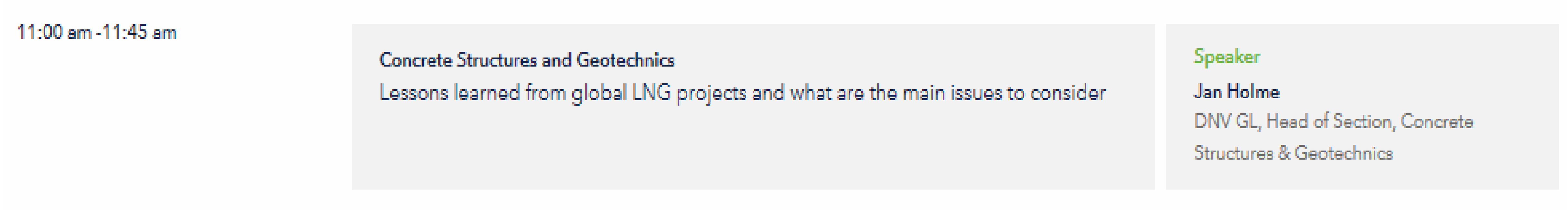
LNG Day Program Agenda



10:45 am - 11:00 am

☕ COFFEE BREAK

LNG Day Program Agenda



11:00 am -11:45 am

Concrete Structures and Geotechnics

Lessons learned from global LNG projects and what are the main issues to consider

Speaker

Jan Holme

DNV GL, Head of Section, Concrete Structures & Geotechnics

DNV·GL

OIL & GAS

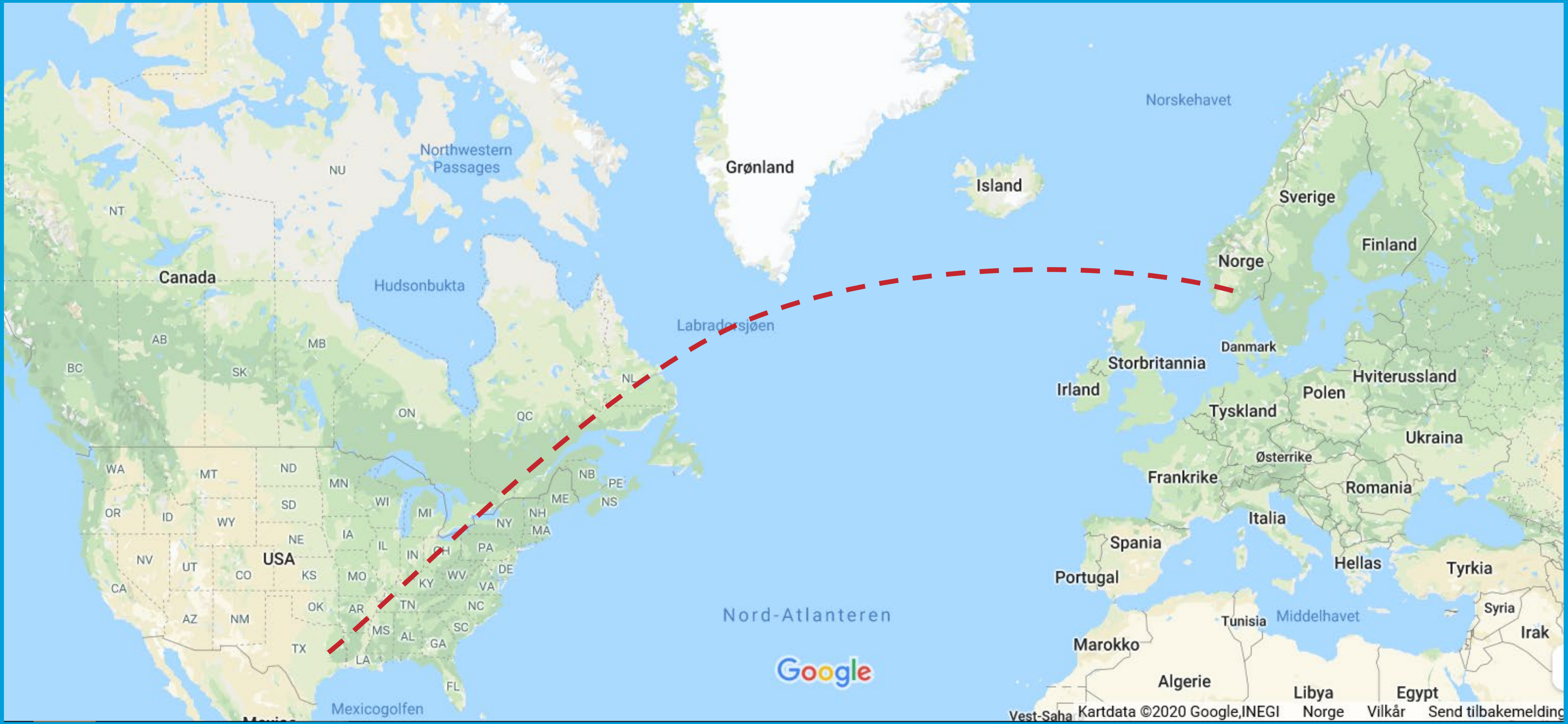
Concrete Structures & Geotechnics

Lessons learned from global LNG projects and what are the main issues to consider

Jan Holme
26 February 2020

Introduction

Concrete Structures & Geotechnics in Norway


Northwestern Passages
NU
NT
Canada
Hudsonbukta
Grønland
Island
Norskehavet
Sverige
Finland
Norge
Labradorsjøen
AB
MB
BC
SK
ON
QC
NL
Danmark
Storbritannia
Irland
Hviterussland
Polen
Tyskland
Ukraina
Østerrike
WA
MT
ND
MN
NB
PE
NS
ME
OR
ID
SD
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OH
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NV
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USA
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KS
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KY
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VA
CA
OK
AR
TN
NC
AZ
NM
MS
AL
SC
GA
TX
LA
FL
Mexicogolfen
Nord-Atlanteren
Google
Frankrike
Romania
Italia
Spania
Hellas
Tyrkia
Portugal
Syria
Irak
Tunisia
Middelhavet
Marokko
Algerie
Libya
Egypt
Vest-Sahara
Kartdata ©2020 Google,INEGI
Norge
Vilkår
Send tilbakemelding

As expressed by US Foreign minister…. we are normal ☺

Our services

CONCRETE STRUCTURES

Concrete structures unit	04
Offshore concrete structures	06
Ports and terminals	08
Infrastructure	09
LNG storage tanks	10
Support structures for wind turbines	11
Grouted connections & structural grouts	12
Construction follow-up	14
Pipelines	15

GEOTECHNICAL SERVICES

Introduction	05
Anchors	06
Ports and Terminals	07
Jacket Foundations	08
Jack-up Foundations	09
Subsea structures	11
Pipelines	12
GBS foundations	13
Wind turbine foundations	14

We are responsible for the following standards, RPs and service specifications


DNV·GL

RECOMMENDED PRACTICE

Edition September 2019

DNVGL-RP-C207

Statistical representation of soil data


DNV·GL

RECOMMENDED PRACTICE

Edition September 2019

DNVGL-RP-C212

Offshore soil mechanics and geotechnical engineering

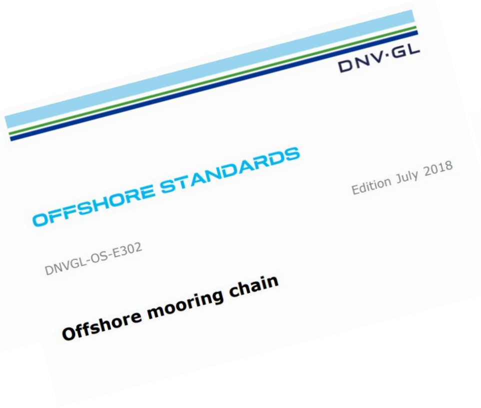

DNV·GL

OFFSHORE STANDARDS

Edition July 2018

DNVGL-OS-E301

Position mooring


DNV·GL

OFFSHORE STANDARDS

Edition July 2018

DNVGL-OS-E302

Offshore mooring chain

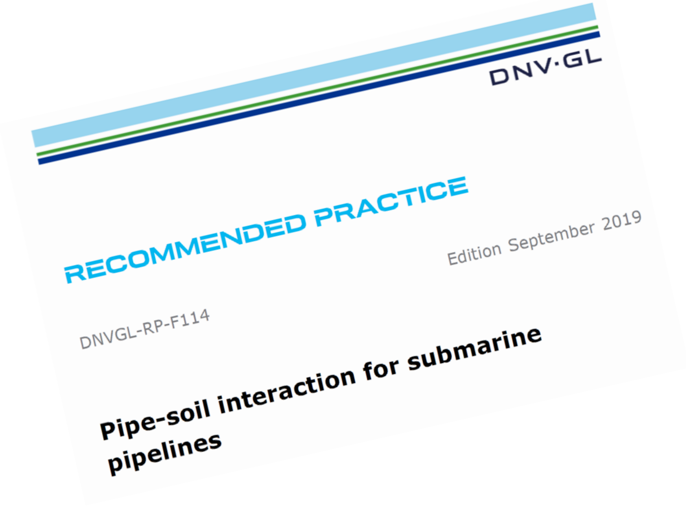

DNV·GL

OFFSHORE STANDARDS

Edition July 2018

DNVGL-OS-E303

Offshore fibre ropes

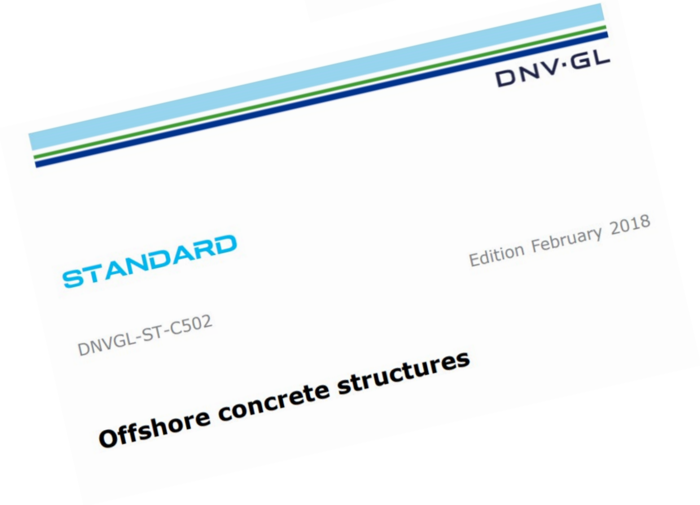

DNV·GL

RECOMMENDED PRACTICE

Edition September 2019

DNVGL-RP-F114

Pipe-soil interaction for submarine pipelines


DNV·GL

STANDARD

Edition February 2018

DNVGL-ST-C502

Offshore concrete structures


DNV·GL

SERVICE SPECIFICATION

Edition December 2018

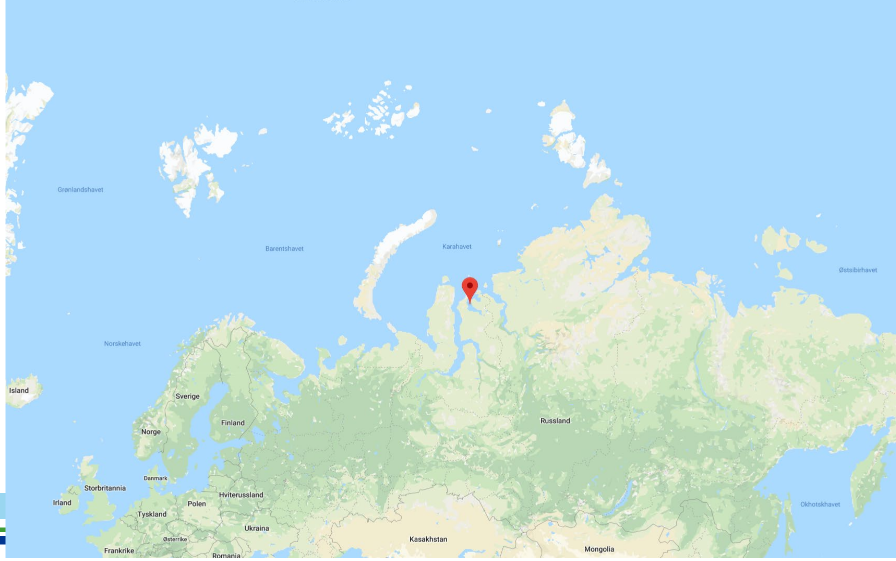
DNVGL-SE-0295

Verification and certification of offshore concrete and grout structures

Some ongoing LNG projects

Novatek Arctic LNG

- Summer 2019 DNV GL UK, sign a significant MWS contract with NOVATEK Arctic LNG. Contract lasting 7 years. DNV GL Norway is a trusted partner within Concrete structures and geotechnics.

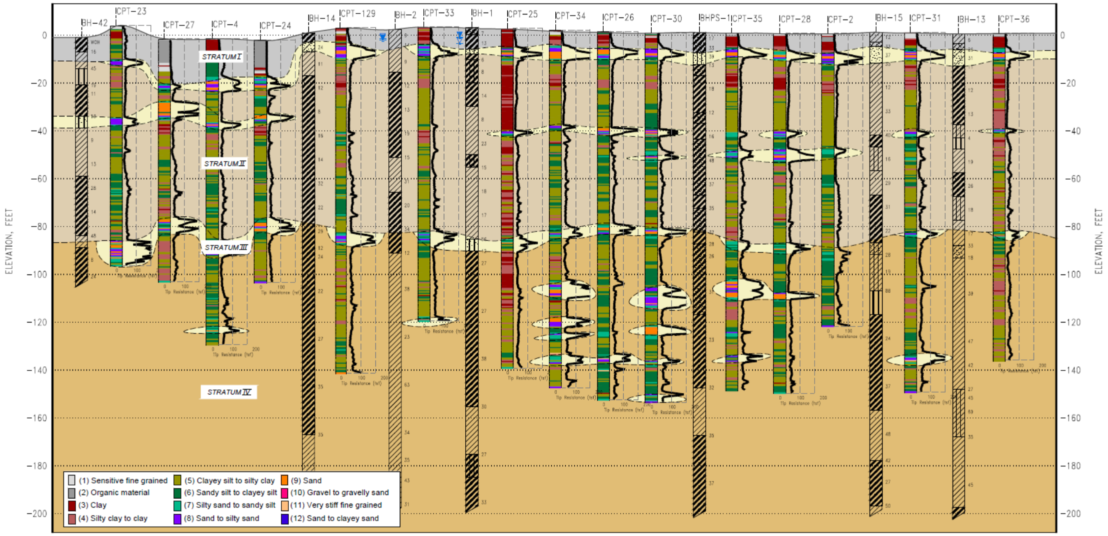


Main issues Geotechnical

Typical civil work issues, driving the cost (geotechnical)

- Soil investigations

anchoring



Typical civil work issues, driving the cost (geotechnical)

- Soil investigations
- Earthquake analyses and liquefaction potential
- Contaminated soil
- Breakwaters (Bearing and settlements)
- Reclaimed area (settlements)
- Scour and scour protection
- Dredging & slope stability
- Compaction of soil (soil improvement)
- Piles: bearing capacity and driveability
- Sheet piling and anchoring

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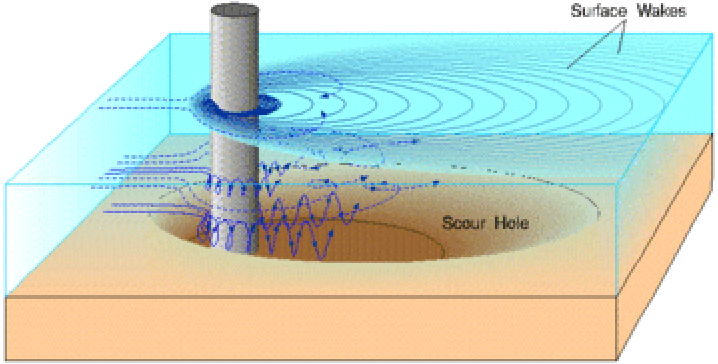

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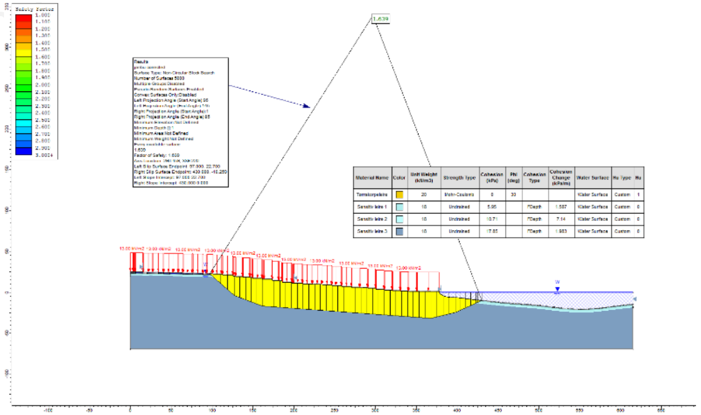

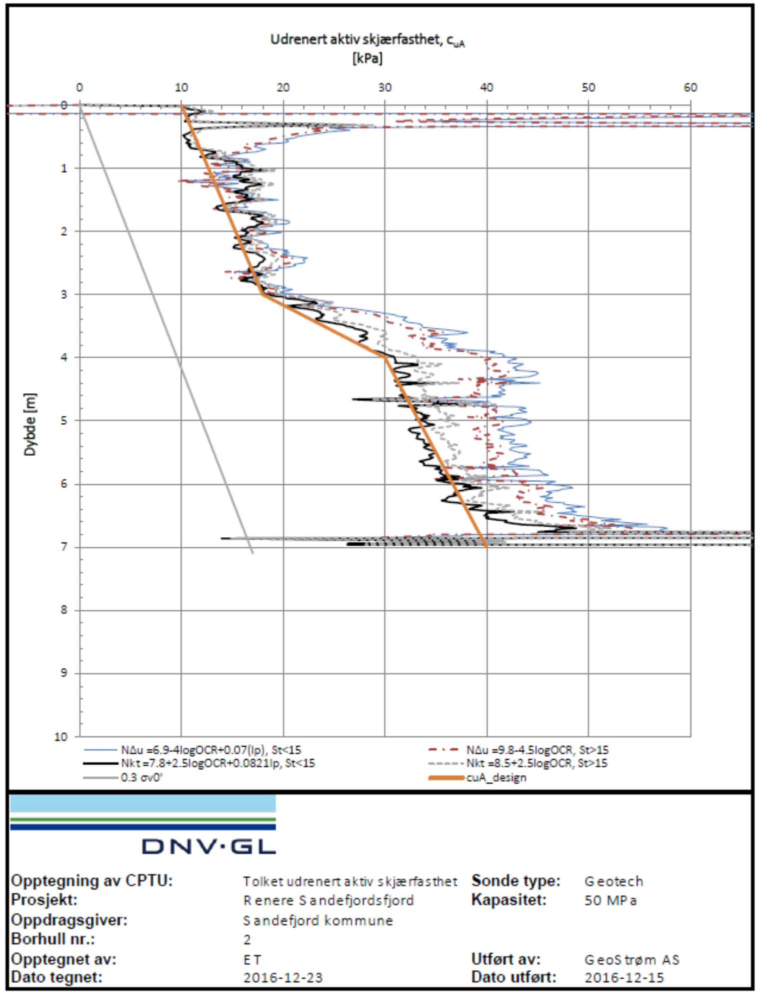

Opptegning av CPTU: Tolket udrenert aktiv skjærfasthet **Sonde type:** Geotech
Prosjekt: Renere Sandefjordsfjord **Kapasitet:** 50 MPa
Oppdragsgiver: Sandefjord kommune
Borhull nr.: 2
Opptegnet av: ET **Utført av:** GeoStrøm AS
Dato tegnet: 2016-12-23 **Dato utført:** 2016-12-15

Typical civil work issues, driving the cost (geotechnical)

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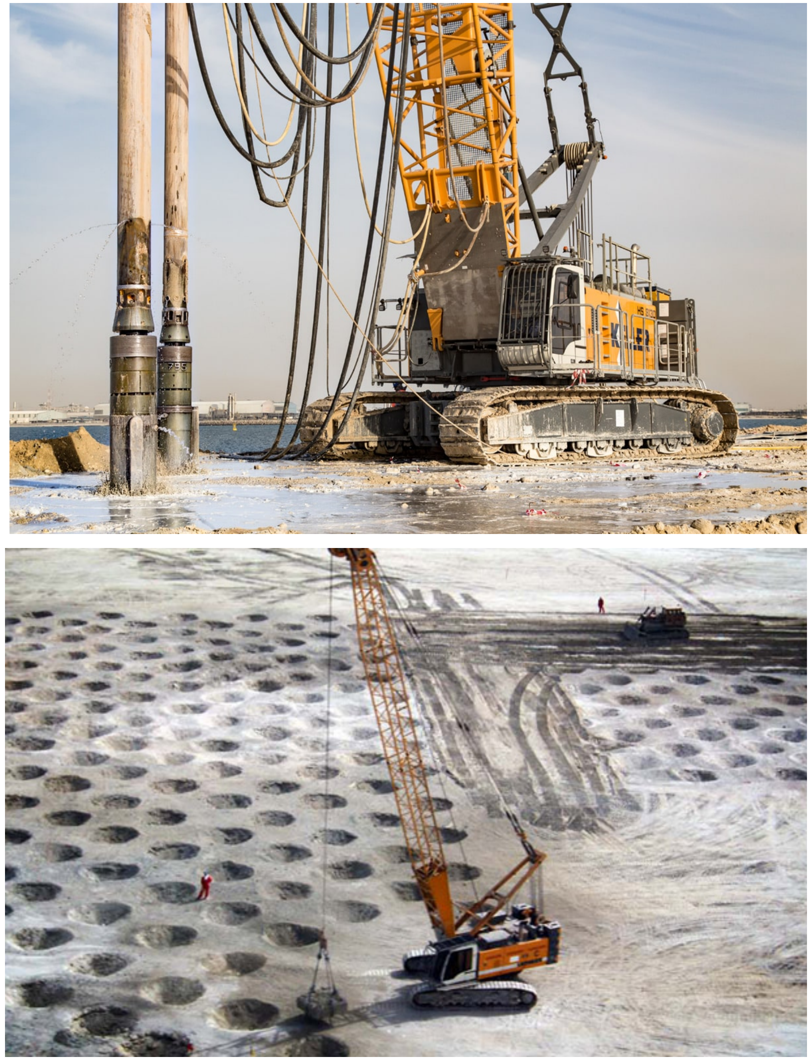

Is there time for preloading

and consolidation?

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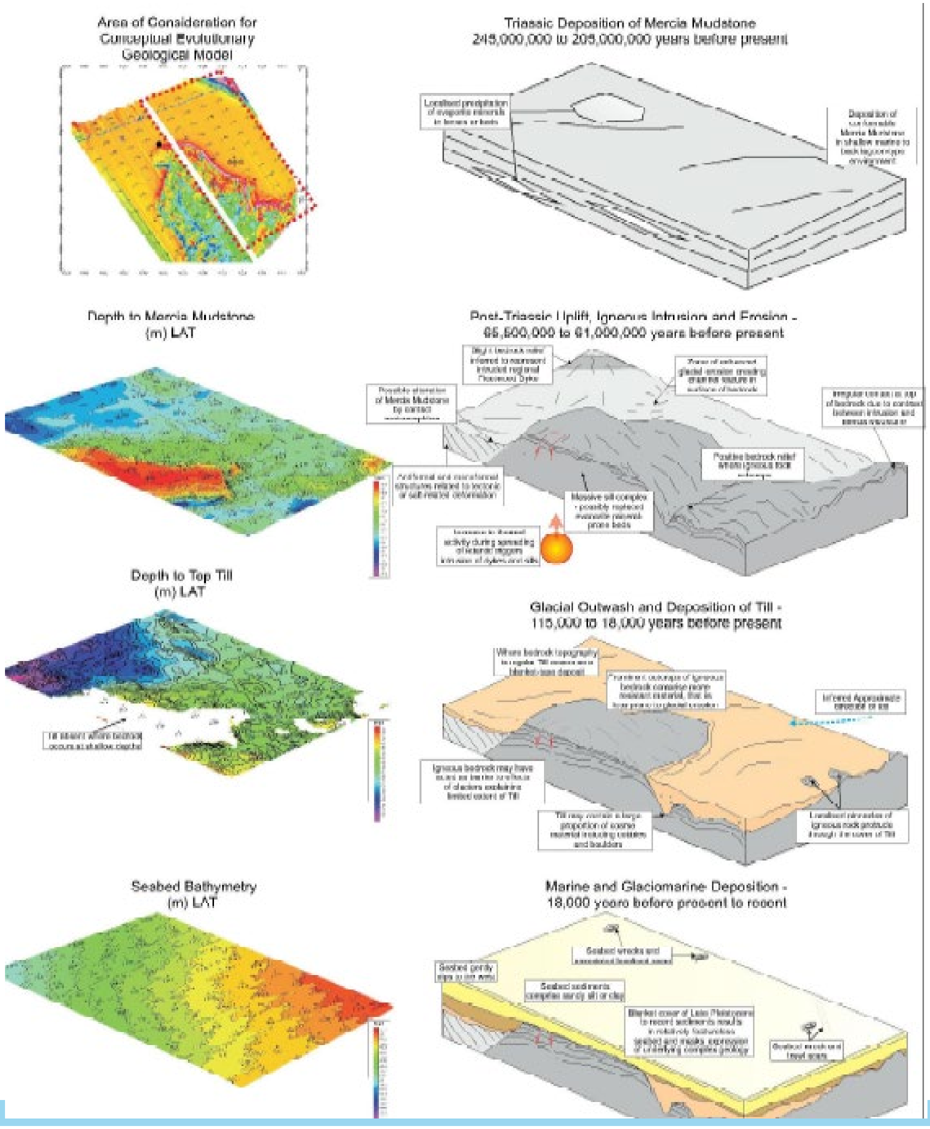
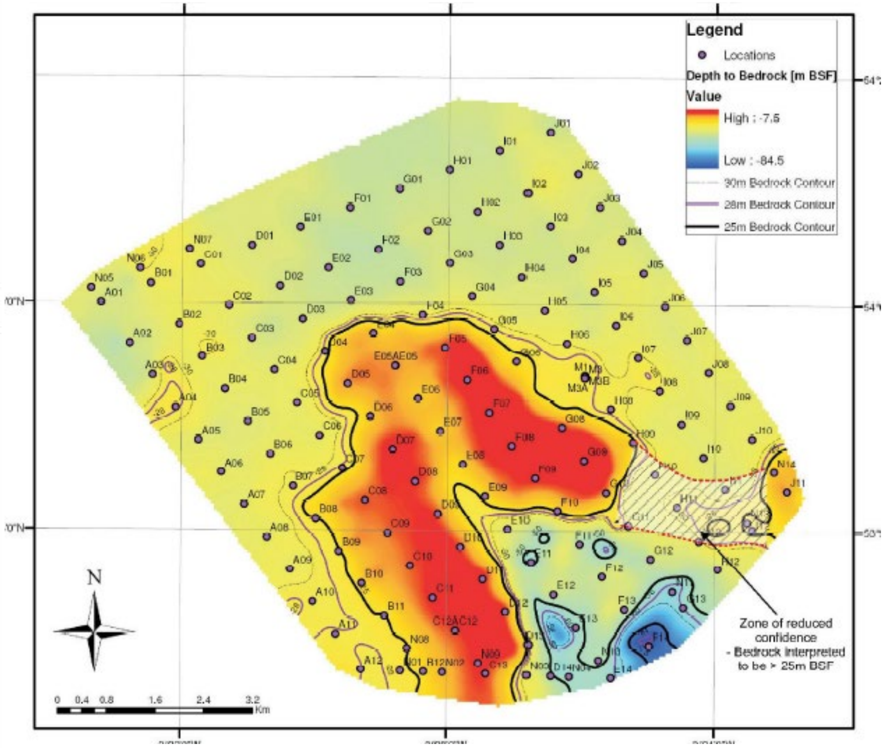
Do you trust the geotechnical engineer?

Geotechnical models and new technology

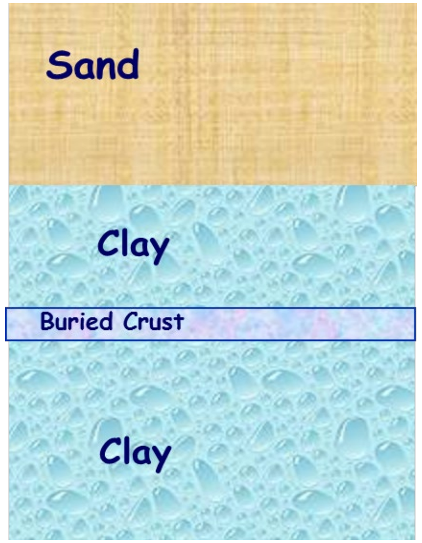
Detailed Geological Model is necessary for a good design

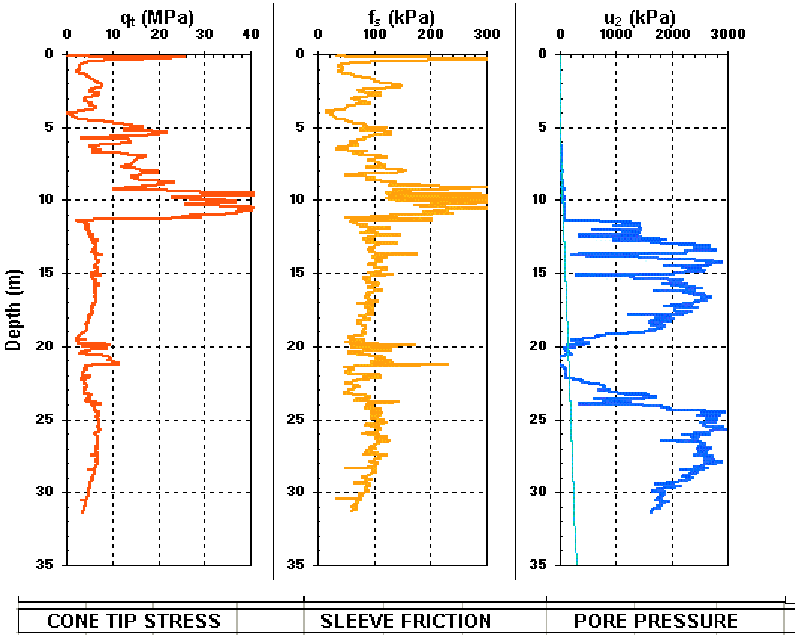




Geotechnical Site Investigations

- in-situ testing, for example
  - Standard penetration testing (SPT)
  - cone penetration tests with pore pressure measurements (PCPT),
  - pressiometer tests,
  - dilatometer tests and
  - shear wave velocity measurements for assessment of maximum shear modulus





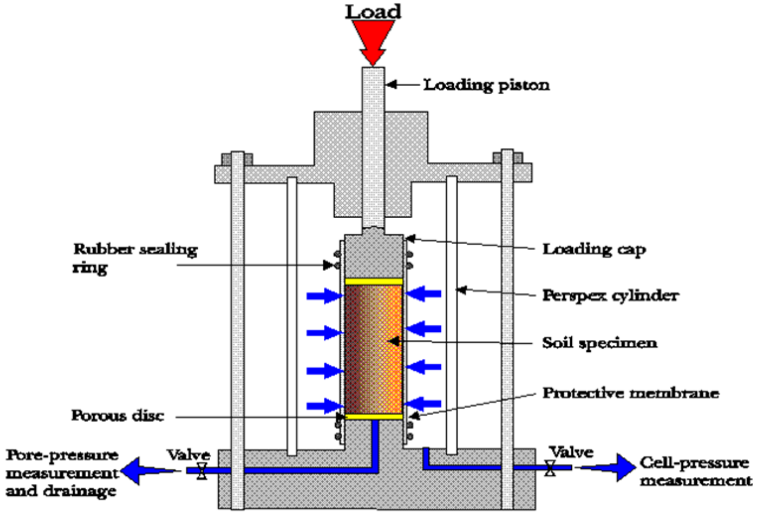
Geotechnical Site Investigations

- soil sampling with subsequent static and cyclic laboratory testing
  - Soil properties
  - Soil strength
  - Soil stiffness
  - Consolidation parameters
  - Cyclic degradation effects

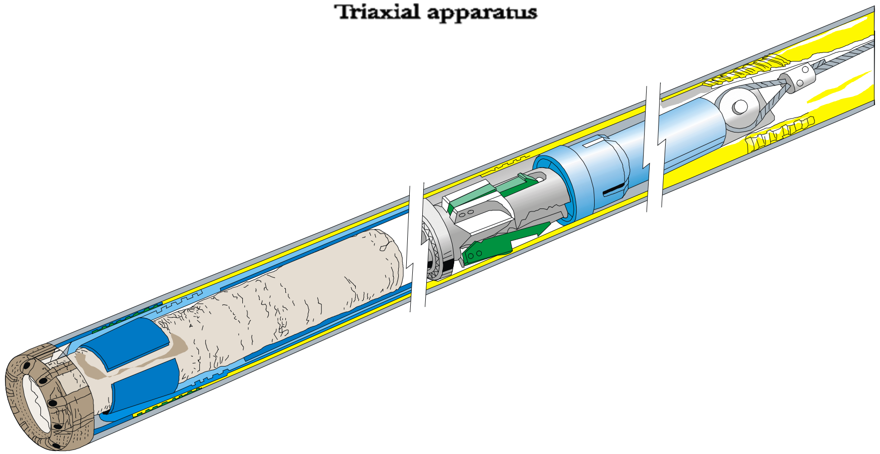
[redacted]

[redacted]

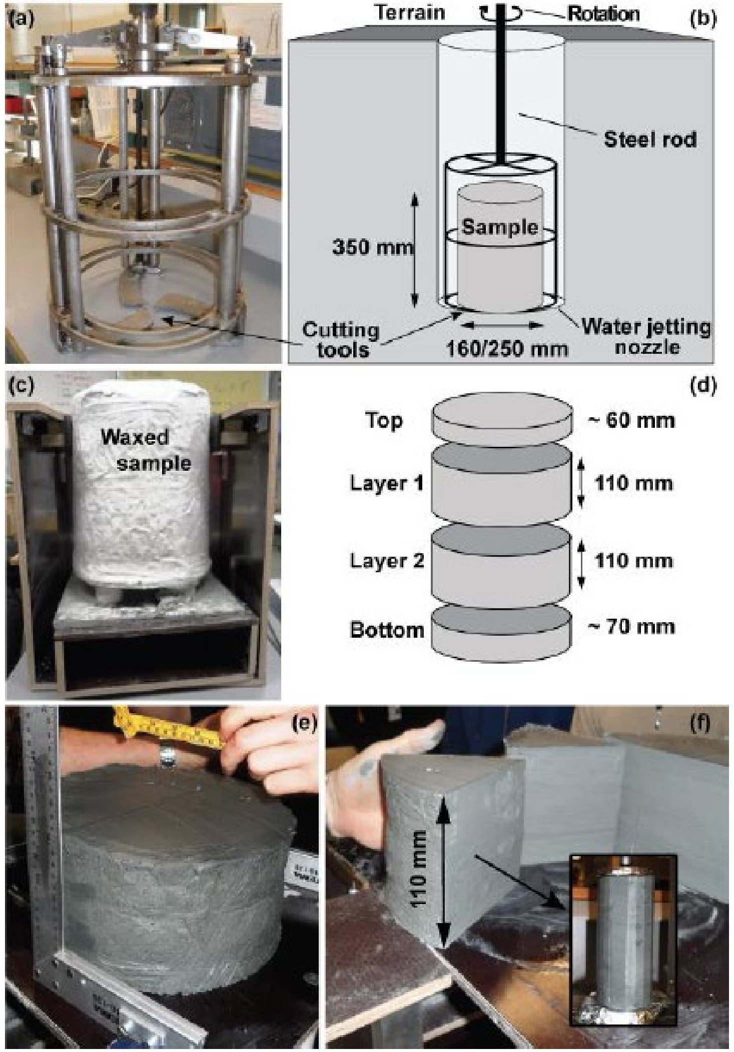
[redacted]



Triaxial apparatus



Example of block sampling (almost undisturbed)



The importance of quality data

Block testing with undisturbed good sample quality

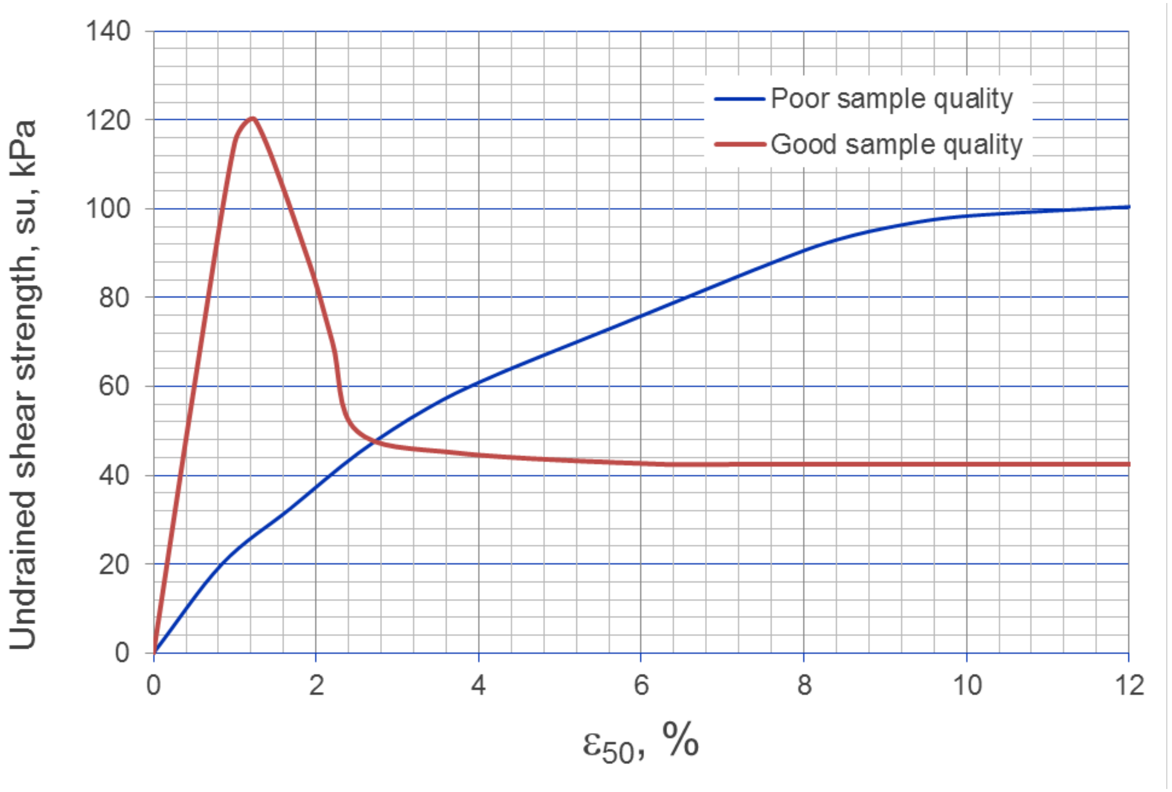
vs

Traditionally 54mm with disturbed poor sample quality.

For the same clay, the interpreted soil strength may differ a lot due to sample disturbance!

What sample would you like to use?

DNV GL recommend to focus on fewer borings with high quality rather than many samples with less quality!

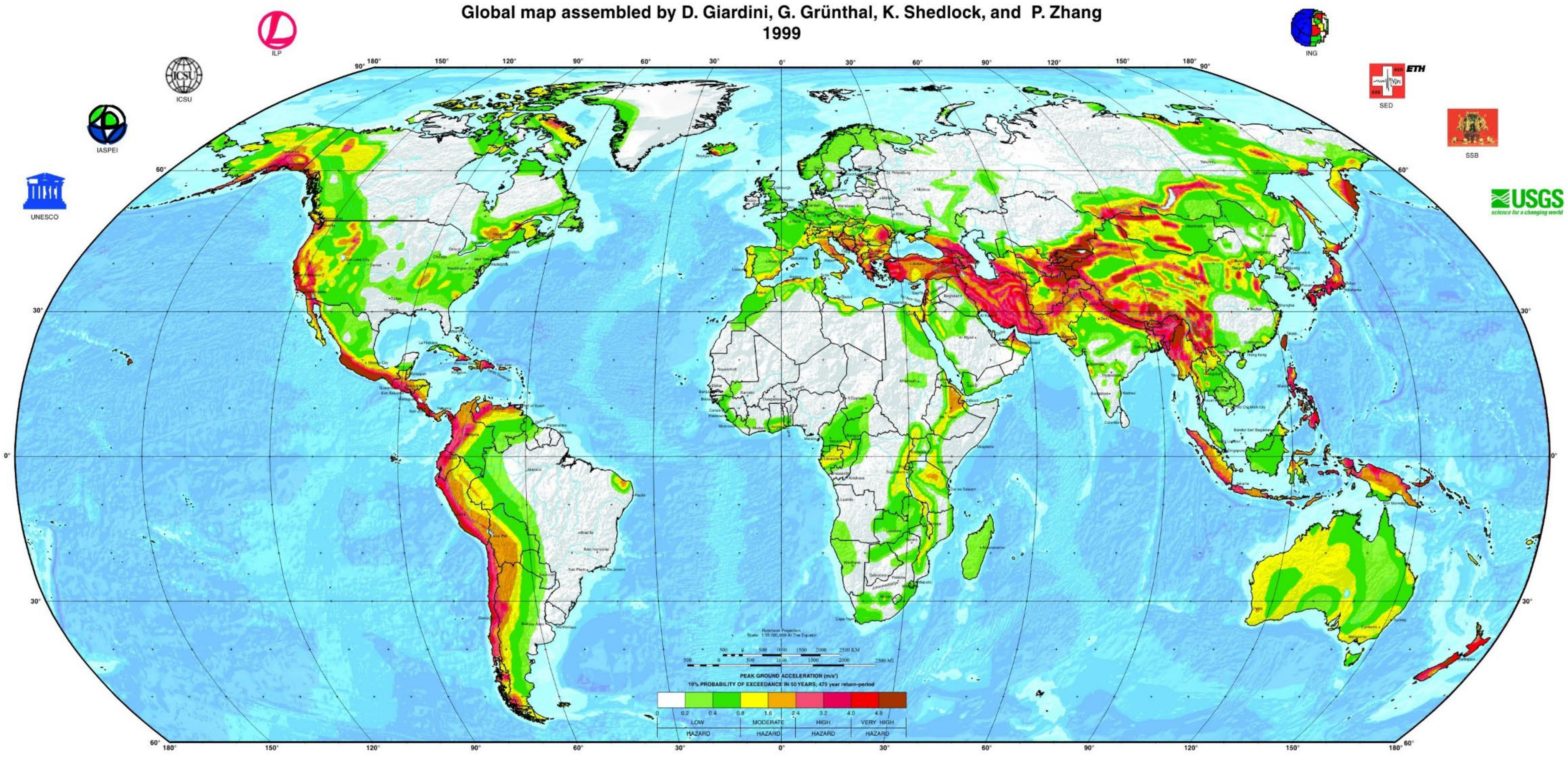


Consider a slab foundation and previous example

- With shear strength 20% lower, the slab foundation needs to be 20% larger in area to maintain same bearing.

- However, note that the shear modulus may deviate much more. In the previous example the shear modulus is about 3 times stiffer for the none disturbed sample. Any thoughts on this related to the dynamic response of structure?

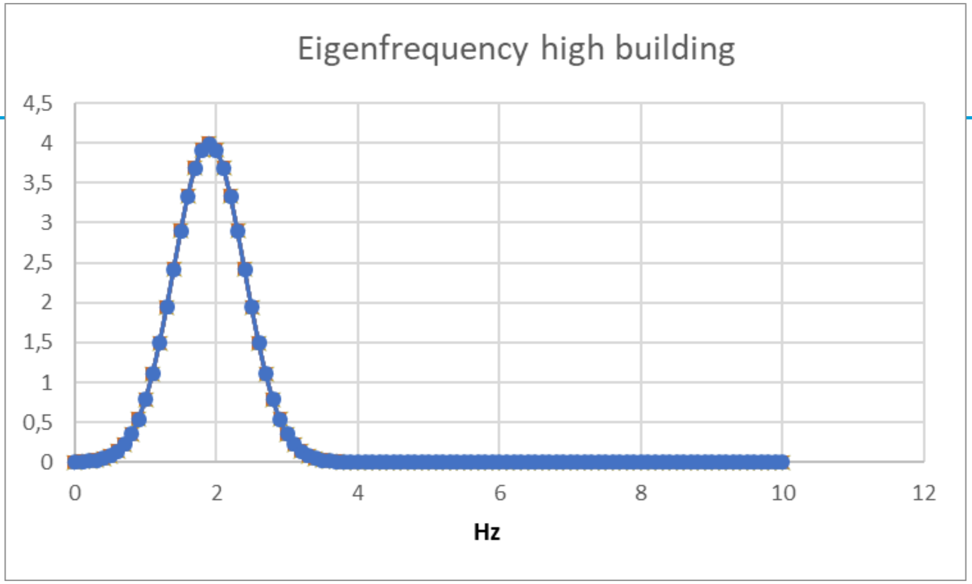
Earthquake may be a major risk

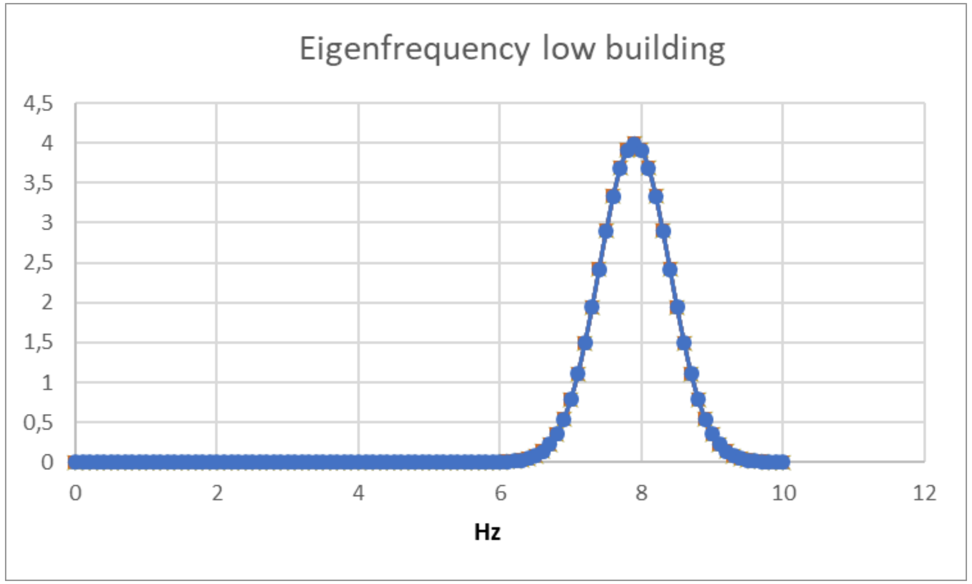


Global map assembled by D. Giardini, G. Grünthal, K. Shedlock, and P. Zhang
1999

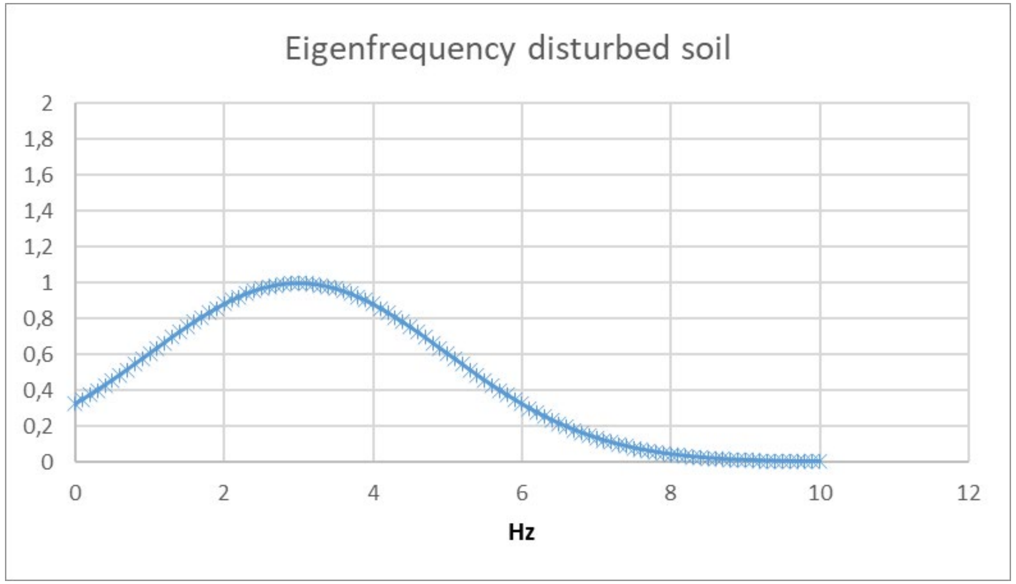
In general…

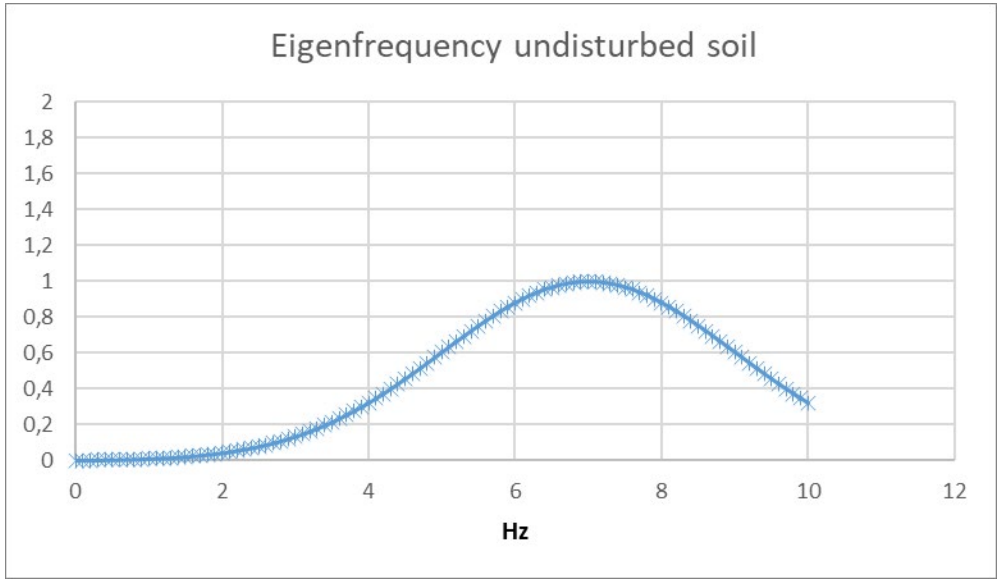
- High buildings shows lower eigenfrequencies than low buildings



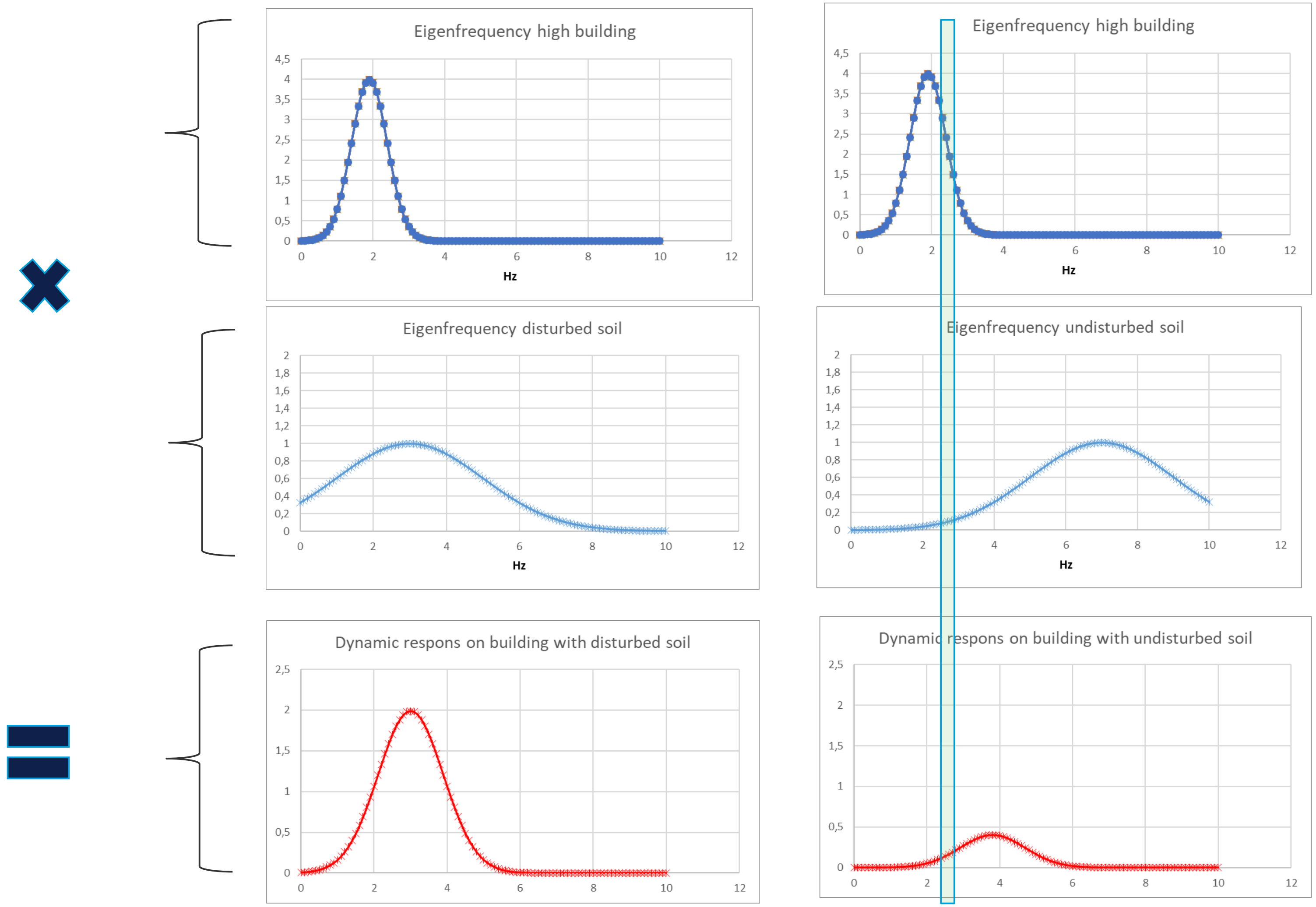


The eigenfrequency of the soil is proportional to the shear modulus





The response is the product of the transfer functions of building and soil

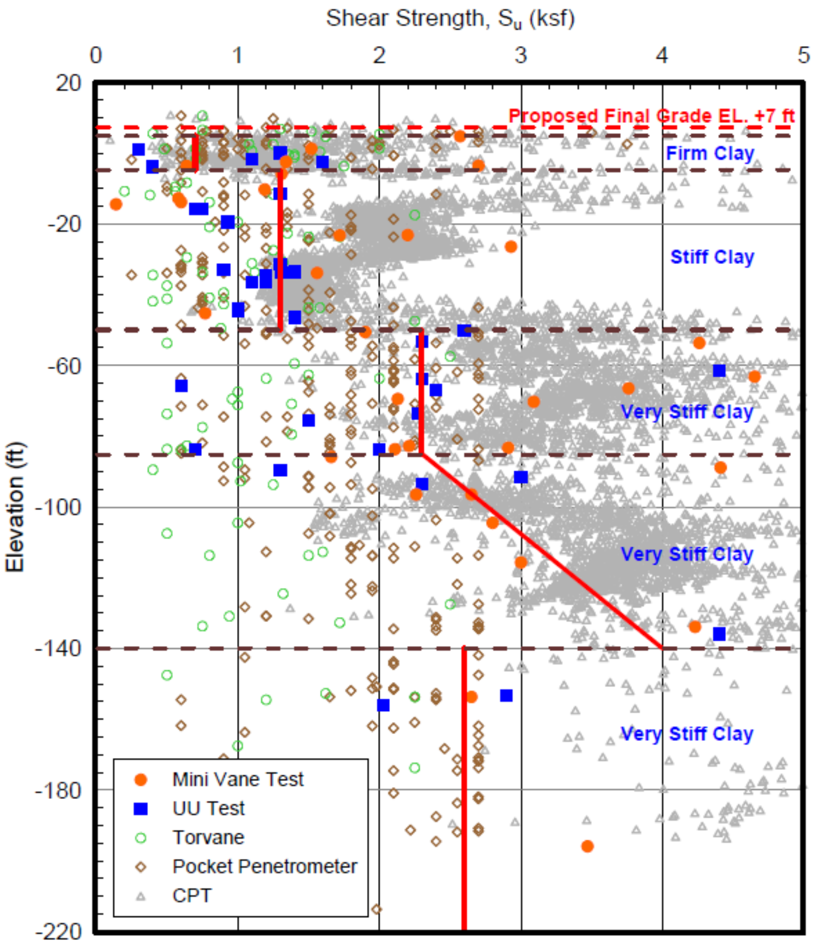


Note:

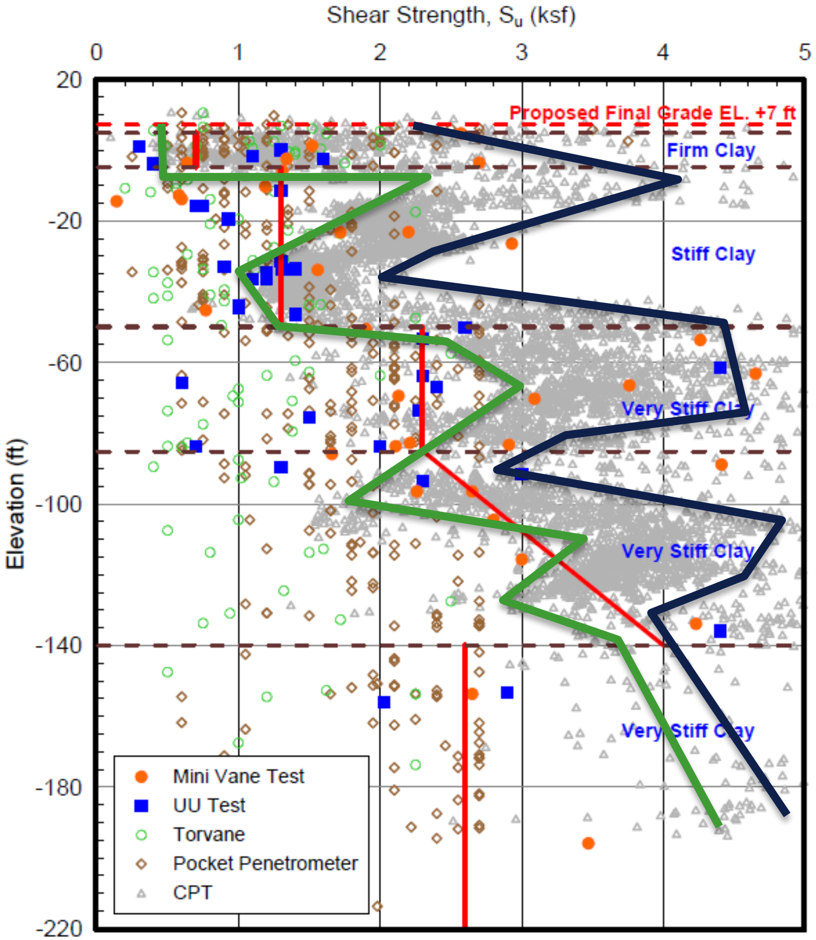
The high building collapsed!

Most likely the eigen frequency of soil was closer to the eigen frequency of the building!

What data is the designer using?



What if we trust CPT more and include both lower bound and upper bound?



Guidance regarding statistical representation of soil data

DNV·GL

RECOMMENDED PRACTICE

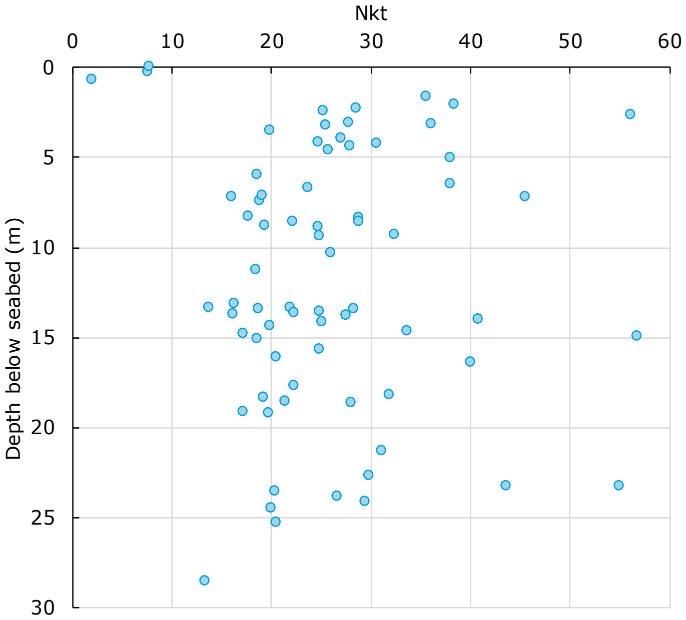
DNVGL-RP-C207 Edition September 2019

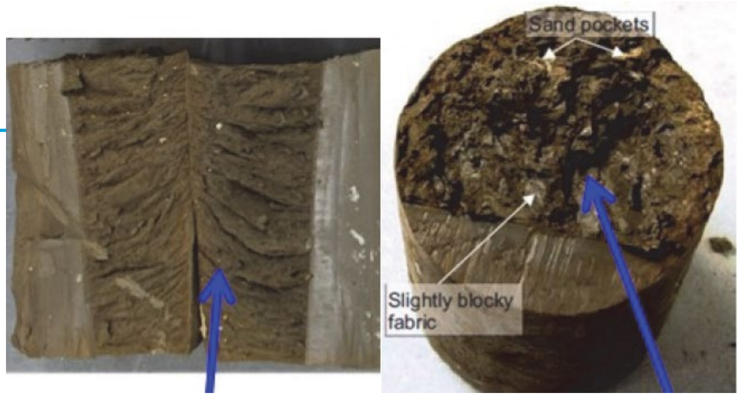
Statistical representation of soil data

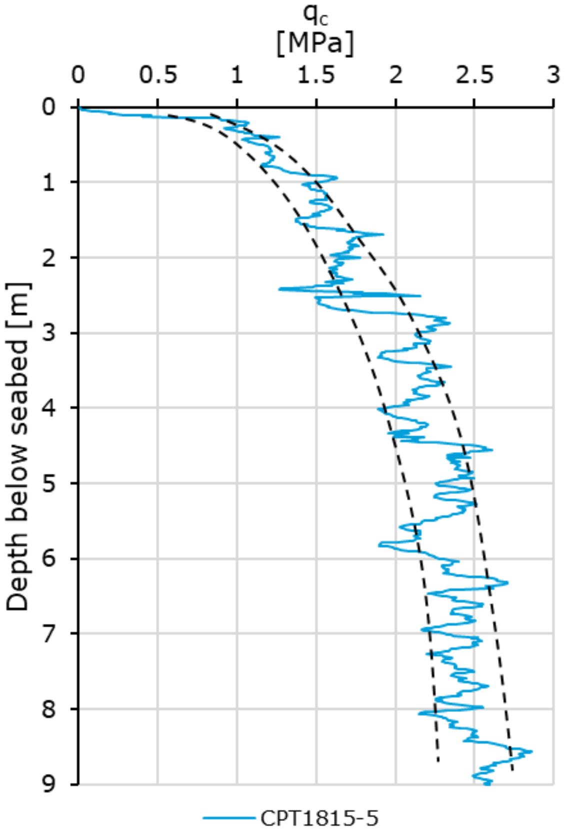
Example of spudcan back-analysis to reduce risk

- Laboratory tests showed high variability in clay strength
- Laboratory test specimen had fissures and structure that affect the strength test results.
- In-situ Cone Penetration Tests (CPT) also show variability but not as variability as Nkt factor correlated from lab test.
- Operational strength of soil supporting large foundation more representative for foundation design.
- *Back-analysis of soil strength from spudcan jacking trials to find correlation of soil strength with CPT*

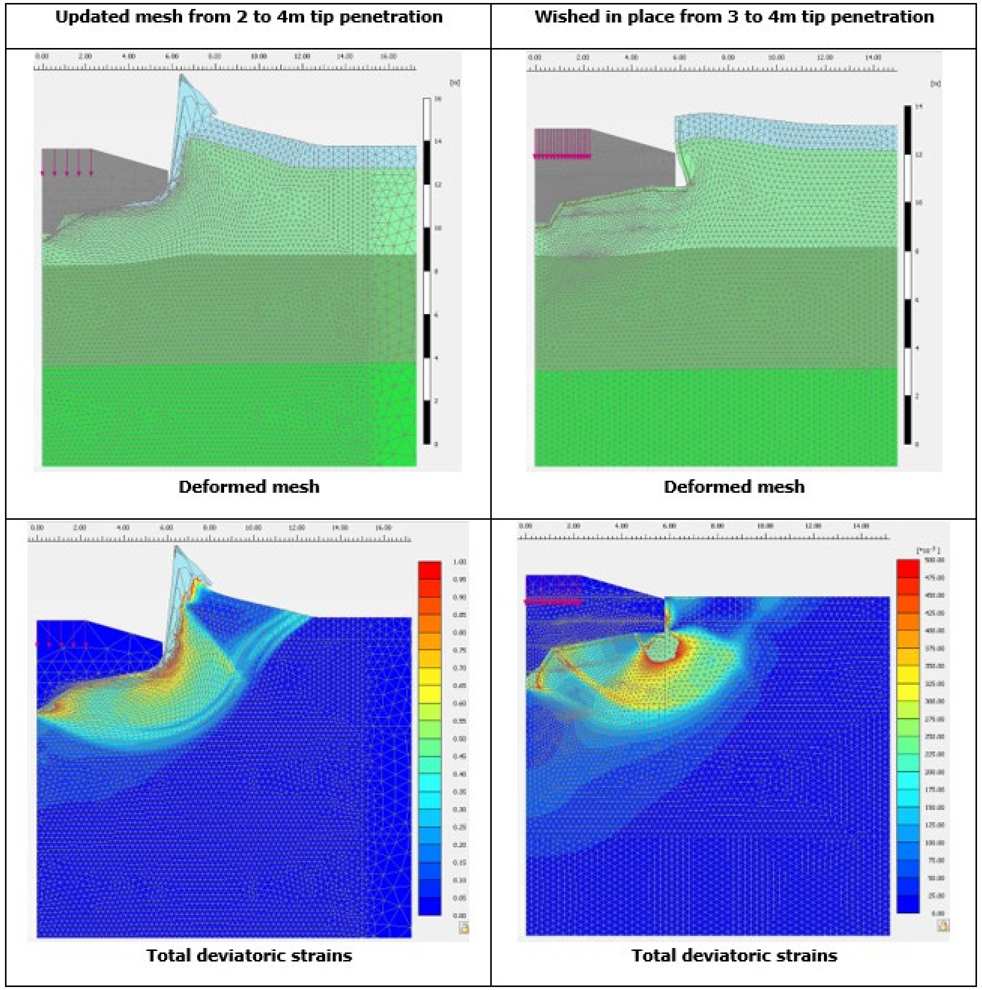
Nkt cone resistance factor to undrained shear strength typically 15-20 for North Sea clays.



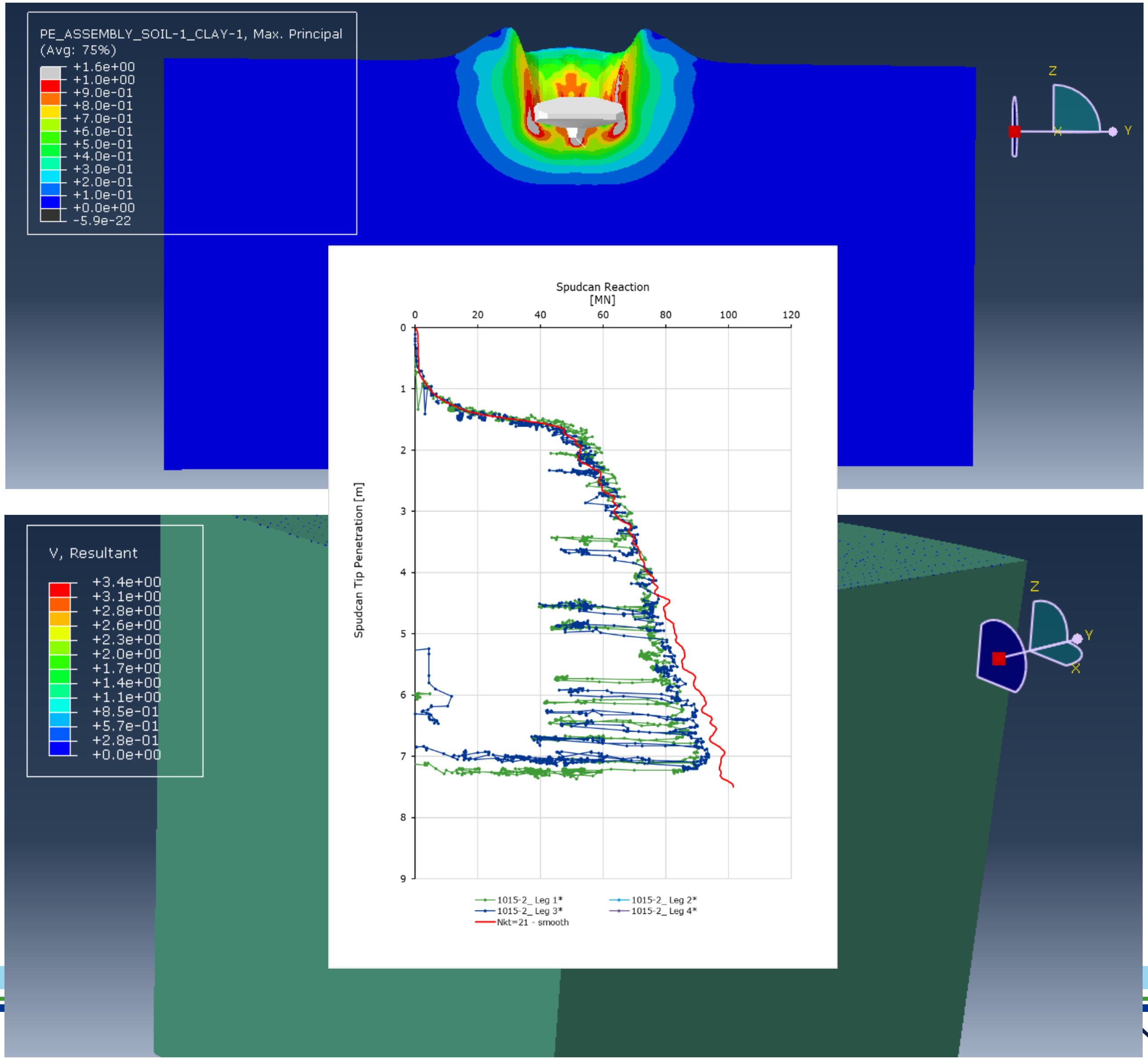




Spudcan Back Analysis Methodology (cont.)



Updated mesh from 2 to 4m tip penetration	Wished in place from 3 to 4m tip penetration
Deformed mesh	Deformed mesh
Total deviatoric strains	Total deviatoric strains



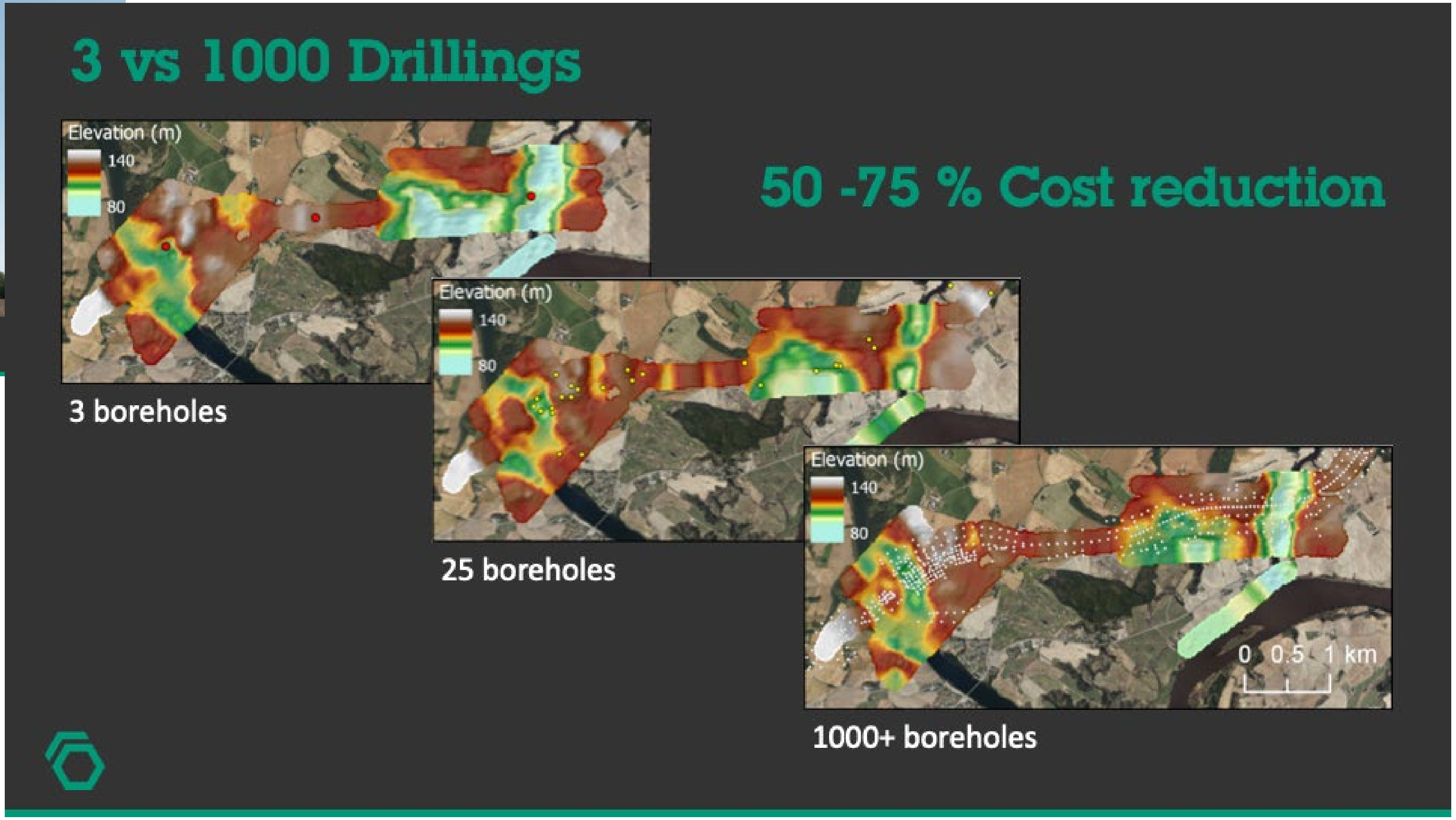
Results and value added

- After consideration of sensitivity studies and soil variability, Nkt for clay refined to **19-21** (previously 3 to 30 based on laboratory tests)

New Technology that can reduce risk and cost


EMerald Geomodelling

emeraldgeo.no


3 vs 1000 Drillings

50 -75 % Cost reduction

3 boreholes

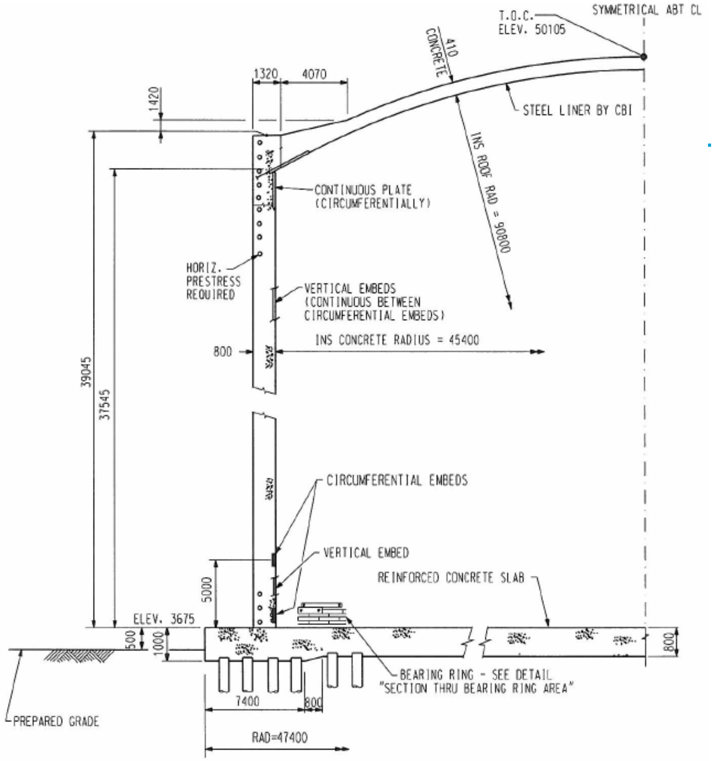
25 boreholes

1000+ boreholes

Main issues Concrete Structure

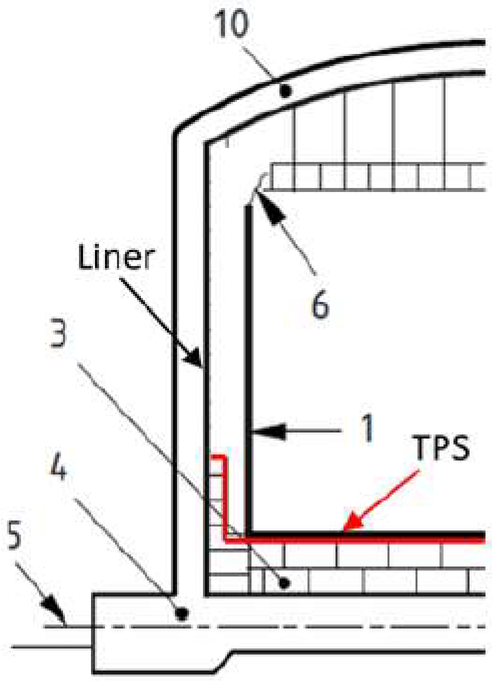
Onshore Full Containment LNG tanks, important issues

- Tank slab / foundation robustness to limit differential settlements
- Tank wall and dome robustness for external threats
- Cryogenic reinforcement required in areas subject to thermal shock
- Tank wall leak tightness requirement (minimum compression zone)
- Outer tank is the vapour barrier (inner tank is open top)
  - However, concrete is not vapour tight;
  - Tank wall and dome are lined with carbon steel
- Construction sequences with interfaces between civil (outer tank) and steel (inner tank)
  - Temporary openings are required in the tank wall
- Post-tensioning of circumferential and vertical tendons
- In moderate seismic regions, designers sometimes require:
  - anchorage of the inner tank to maintain its stability, or
  - seismic base isolation of the complete tank



Onshore Full Containment LNG tanks, a design issue of note

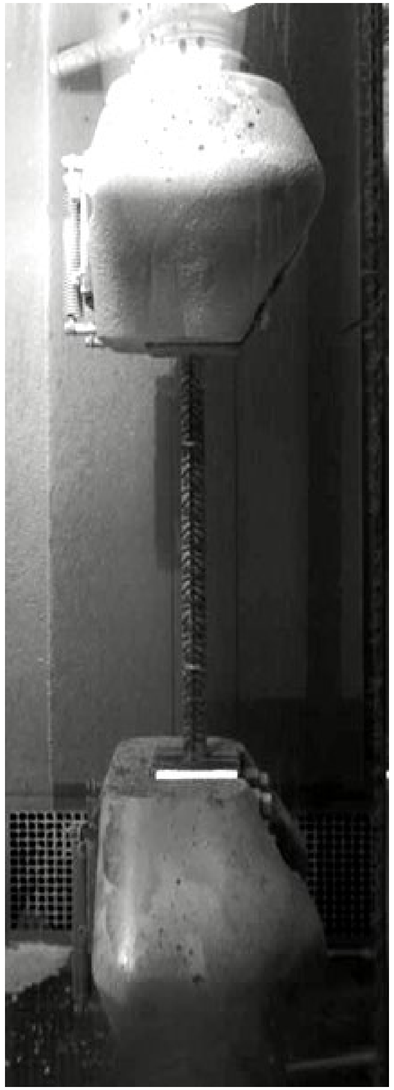
- The robustness of design assumptions: Thermal corner protection (TCP) should be challenged.
- Tanks in operation are experiencing off-gassing through the base slab and/or lower portion of the tank wall.
- Subsequently, the structural integrity of the tank to withstand thermal shock behind the TCP is questioned.
- Material testing (see next slide) and advanced NLFEA can evaluate the asset integrity issue for the tank.
- However, the environmental impact of leaking tanks should be considered in current climate context. Not to mention the potential for gas clouds and explosion risks.
- DNV GL welcome to participate in a JIP should the industry wish to look into root causes for the leakage and possible mitigations, ref paper on Gas migration.

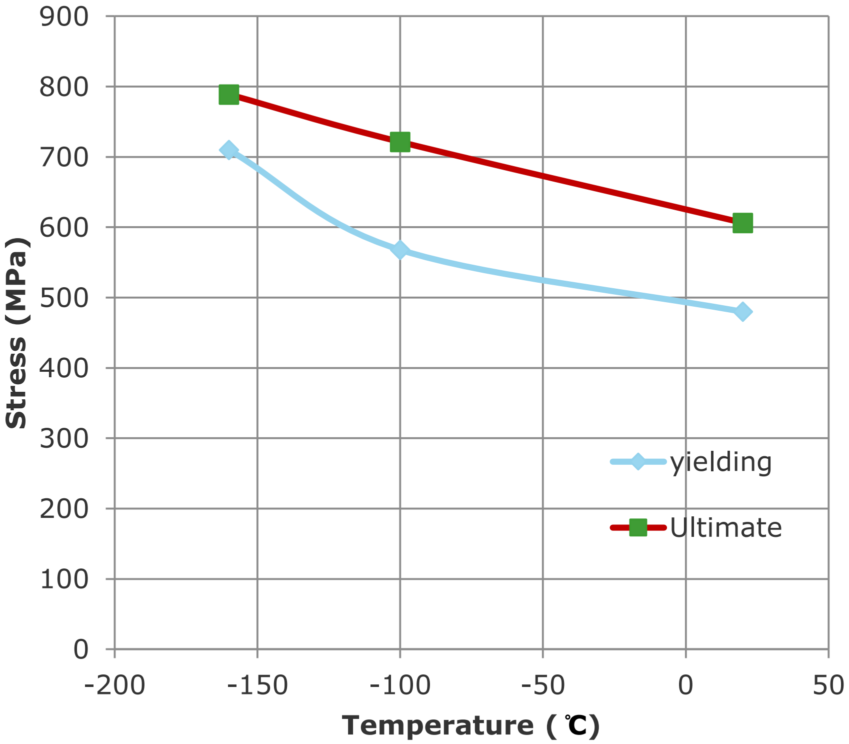



GAS MIGRATION FROM LNG FULL CONTAINMENT TANKS

Chris Blackmore, Paola Mayorca, and Tim Wiley

Testing of normal reinforcement under cryogenic conditions





Onshore Full Containment LNG tanks, construction issues of note

- Importance of QC for civil works.
  - Do it well, do it once.
  - Difficult to remediate defective concrete placement.
  - Poor execution on civil works has a major impact on the schedule

- Importance of weld procedures and NDT for all steel elements including primary inner tank, secondary barrier, TCP, and carbon steel vapour barrier. Note some of these are difficult to "prove" tight through pneumatic and/or hydro tests. Importantly, the steel exposed to LNG temperatures will see quite some contraction / movement. Therefore, the tightness in service cannot be guaranteed through the pre-commissioning tests.
  - Are the weld details robust or suspect?
  - Are there reliable volumetric examination methods to check quality of the weld where visual survey is not possible?
  - Are the NDT technicians qualified through reference tests?

Summary

Lessons learned regarding concrete structures and geotechnics

- Pay attention to soil investigations and focus on high quality data!
- You also pay for the soil investigations you skipped!
- New technologies enables the owner to map a better geological 3D model and reduce risks related to ground conditions!
- Earthquake and low temperature are the two main load cases for design of the LNG tank
- The LNG tank is the critical asset in terms of project delivery. Thorough planning, robust design and follow up with close inspection are key for a successful project. DNV GL consider remote inspection as a good alternative to increase quality with low cost.
- Leakuage is identified as a challenge in the industry and often related to the above

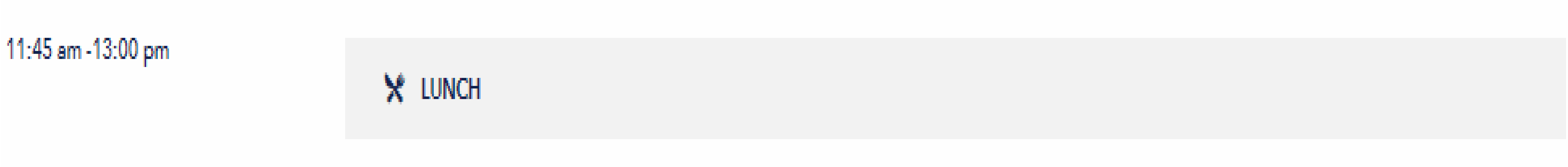
Thanks for your attention!

Jan.Holme@dnvgl.com
+47 930 27 568

www.dnvgl.com

SAFER, SMARTER, GREENER

LNG Day Program Agenda



11:45 am -13:00 pm	LUNCH

LNG Day Program Agenda

13:00 -13:45	The next wave of FLNG	Speaker **Conn Fagan** DNV GL, Vice President, Business Development Offshore Gas Projects

The Next Wave of FLNG

LNG Day 2020

Conn Fagan

DNV GL has been at the forefront of the FLNG development and classifies more than half of the global FLNG fleet today

1962

1979

1991

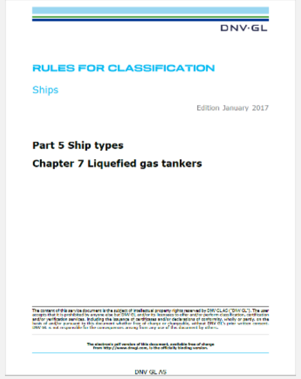
2004

2017

2017/18

DNV GL has been part of defining the LNG industry

First classification society to publish rules for gas carriers in 1962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RULES FOR CLASSIFICATION

Ships

Edition January 2017

Part 5 Ship types

Chapter 7 Liquefied gas tankers

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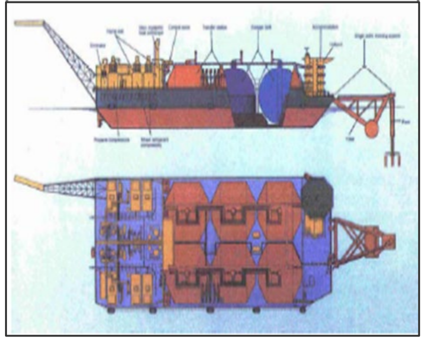
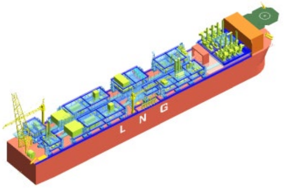
DNV GL AS

Development of **Rules for Barge Mounted LNG Plant**

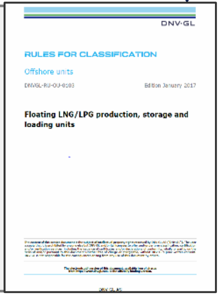



Spadeadam test facility



Guidelines and criteria for floating LNG FPSO and terminals

Latest revision of FLNG rules


DNV·GL

RULES FOR CLASSIFICATION

Offshore units

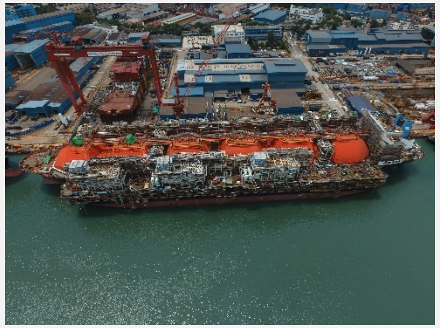
DNVGL-RU-OU-0103 Edition January 2017

Floating LNG/LPG production, storage and loading units

DNV GL AS

First newbuild FLNG – DNVGL classed *PFLNG Satu*

First conversion FLNG – DNVGL classed *Golar Hilli*



DNV GL Engagement with Floating LNG Projects

<table>
<tr><th></th><th>Strategy</th><th>Feasibility</th><th>Concept / preFEED</th><th>FEED</th><th>EPCI</th><th>Installation & Commissioning</th><th>Operations & Life Extension</th><th>Decommissioning</th></tr>
<tr><td rowspan="13">Consultancy</td><td colspan="8">Environmental impact assessment</td></tr>
<tr><td colspan="8">Safety risk management (Hazid, Hazop, QRA, safety case)</td></tr>
<tr><td></td><td></td><td colspan="4">Project risk management</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Due Diligence</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Technology qualification</td><td></td><td></td><td></td></tr>
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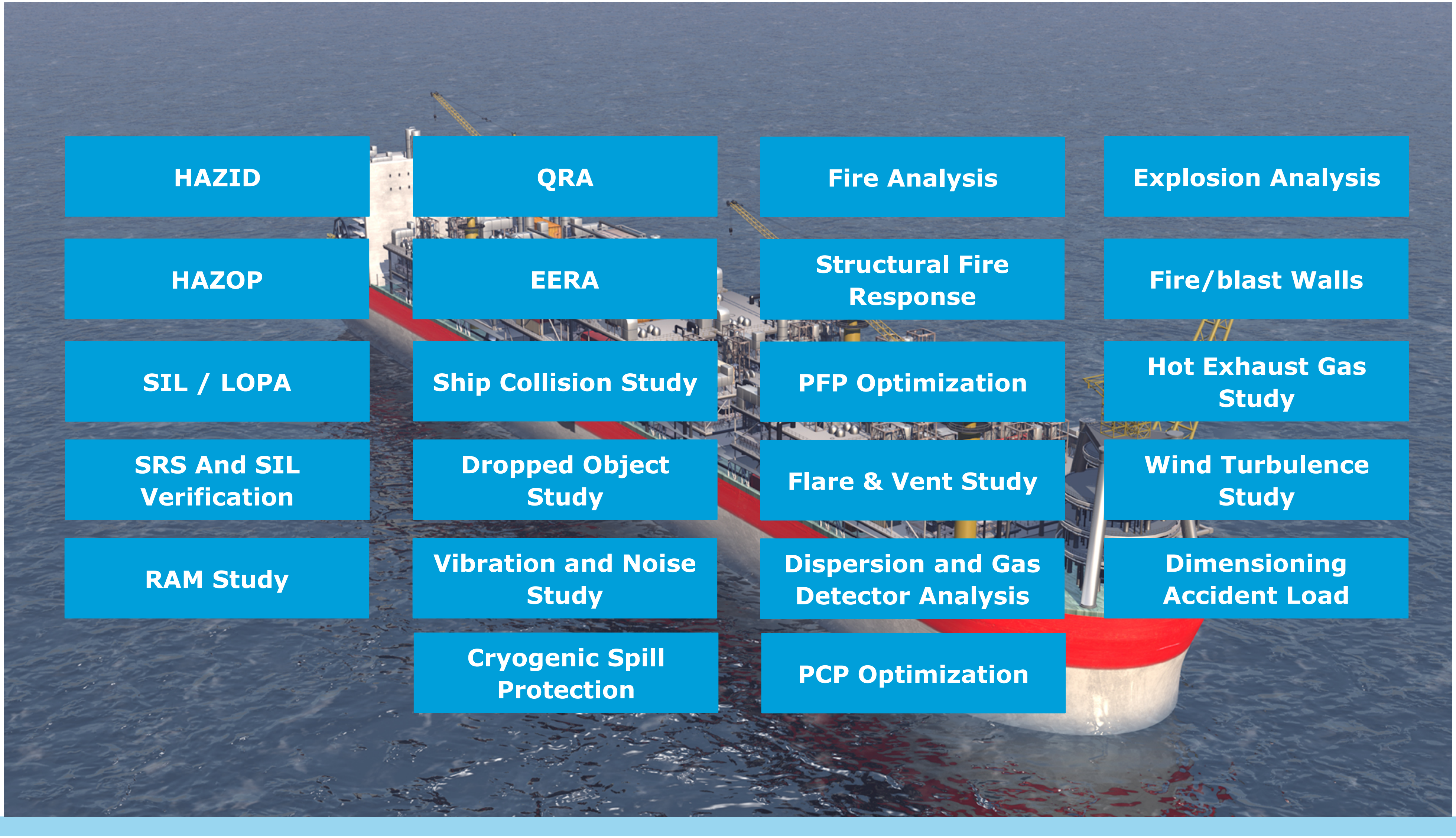
<tr><td></td><td></td><td colspan="2">RAM</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Concept/pre FEED Studies</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>Debottle.</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>AIM</td><td></td></tr>
</table>

<table>
<tr><td rowspan="2">Regulatory Compliance</td><td colspan="4">Validation/Verification/Certification</td></tr>
<tr><td></td><td>AiP</td><td>Classification</td><td></td></tr>
</table>

FLNG Safety Studies



- HAZID
- HAZOP
- SIL / LOPA
- SRS And SIL Verification
- RAM Study
- QRA
- EERA
- Ship Collision Study
- Dropped Object Study
- Vibration and Noise Study
- Cryogenic Spill Protection
- Fire Analysis
- Structural Fire Response
- PFP Optimization
- Flare & Vent Study
- Dispersion and Gas Detector Analysis
- PCP Optimization
- Explosion Analysis
- Fire/blast Walls
- Hot Exhaust Gas Study
- Wind Turbulence Study
- Dimensioning Accident Load

The First Wave

						
Petronas FLNG-1 *Malaysia*	*Shell Prelude FLNG* *Australia*	*Petronas FLNG-2* *Malaysia*	*ENI Coral FLNG* *Mozambique*	*Exmar FLNG barge* *YPF Argentina* *(small-scale: costs > 500 $/t)*	*Golar Hilli Episeyo,* *Cameroon*	*BPK / Golar Gimi* *Mauritania/Senegal*
🟦	🟦	🟨	🟩	🟦	🟦	🟩
1.2 MTPA	3.5 MTPA	1.5 MTPA	3.4 MTPA	0.5 MTPA	2.4 MTPA	2.45 MTPA

Source : Delfin

Capacity (Small/Medium/Large)

N2 cycles	1-2 mtpa
SMR	2-4 mtpa
DMR	3-5 mtpa
Tank volume	Determined by shuttle tanker

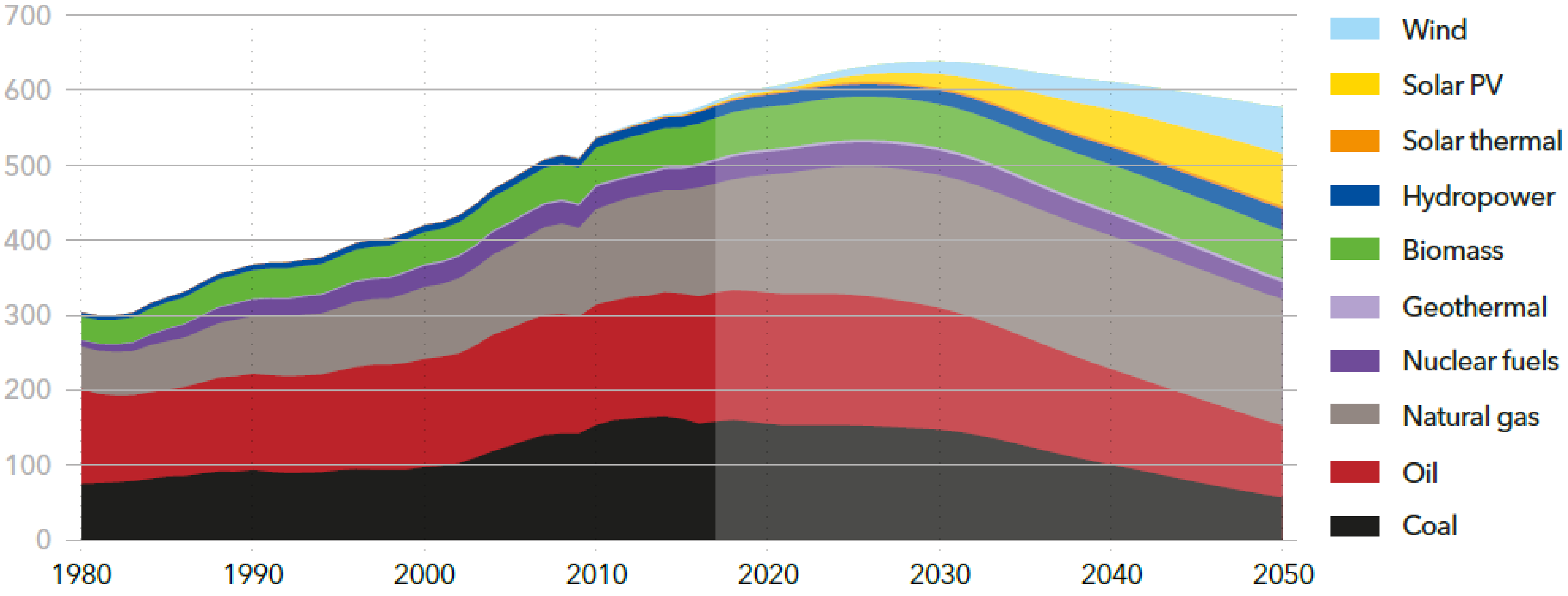
Waiting for the next wave………

Source of Energy (DNVGL Energy Transition Outlook)

FIGURE 2.2

World primary energy supply by source

Units: EJ/yr

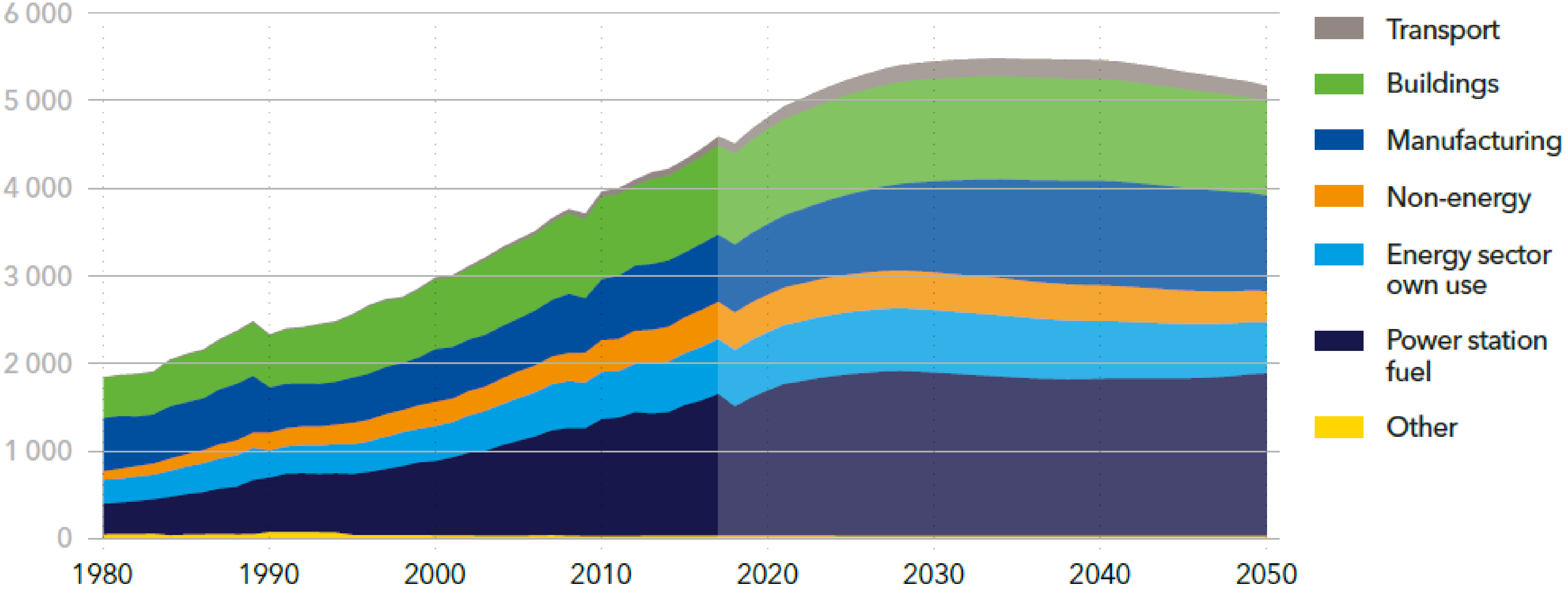


Historical data source: IEA WEB (2018)

Consumption of Natural Gas (DNVGL Energy Transition Outlook)

World natural gas demand by sector

Units: Gm³/yr



Includes natural gas liquids. Historical data source: IEA WEB (2018)

Source of Natural gas (DNVGL Energy Transition Outlook)

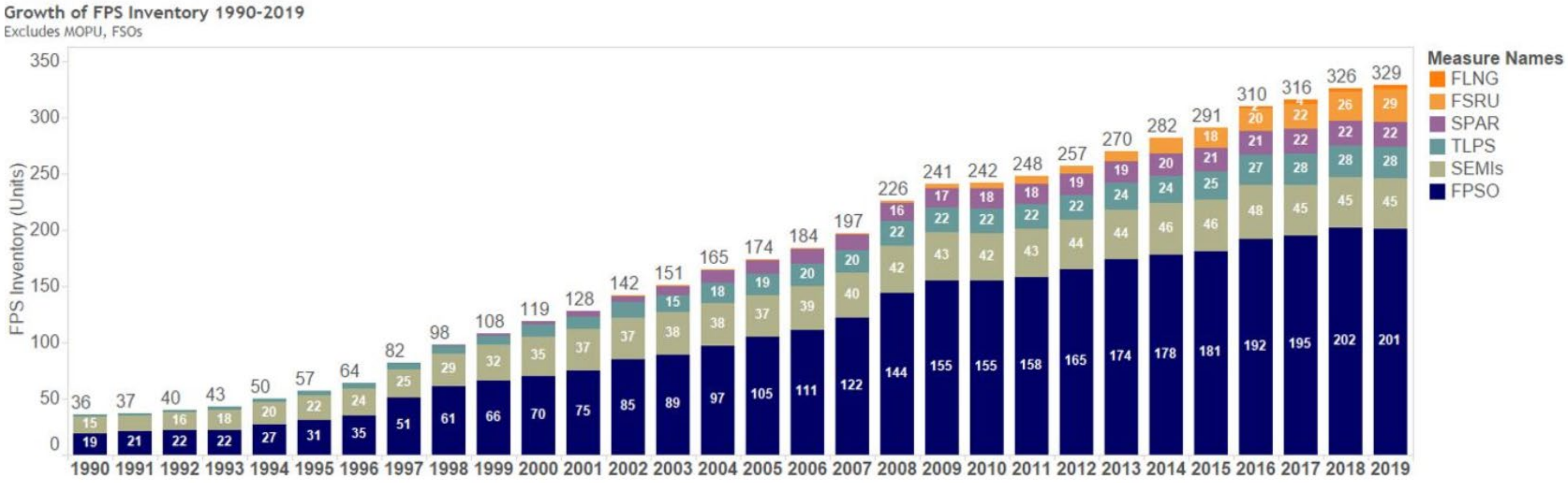
🟩 Conventional onshore

⬛ Unconventional onshore

🟦 Offshore

Floating Fleet 2020

Floating Production System Growth: FPSOs still Dominate



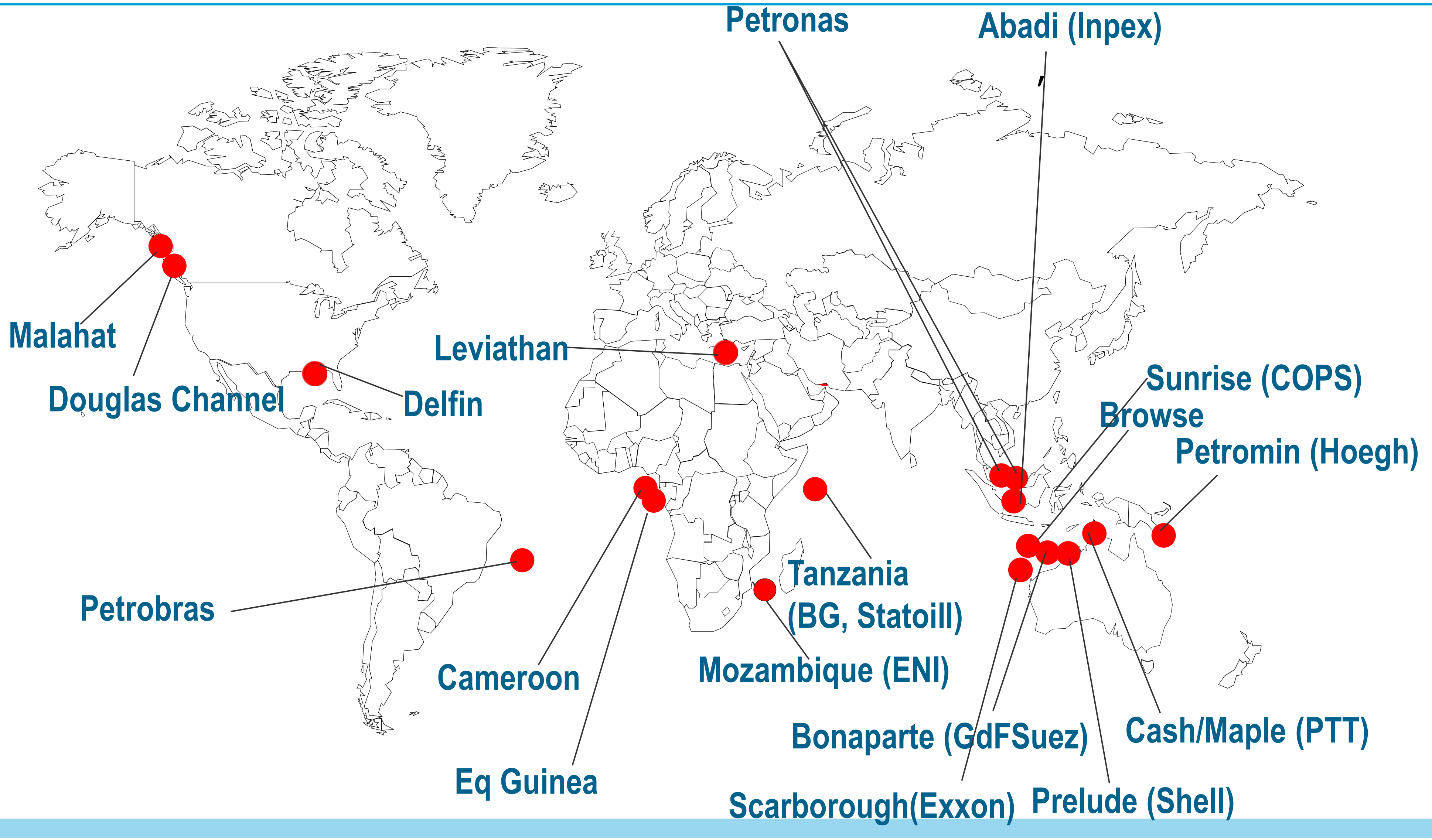
- ☐ FPSOs are the most successful FPS unit type, growing from 19 to 201 in 25+ years
- ☐ FSRUs in service have grown from 2 to 29 over past ten years, with 14 more on order

Offshore FPSO/FLNG

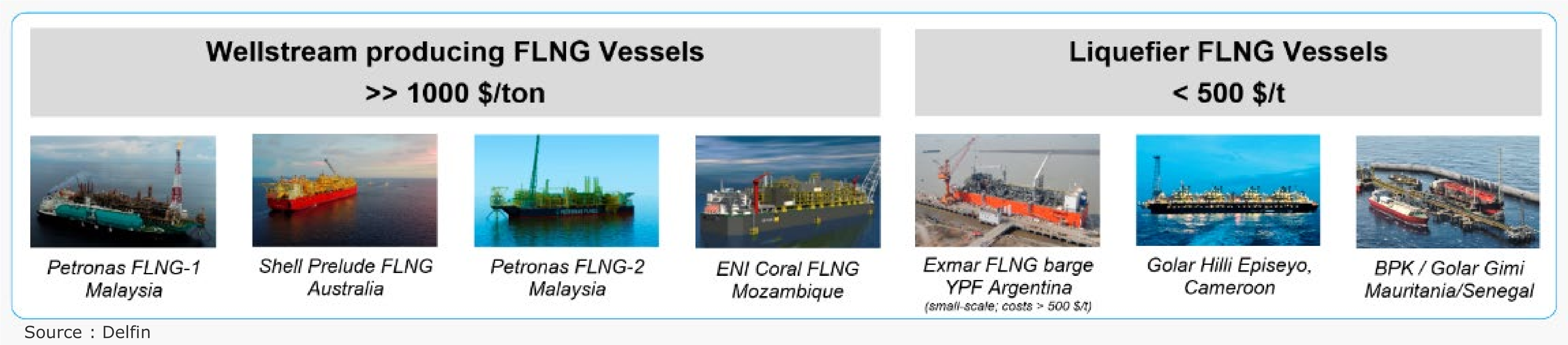
Ten Reasons to Choose FLNG

- Unlock smaller fields
- Access remote fields
- Avoid onshore “no go zones” (Israel)
- Reduce environmental footprint
- Faster and cheaper projects
- Avoid the “Gold Rush” effect !!!in remote areas
- Put projects in a “safe pair of hands”
- Peace of mind from security worries (but piracy and Israel!)
- Mitigate political risk (nationalisation)
- Financing options (leasing, tax)

Previously Suggested FLNG Projects (2015)



The First Wave



Wellstream producing FLNG Vessels
>> 1000 $/ton

Liquefier FLNG Vessels
< 500 $/t

Petronas FLNG-1 Malaysia

Shell Prelude FLNG Australia

Petronas FLNG-2 Malaysia

ENI Coral FLNG Mozambique

Exmar FLNG barge YPF Argentina
(small-scale; costs > 500 $/t)

Golar Hilli Episeyo, Cameroon

BPK / Golar Gimi Mauritania/Senegal

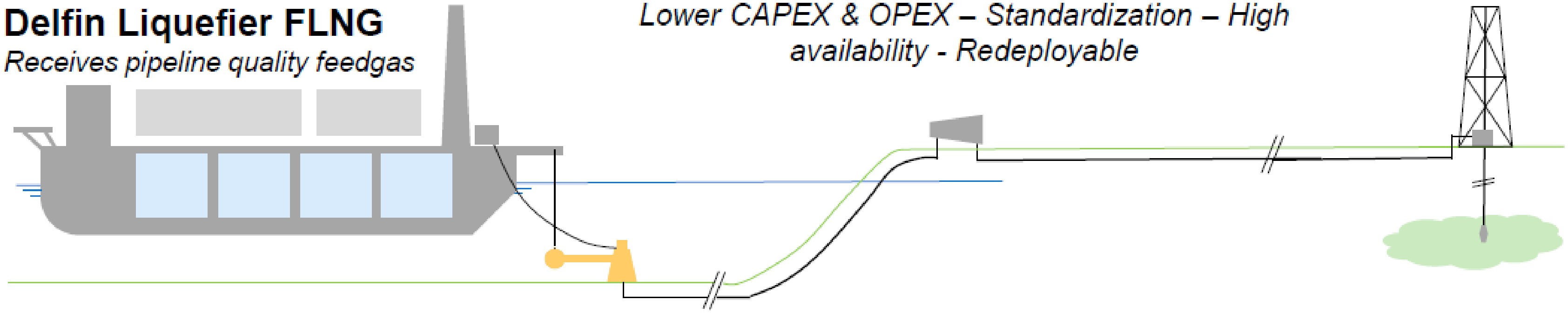
Source : Delfin

1.2 MTPA 3.5 MTPA 1.5 MTPA 3.4 MTPA 0.5 MTPA 2.4 MTPA 2.45 MTPA

Capacity (Small/Medium/Large)

N2 cycles	1-2 mtpa
SMR	2-4 mtpa
DMR	3-5 mtpa
Tank volume	Determined by shuttle tanker

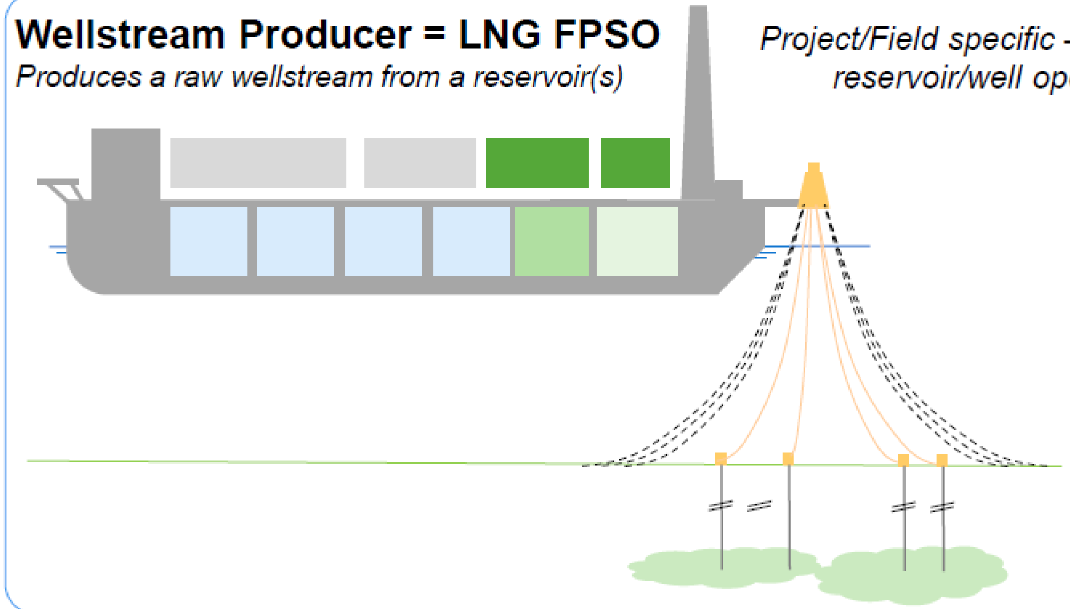
Liquefaction Vessel vs LNG FPSO



Delfin Liquefier FLNG

Receives pipeline quality feedgas

Lower CAPEX & OPEX – Standardization – High availability - Redeployable



Wellstream Producer = LNG FPSO

Produces a raw wellstream from a reservoir(s)

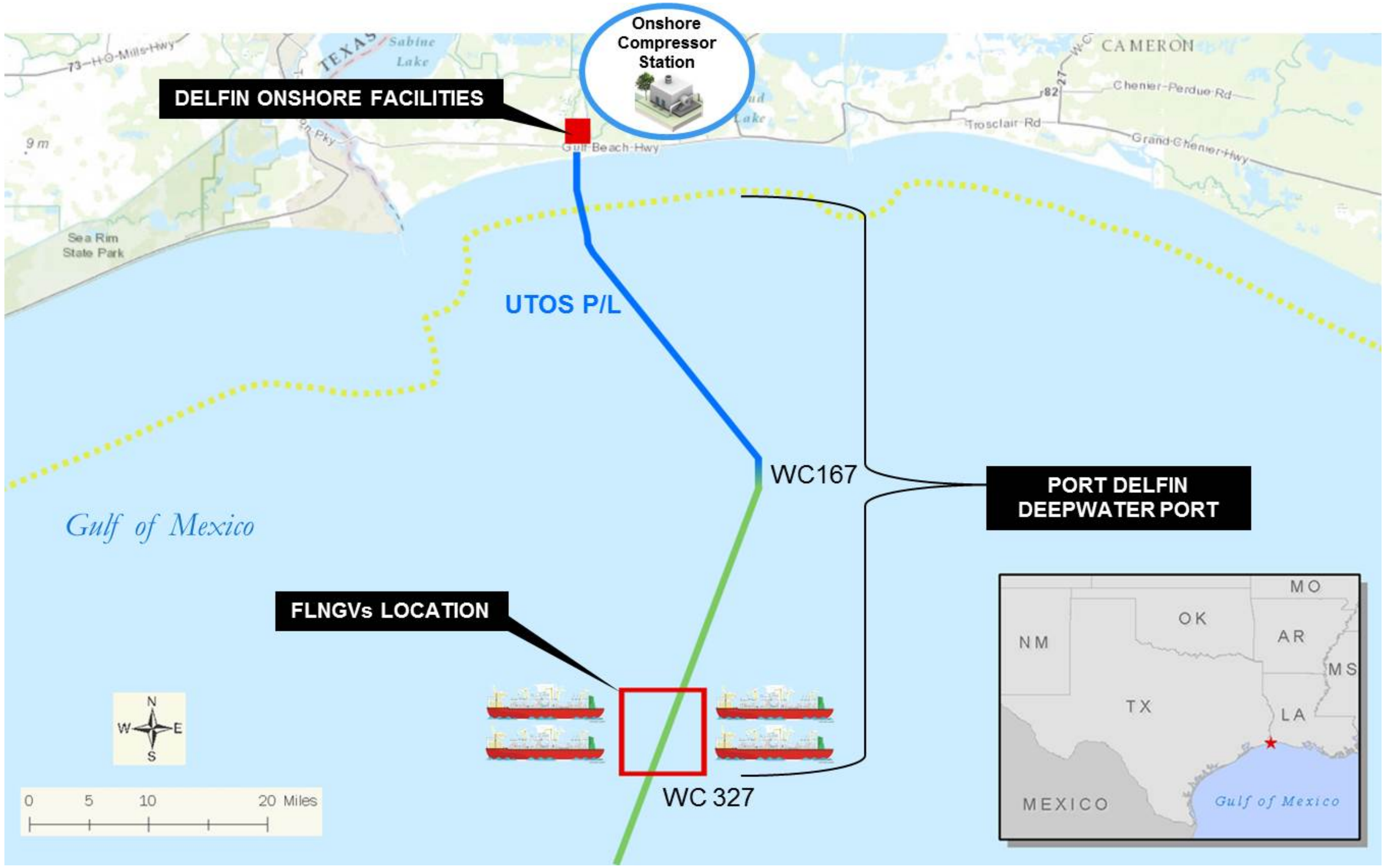
Project/Field specific – additional complex process systems - reservoir/well operations – higher CAPEX & OPEX

Typical additional features

- Reservoir, well and subsea controls
- Multiple risers and umbilical system
- Flow assurance systems
- Inlet separation and treatment (water, sand, impurities, liquids, etc.)
- Condensate / LPG separation, handling, storage and offloading
- Additional utility and support systems

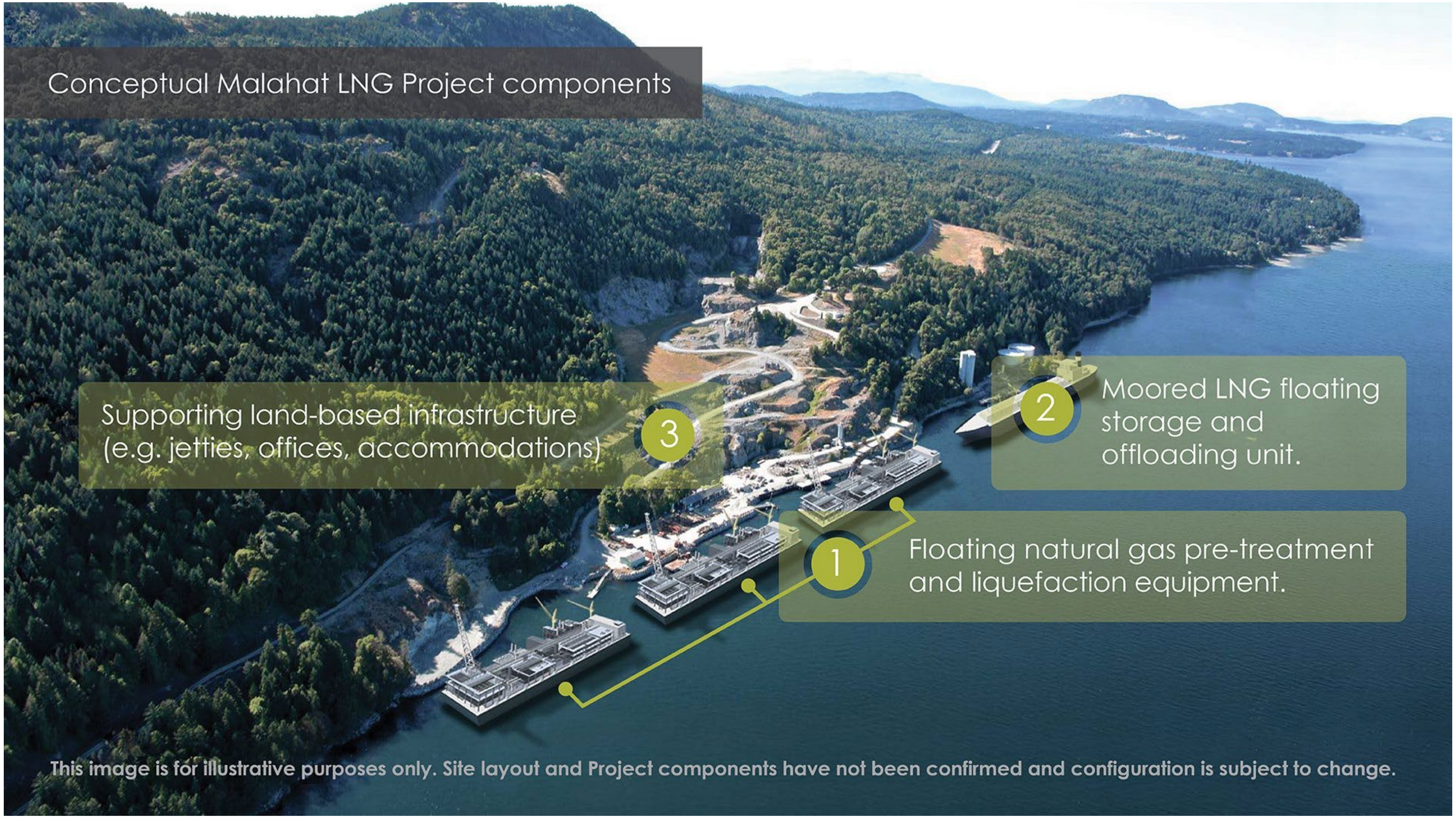
Courtesy Delfin

Delfin FLNG – US GoM



Lavaca FLNG – Tx – (Excelerate)

Kwispaa



Conceptual Malahat LNG Project components

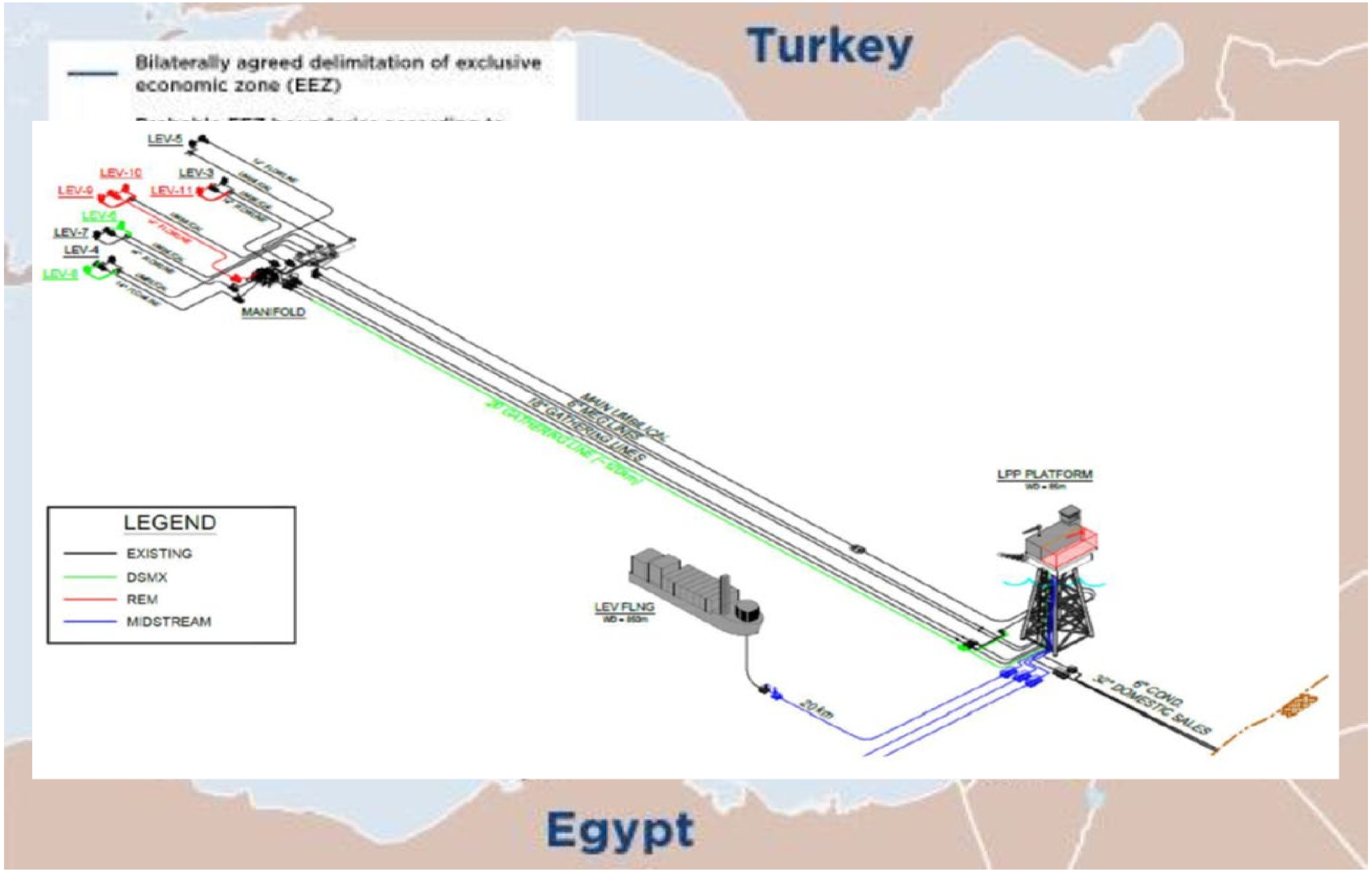
3 Supporting land-based infrastructure (e.g. jetties, offices, accommodations)

2 Moored LNG floating storage and offloading unit.

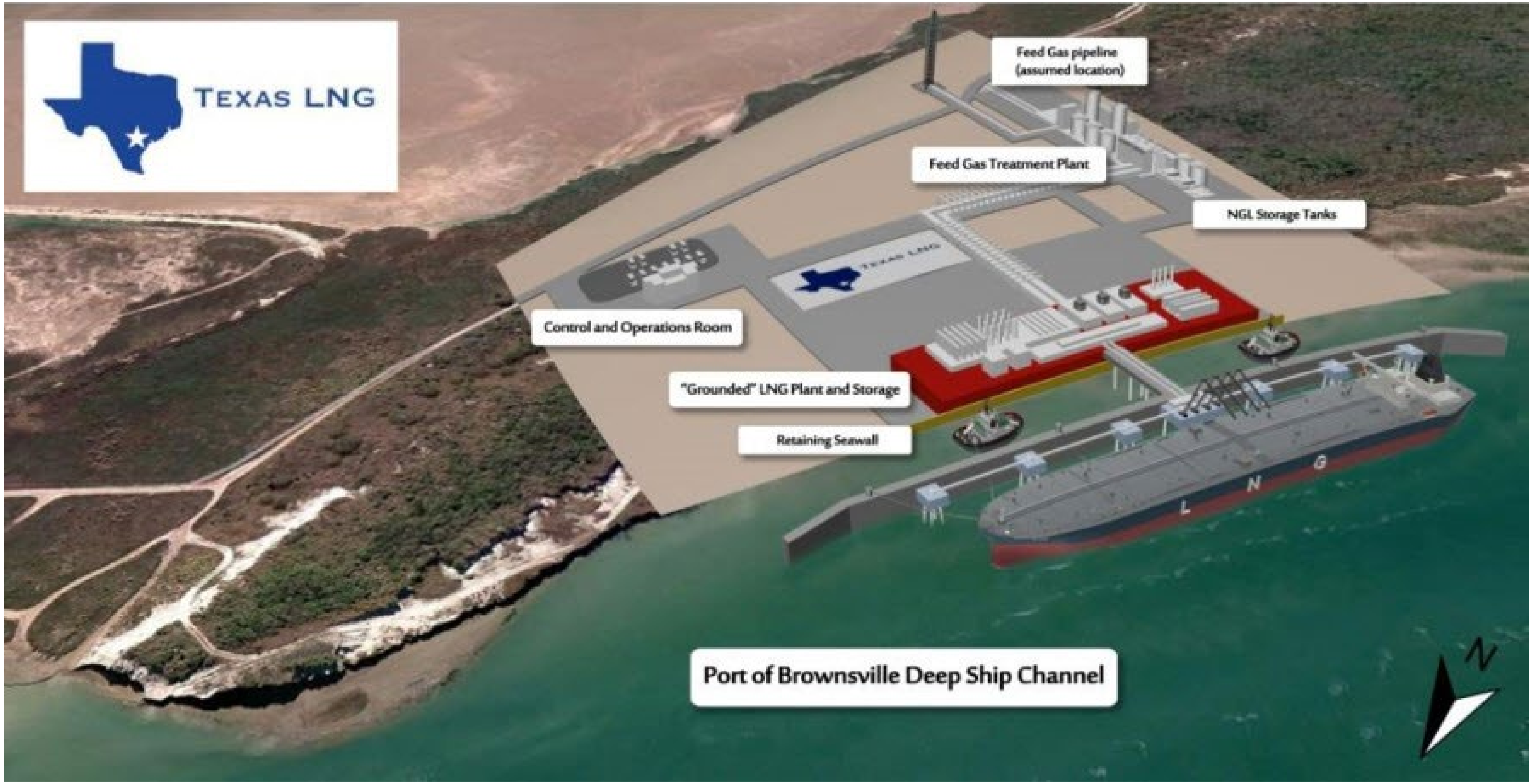
1 Floating natural gas pre-treatment and liquefaction equipment.

This image is for illustrative purposes only. Site layout and Project components have not been confirmed and configuration is subject to change.

East Mediterranean



Texas LNG(Brownsville)



Snøhvit /Hammerfest Norway

GBS LNG – floated into place

Factors affecting the next wave?

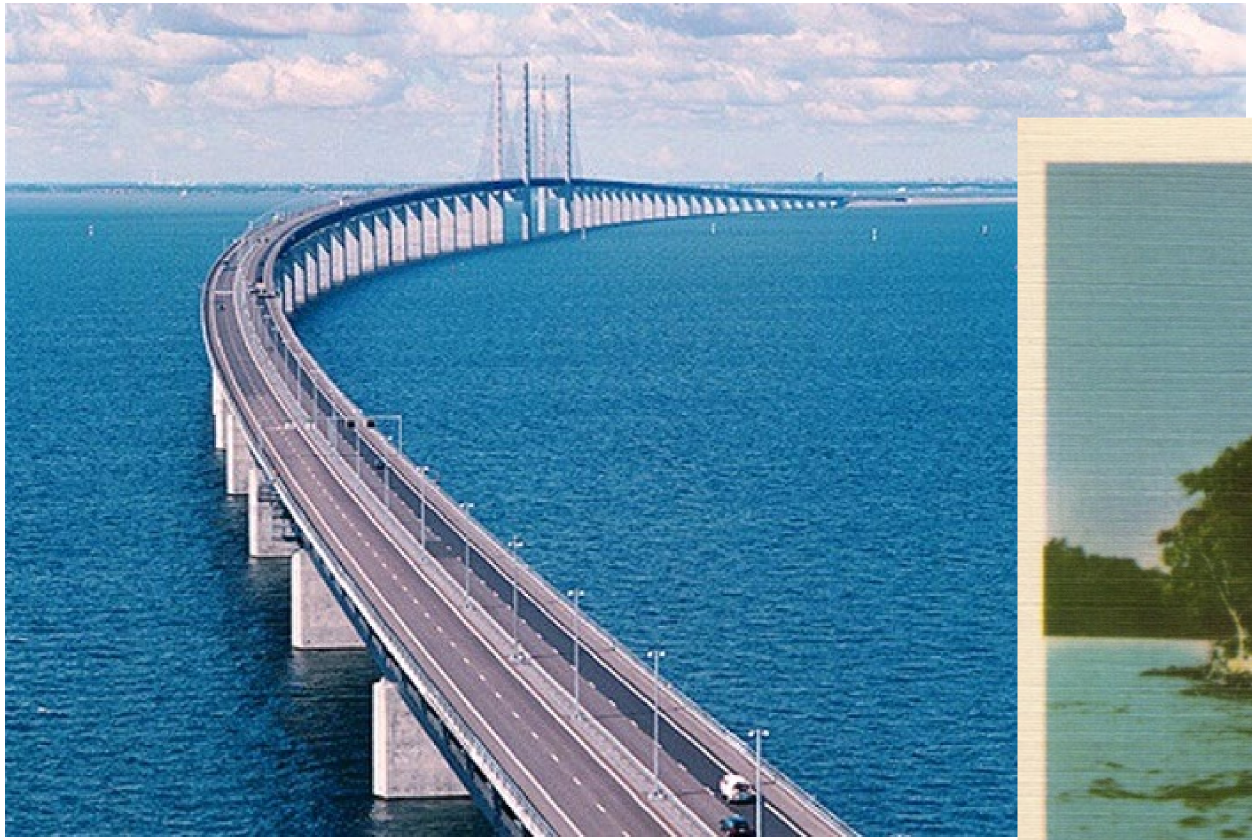
- Cost
  - Small scale?
  - From bottom line
  - Leasing
- Contracts
  - Long term
  - Spot market
- Competition
  - Pipelines
  - Qatar
  - National needs

- Local Content
  - Land-based vs FLNG

- Technology
  - Harsh vs Benign
  - Transfer to carrier

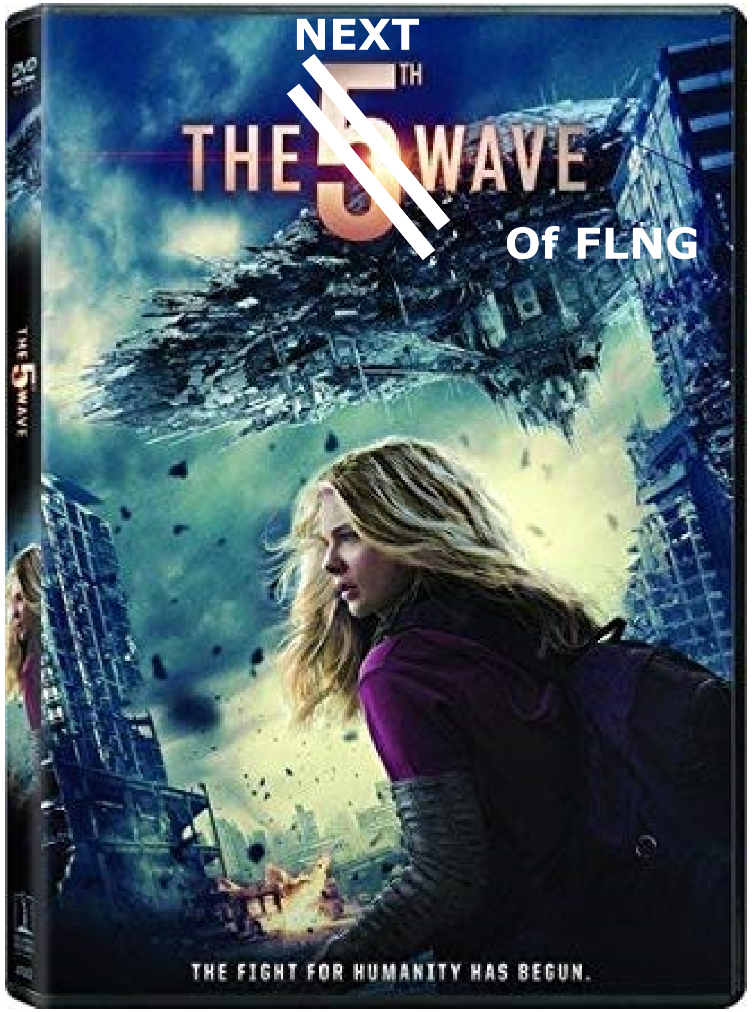
- Environmental opposition

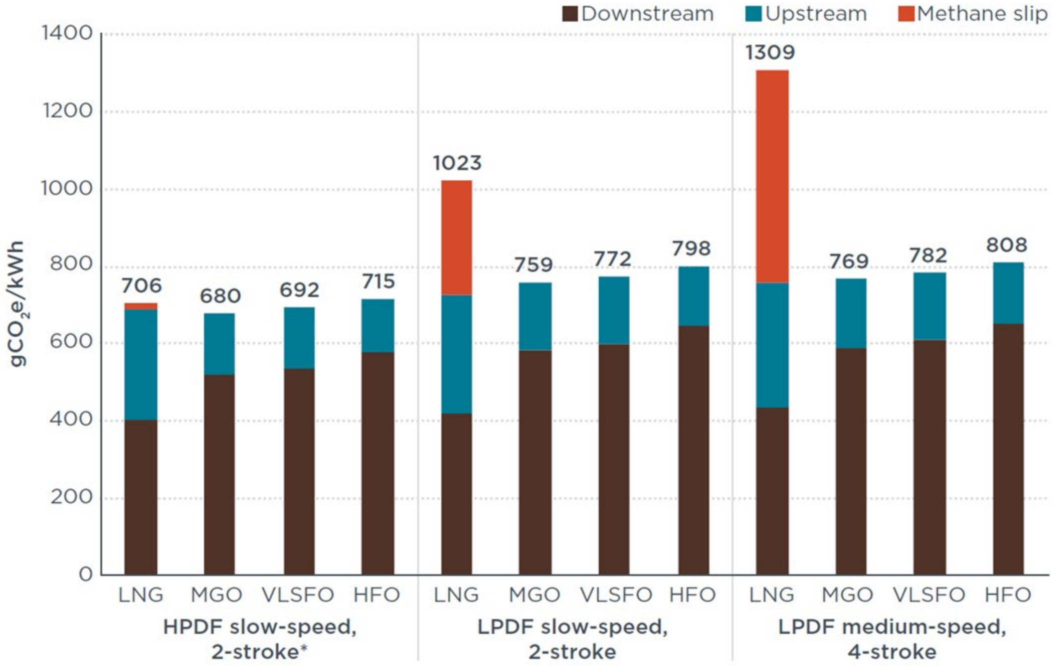
Gas as a bridging fuel



SMALLEST INTERNATIONAL BRIDGE IN THE WORLD, THOUSAND ISLANDS, ONTARIO, CANADA 3

LNG and Climate





*SSD has similar life-cycle emissions as HPDF for conventional fuels.

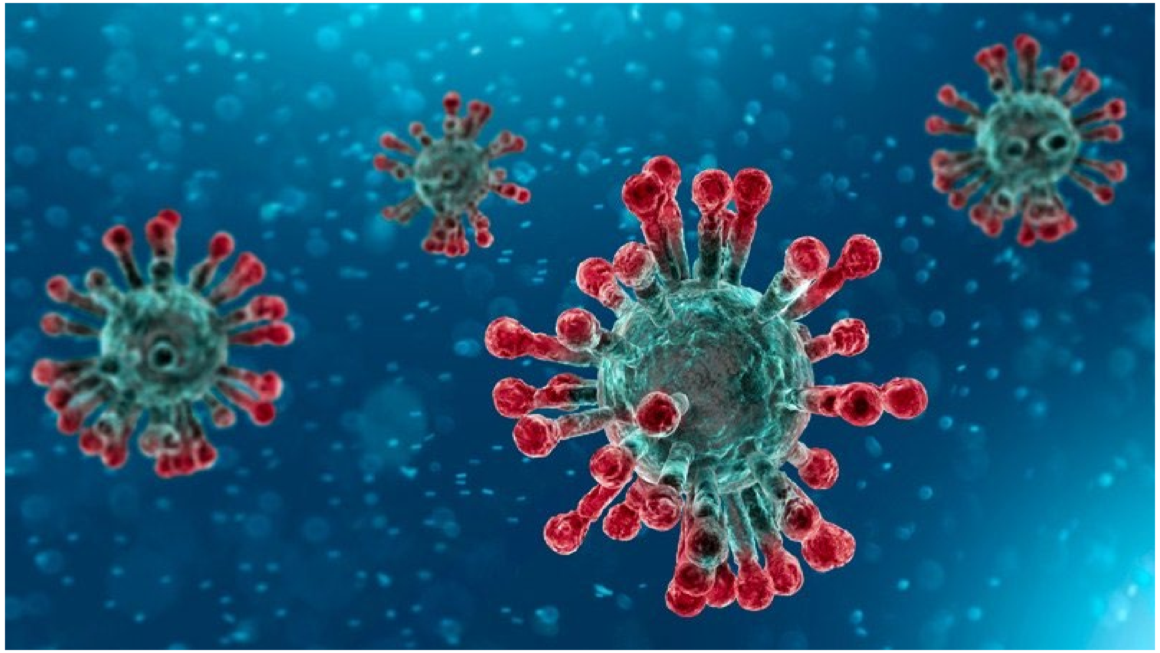
Figure 8. Life-cycle GHG emissions by engine and fuel type, 20-year GWP, higher methane scenario

WORKING PAPER 2020-02

Conclusions

" there are two types of forecasts … lucky or wrong!!!! "

- Competition from renewables
- Availability of easier land-based solutions
- Availability of finance
- Oversupply of gas
- Continued demand for gas



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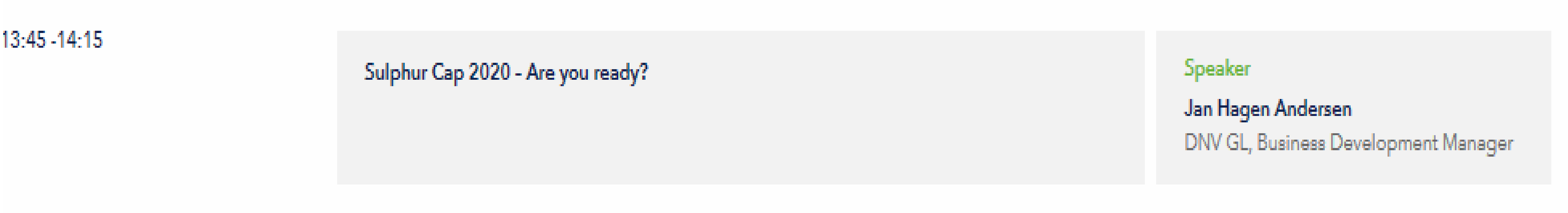
LNG Day Program Agenda



13:45 -14:15

Sulphur Cap 2020 - Are you ready?

Speaker

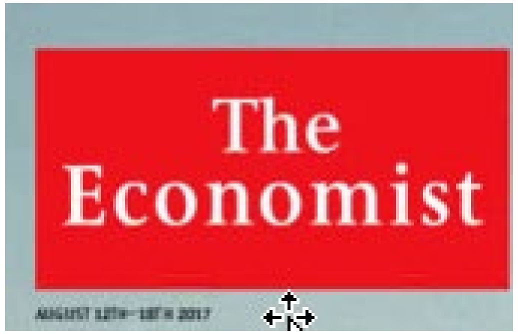
Jan Hagen Andersen

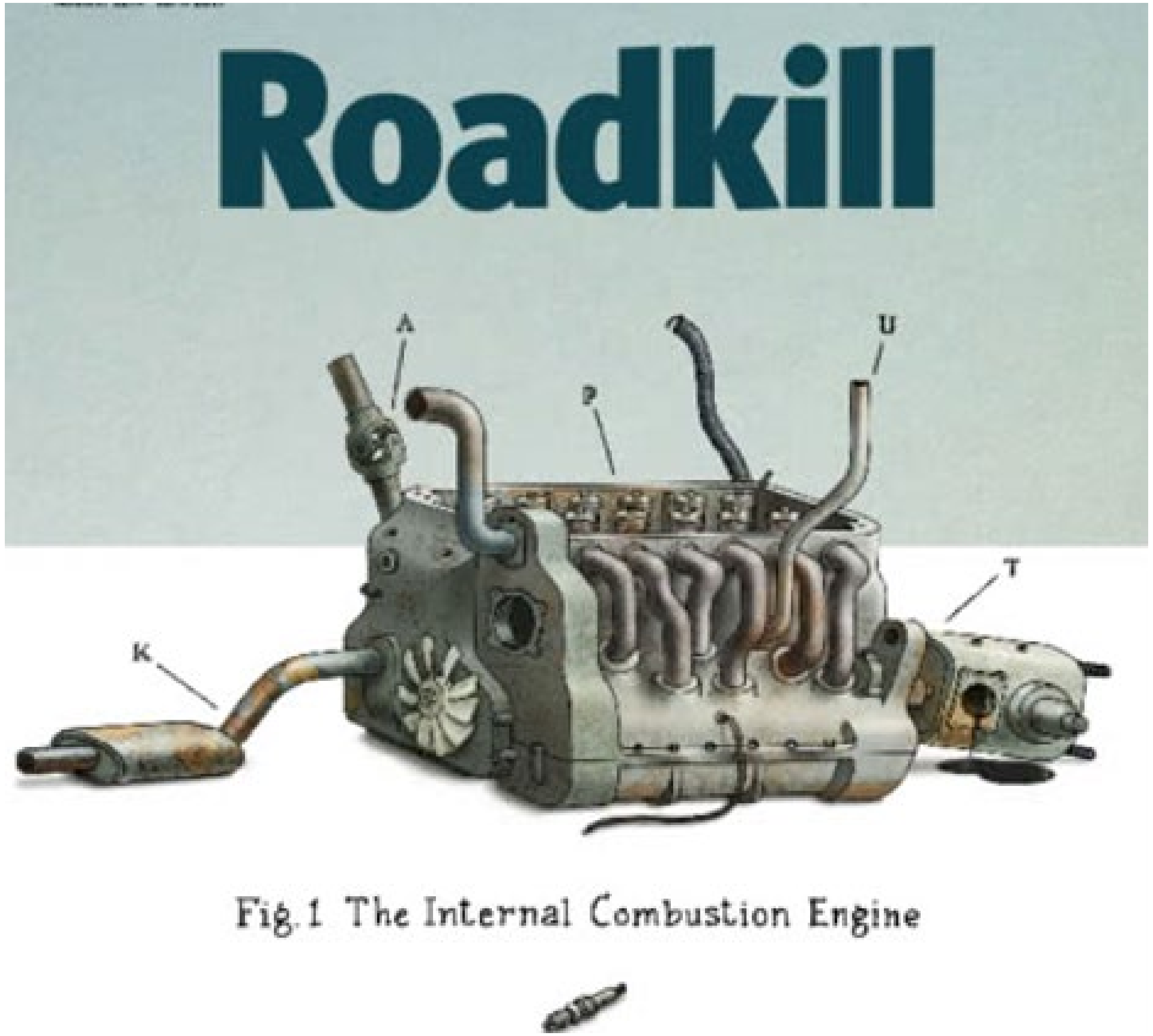
DNV GL, Business Development Manager

THE MARITIME INDUSTRY ADJUSTING TO THE SULPHUR CAP 2020

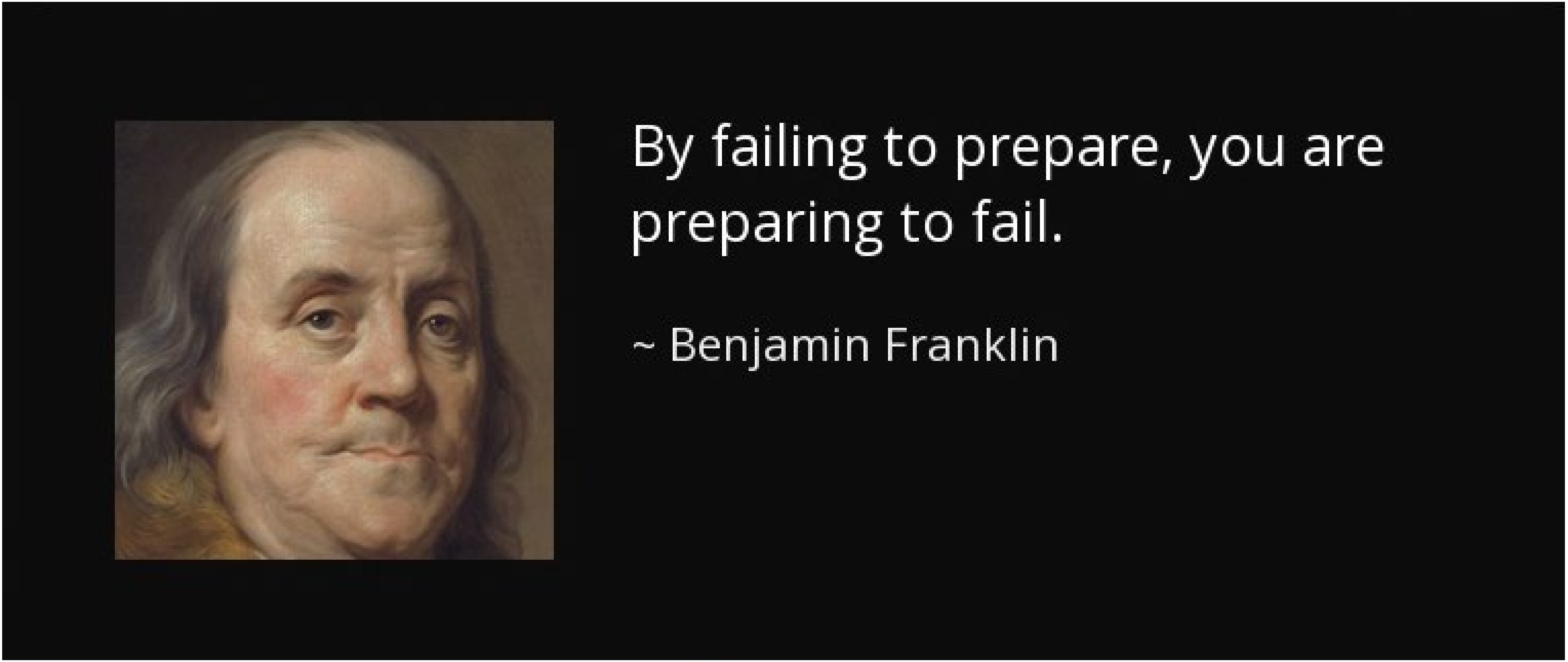
Jan Hagen Andersen, P.E., Business Development, DNV GL – Maritime Americas

The perception of the future…





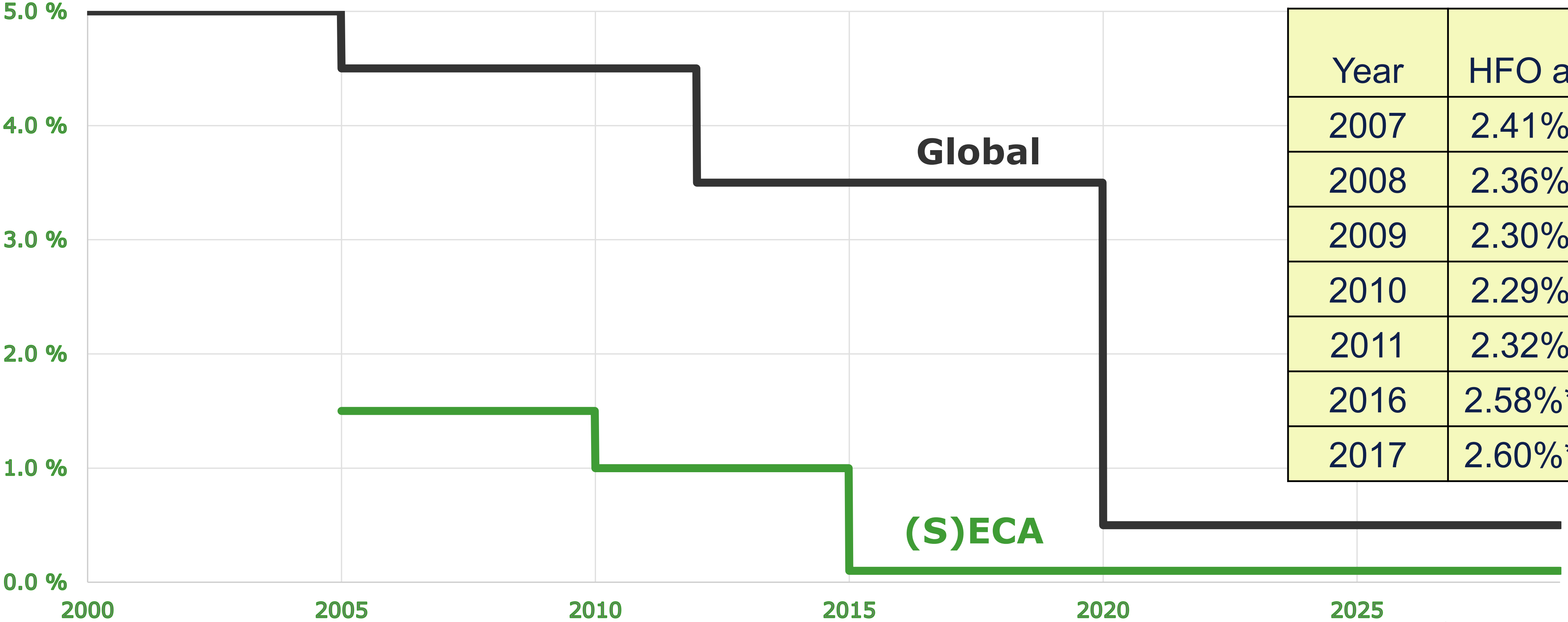
Overview & regulatory developments



By failing to prepare, you are preparing to fail.

~ Benjamin Franklin

Sulphur Level



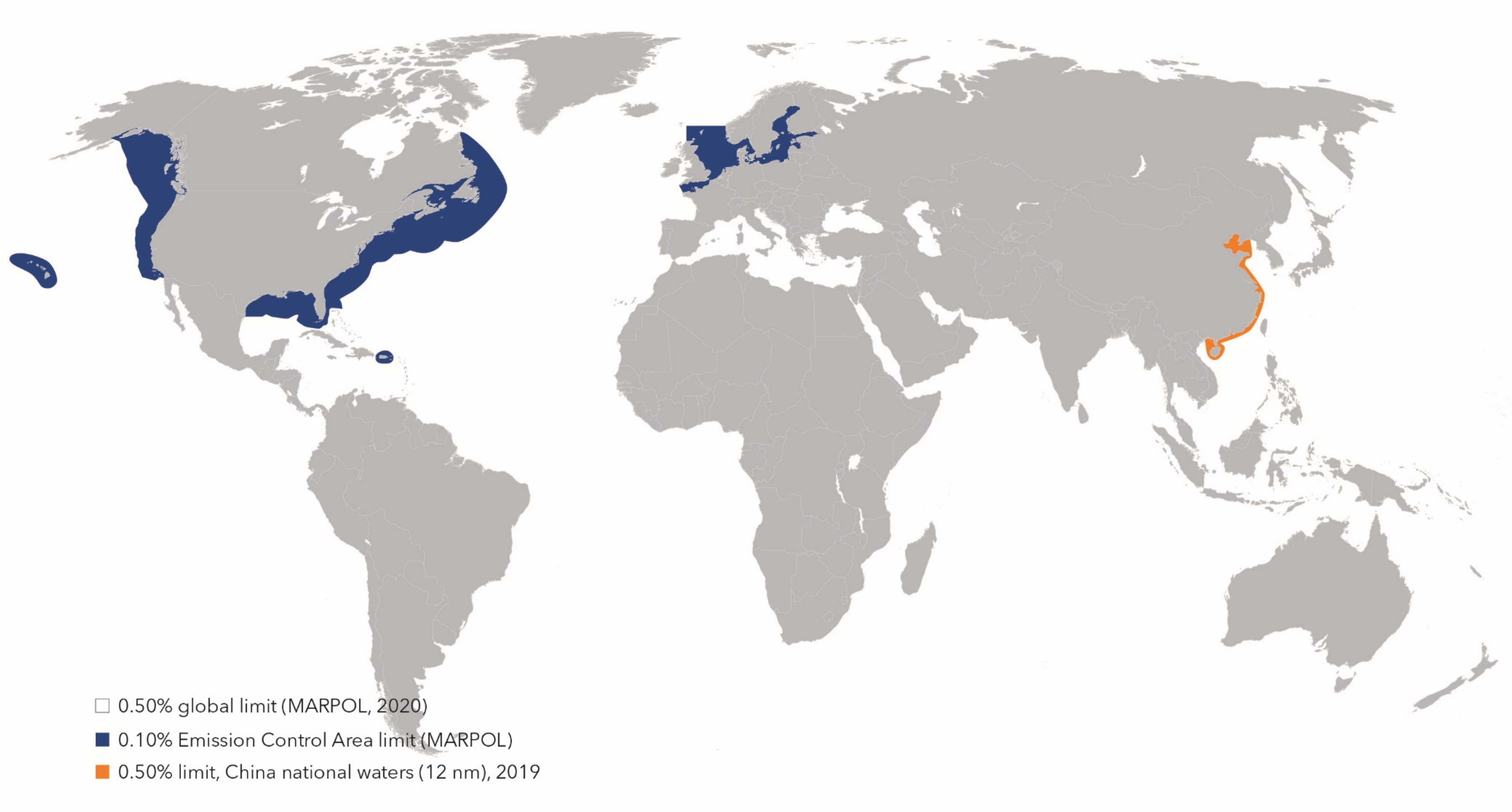
Global HFO Average

Year	HFO all
2007	2.41%*
2008	2.36%*
2009	2.30%*
2010	2.29%*
2011	2.32%*
2016	2.58%**
2017	2.60%**

* Source: DNVPS

** Source: IBIA

Global sulphur cap 2020 overview

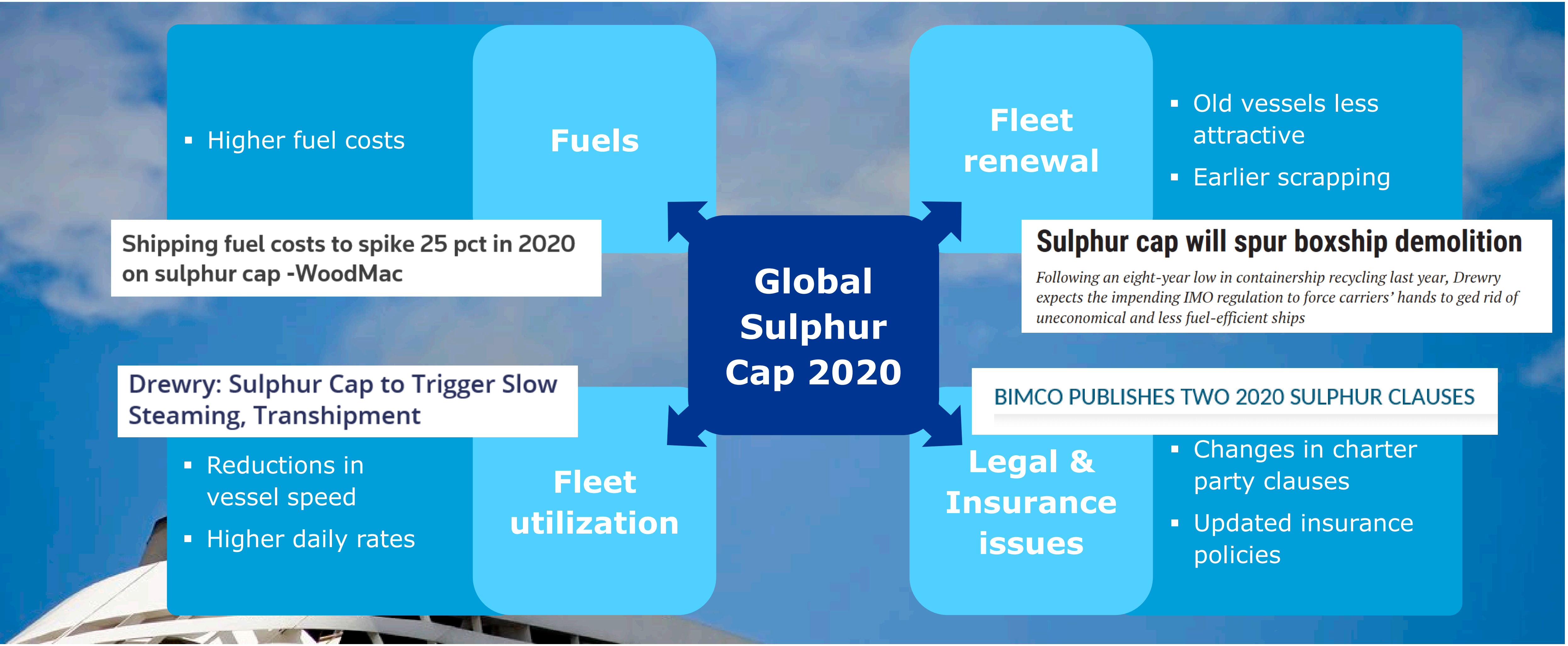


☐ 0.50% global limit (MARPOL, 2020)
■ 0.10% Emission Control Area limit (MARPOL)
🟧 0.50% limit, China national waters (12 nm), 2019

Ratification of MARPOL Annex VI – what will happen in unratified ports?

Source: Skuld

Global Sulphur Cap implications for the entire shipping industry



Global Sulphur Cap 2020

Fuels

- Higher fuel costs

Shipping fuel costs to spike 25 pct in 2020 on sulphur cap -WoodMac

Fleet renewal

- Old vessels less attractive
- Earlier scrapping

Sulphur cap will spur boxship demolition

Following an eight-year low in containership recycling last year, Drewry expects the impending IMO regulation to force carriers' hands to ged rid of uneconomical and less fuel-efficient ships

Fleet utilization

Drewry: Sulphur Cap to Trigger Slow Steaming, Transhipment

- Reductions in vessel speed
- Higher daily rates

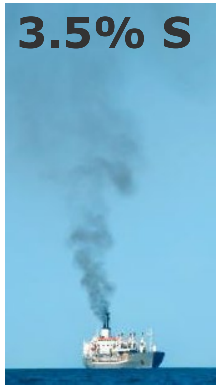
Legal & Insurance issues

BIMCO PUBLISHES TWO 2020 SULPHUR CLAUSES

- Changes in charter party clauses
- Updated insurance policies

What are the options?

2020-01-01



3.5% S

0.50% S

Compliance options:

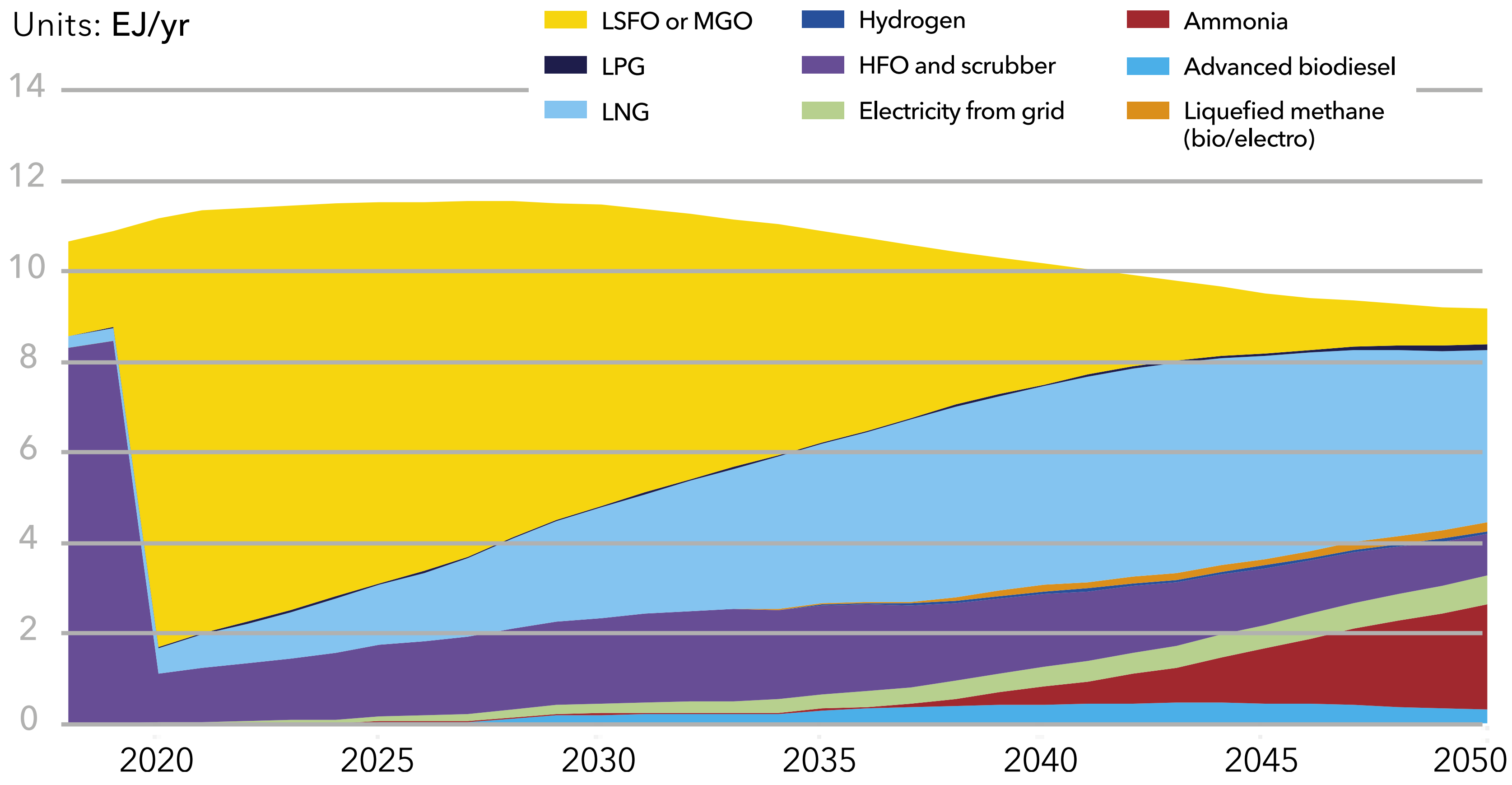
MGO
(<0.10% S)
MGO
(0.5% 2020)

ULSFO
(< 0.10% S)
VLSFO
(0.5% 2020)

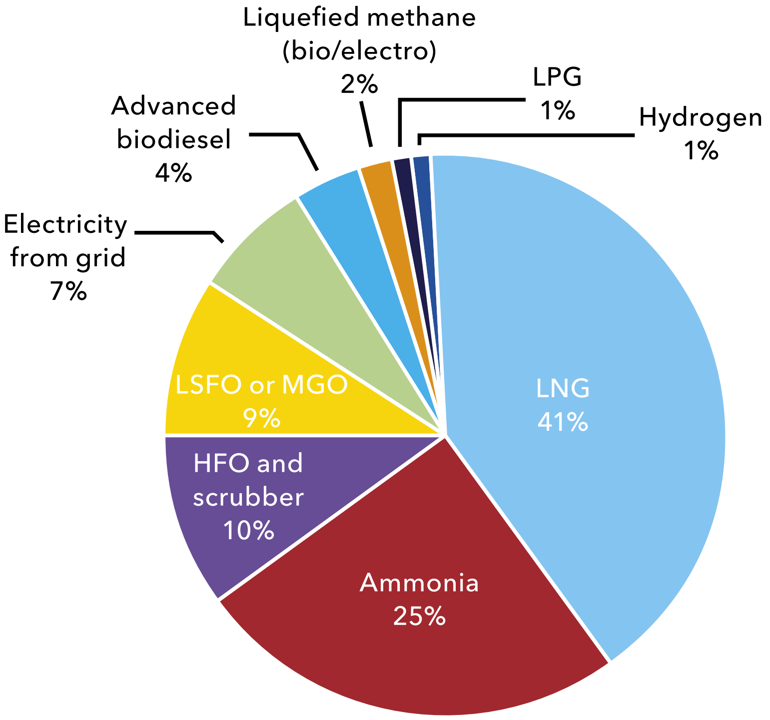
HSFO
+Scrubber

Alternative Fuels
(LNG, LPG, Methanol, etc)

Fuel mix towards 2050 in the ‘design requirements’ pathway



In 2050

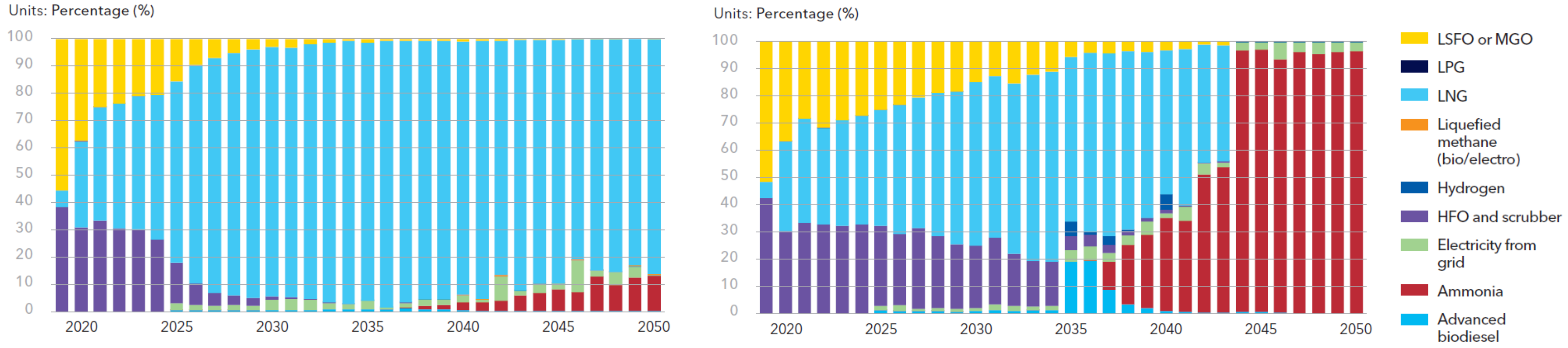


In all three pathways modelled, liquefied methane (both fossil and non-fossil) ends up dominating the fuel mix.

Several ways to meet the IMO targets – policy matters

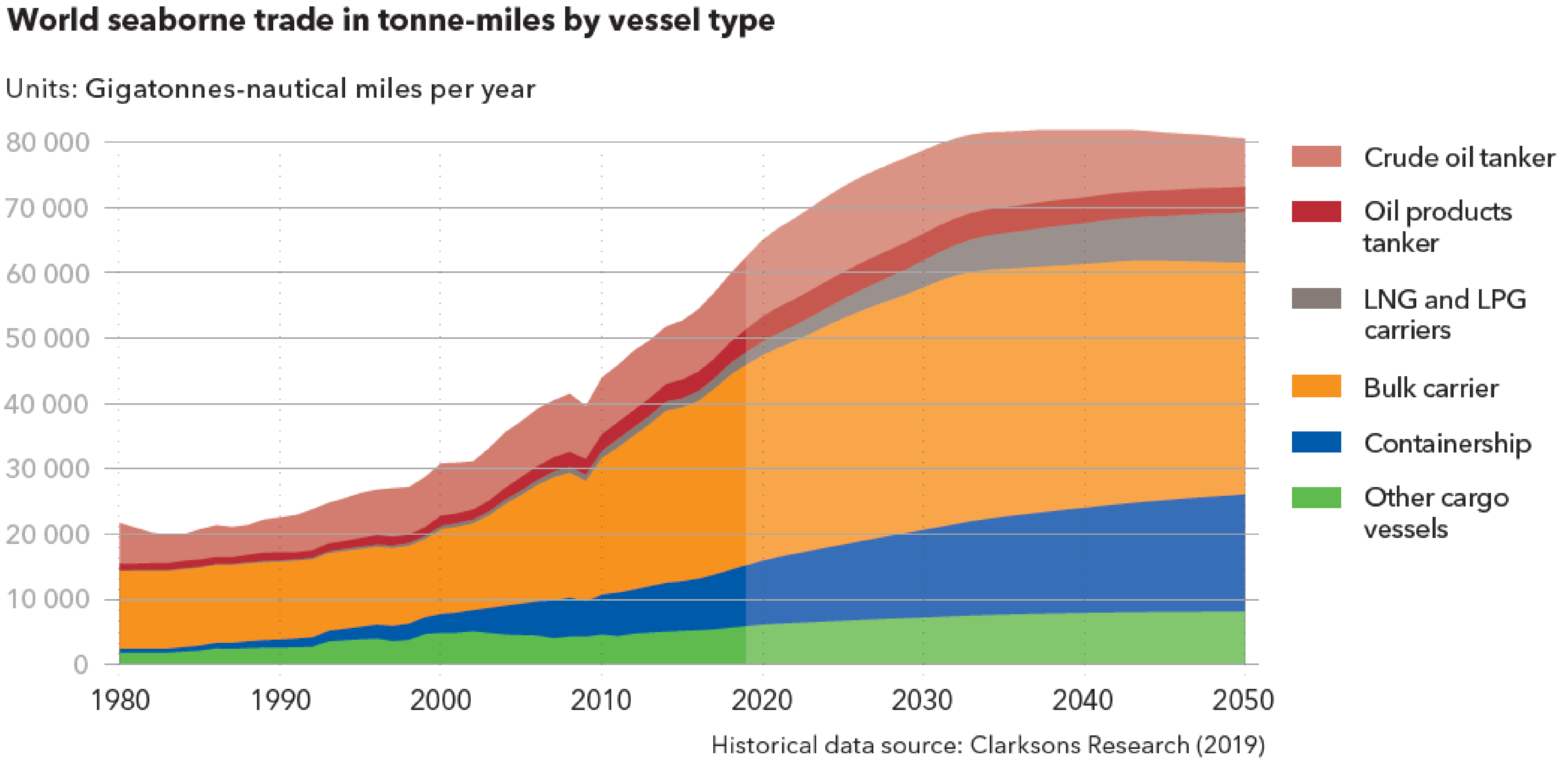
Focusing on **operational requirements**, the uptake of alternative fuel for newbuildings is more gradual

If main focus is on **design requirements**, the shift in fuel and fuel-converter technology on newbuildings is very abrupt



LNG play an important role – transition to carbon neutral fuels will be needed

Demand for seaborne transport will grow 39% by 2050



Historical data source: Clarksons Research (2019)

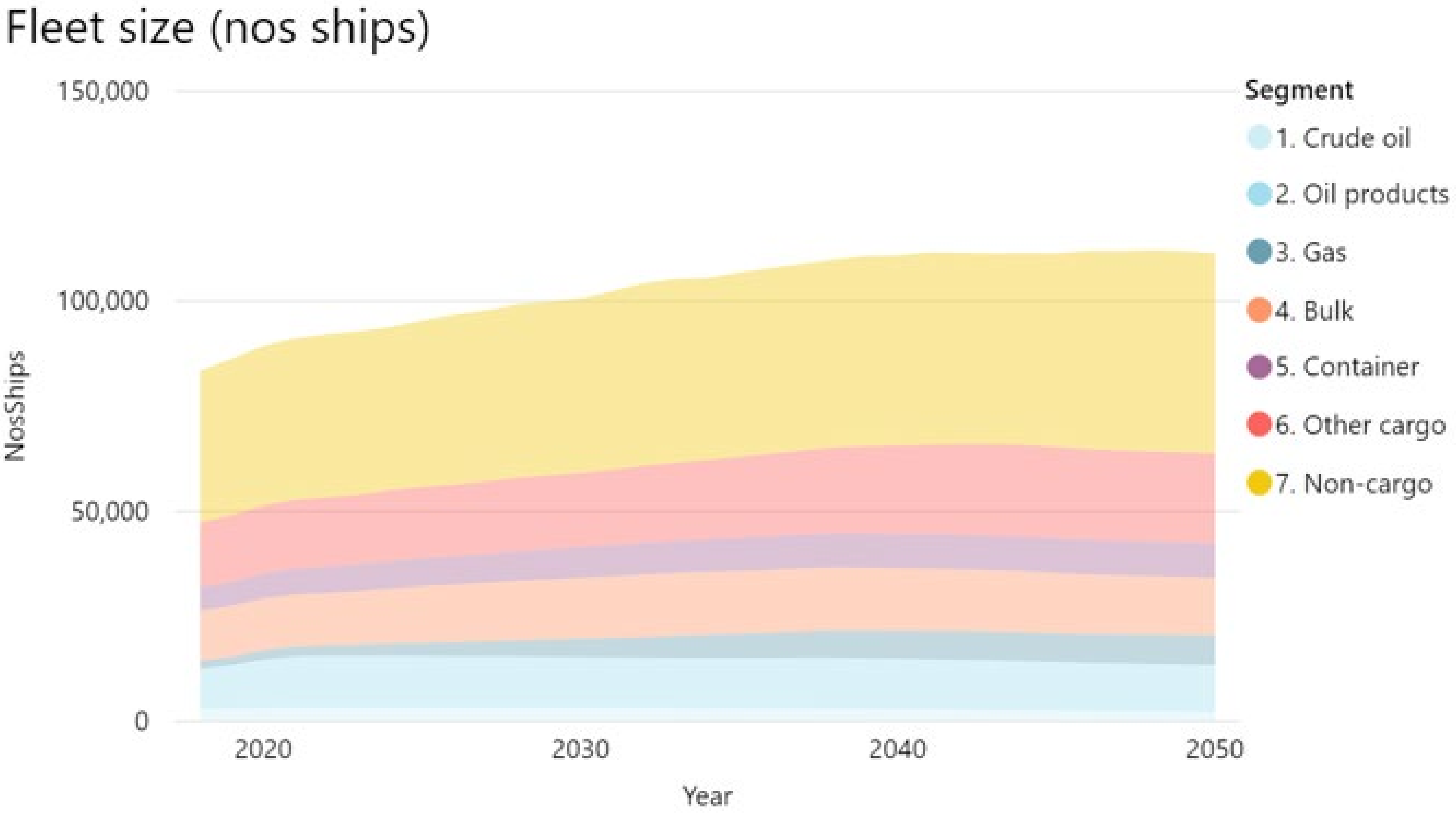
Average growth of 2.3%/yr to 2030, then 0.3%/yr towards 2050

Fleet growth per vessel segments

For LNG carriers;
2018 – 500+ ships

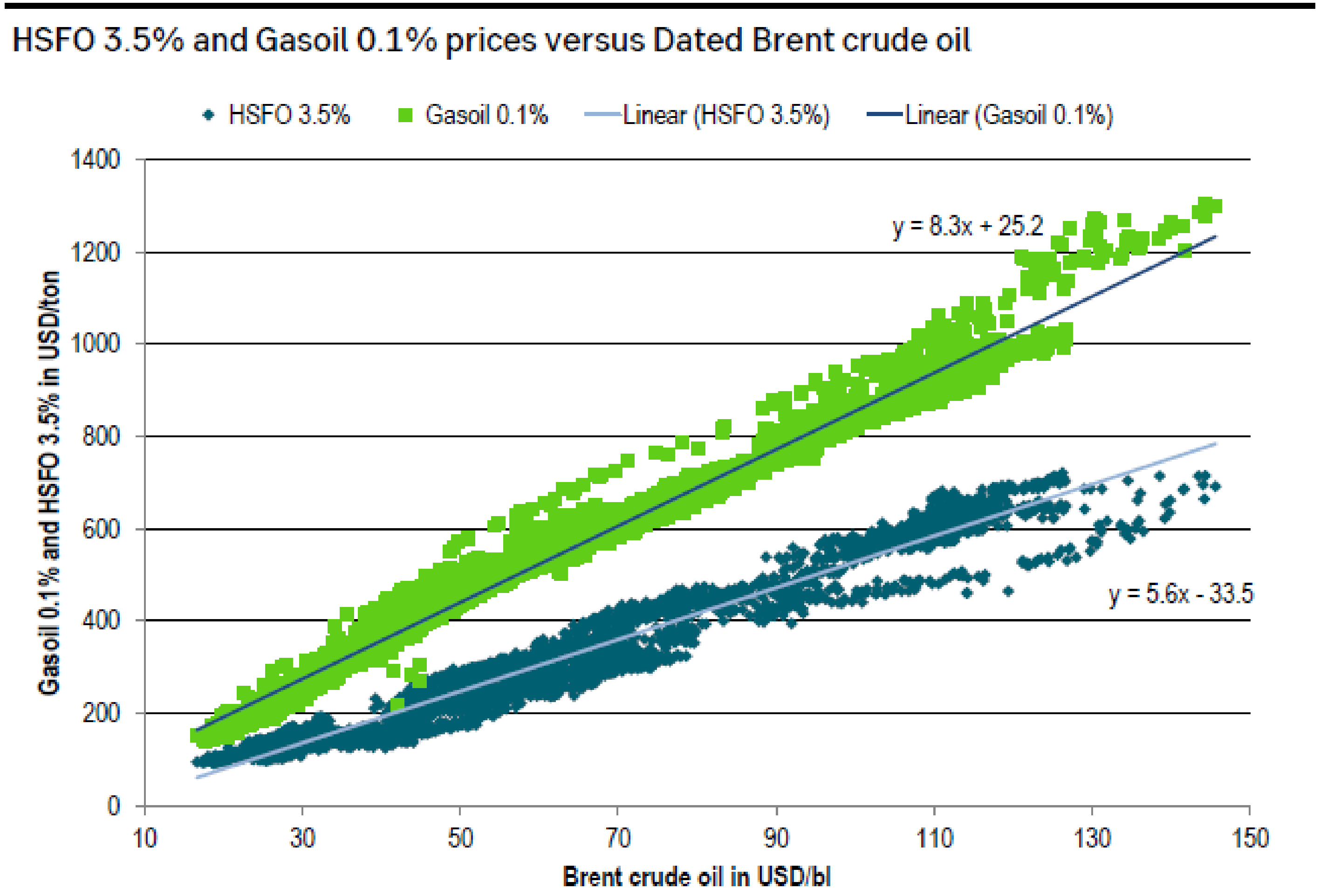
Double by 2030
Triple by early 2040s

High growth also for LPG



Availability, pricing?

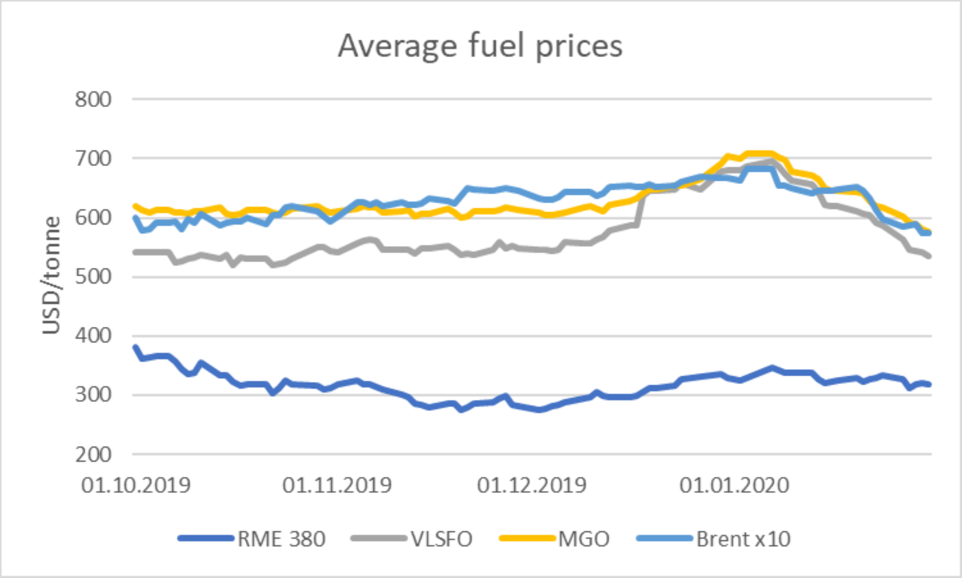
Impact of oil price on MGO-HSFO spread

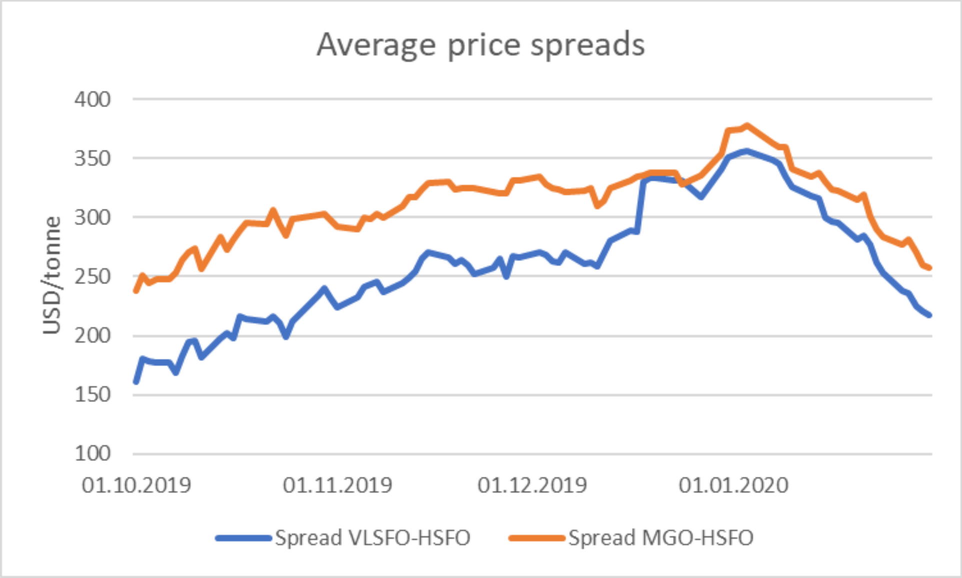


Source: SEB, Bloomberg

Latest fuel price developments

Updated: 31 January 2020



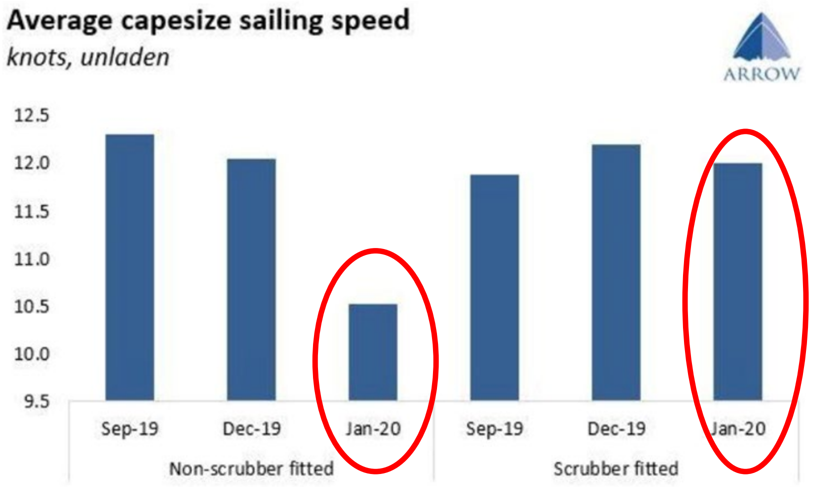


Fuel prices: Average of prices in Rotterdam, Singapore, Fujairah, Houston

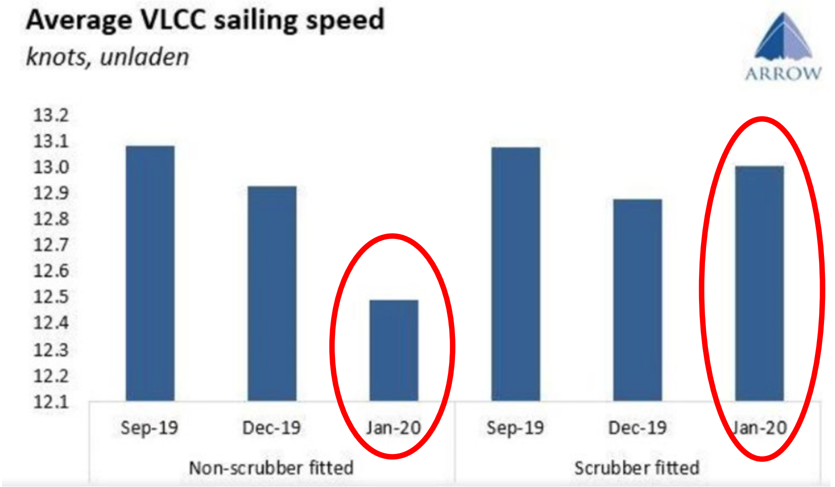
HSFO prices have declined since 1st October, while MGO remains at constant level; VLSO increased in December

Data Source: Prime’s Bunkersplus

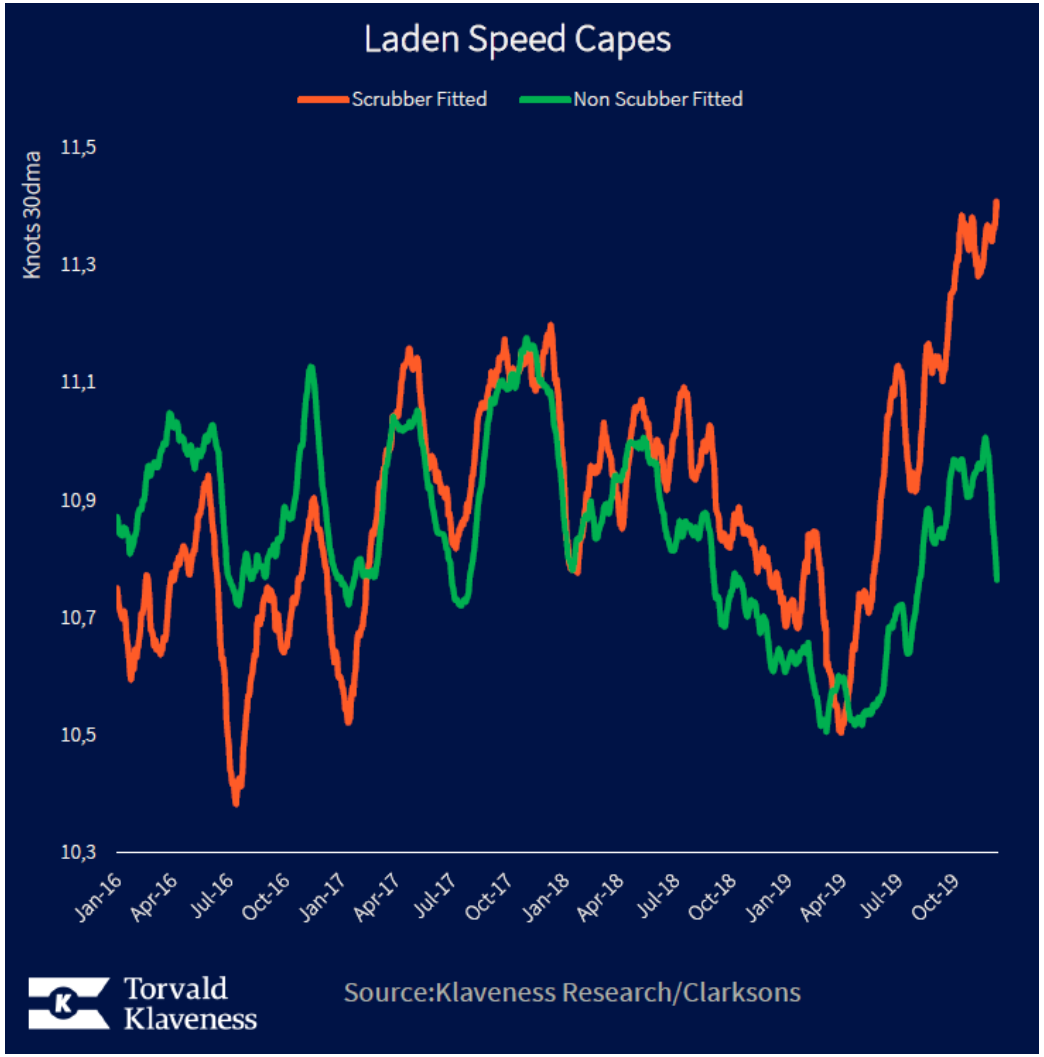
Vessels without scrubbers reducing speed


Average capesize sailing speed

knots, unladen


Average VLCC sailing speed

knots, unladen


Laden Speed Capes

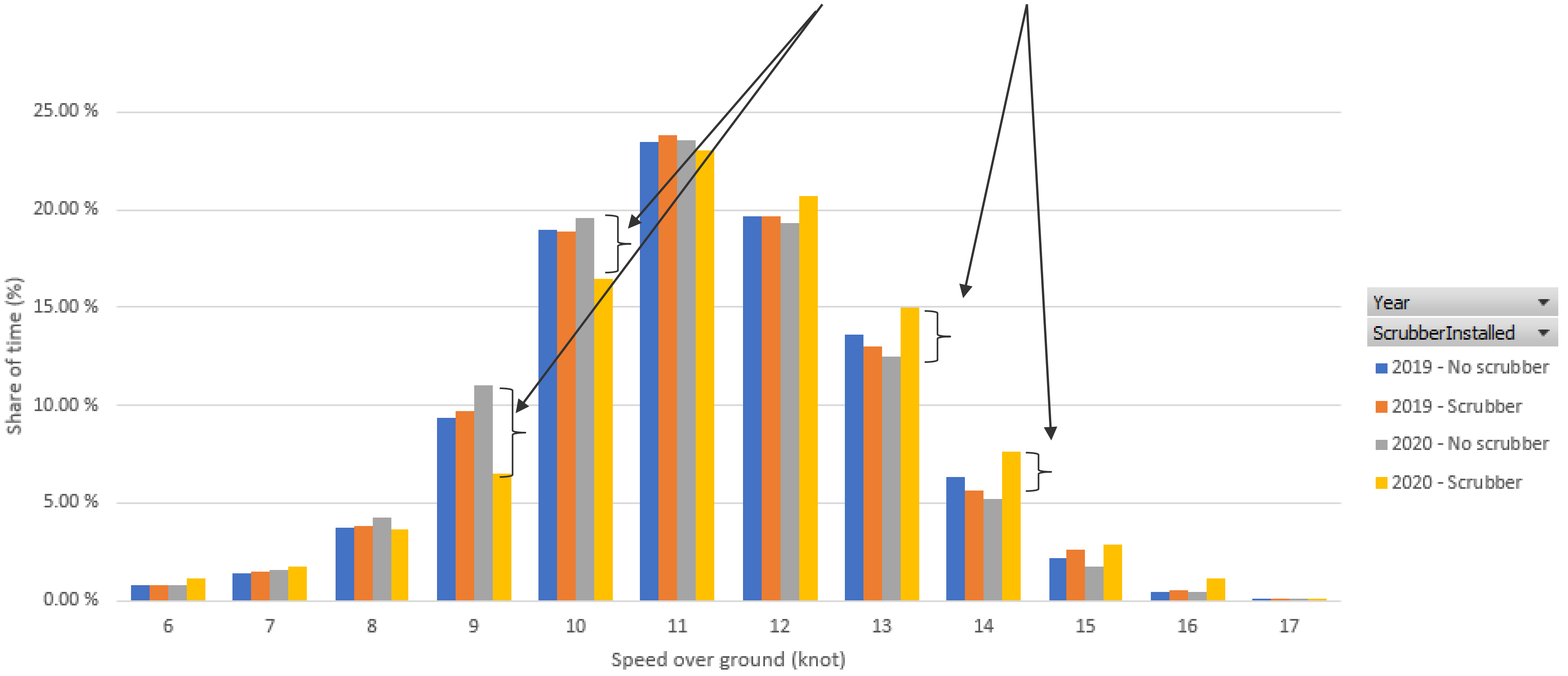
Source:Klaveness Research/Clarksons

Bulk

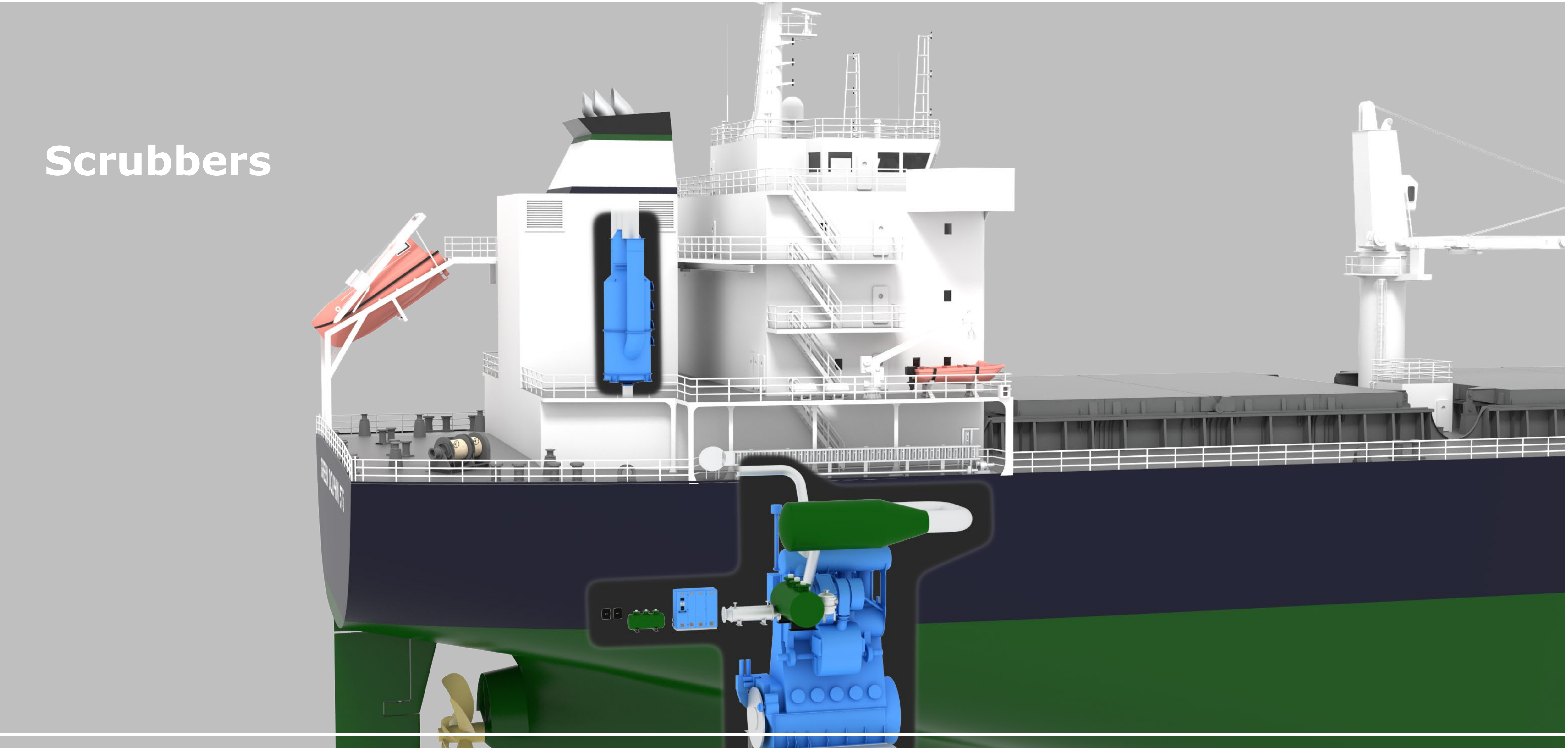
- 1720 Bulk vessels > 120 000 DWT
- 211 Bulk vessels with scrubber
- Data period:
  - Jan 2019
  - Jan 2020 (20 days)

Indicating higher avg. speed

for scrubber vessels in 2020 (grey bars)

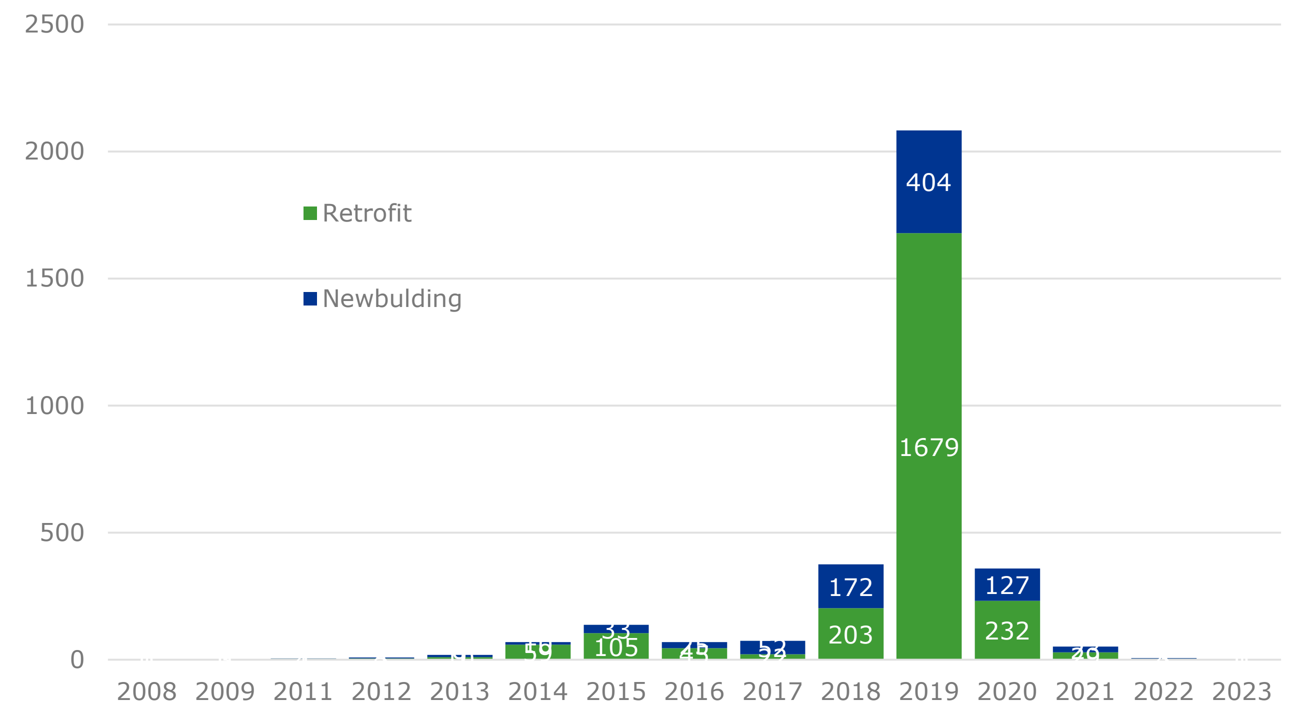


Scrubbers



Confirmed orders (all classes): Data from DNV GL "AFI" Portal

Annual number of confirmed scrubber system installations

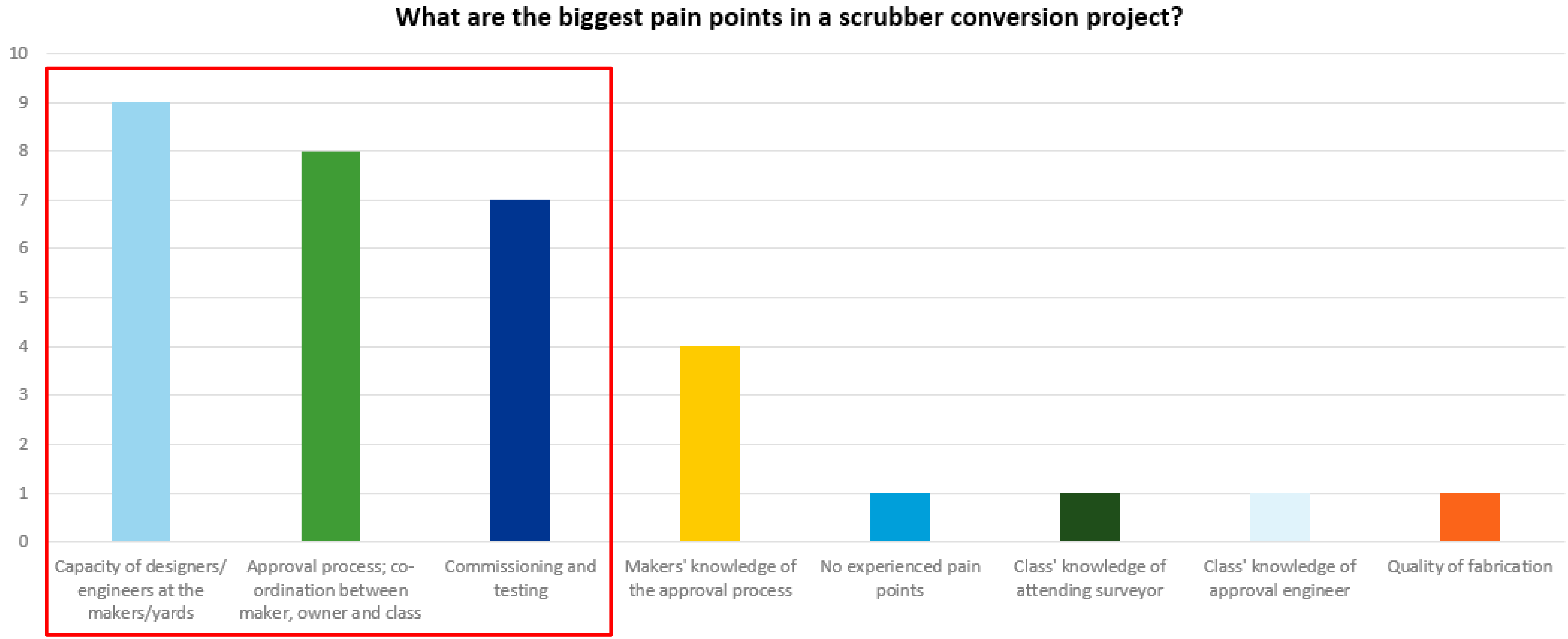


- There are more than **3000** ships with installed or firmly planned scrubber systems installations (NB+Conversion)
- Optimistic predictions estimate max. 4000 installations totally (all classes)
- IMO GESAMP study estimates a max. annual docking capacity of 3000 ships (MEPC 70/INF.6)
- The "scrubber wave" is now on, with 2100 confirmed retrofit installation in 2019 (all classes)
- Peak of installations will be in June/July 2019

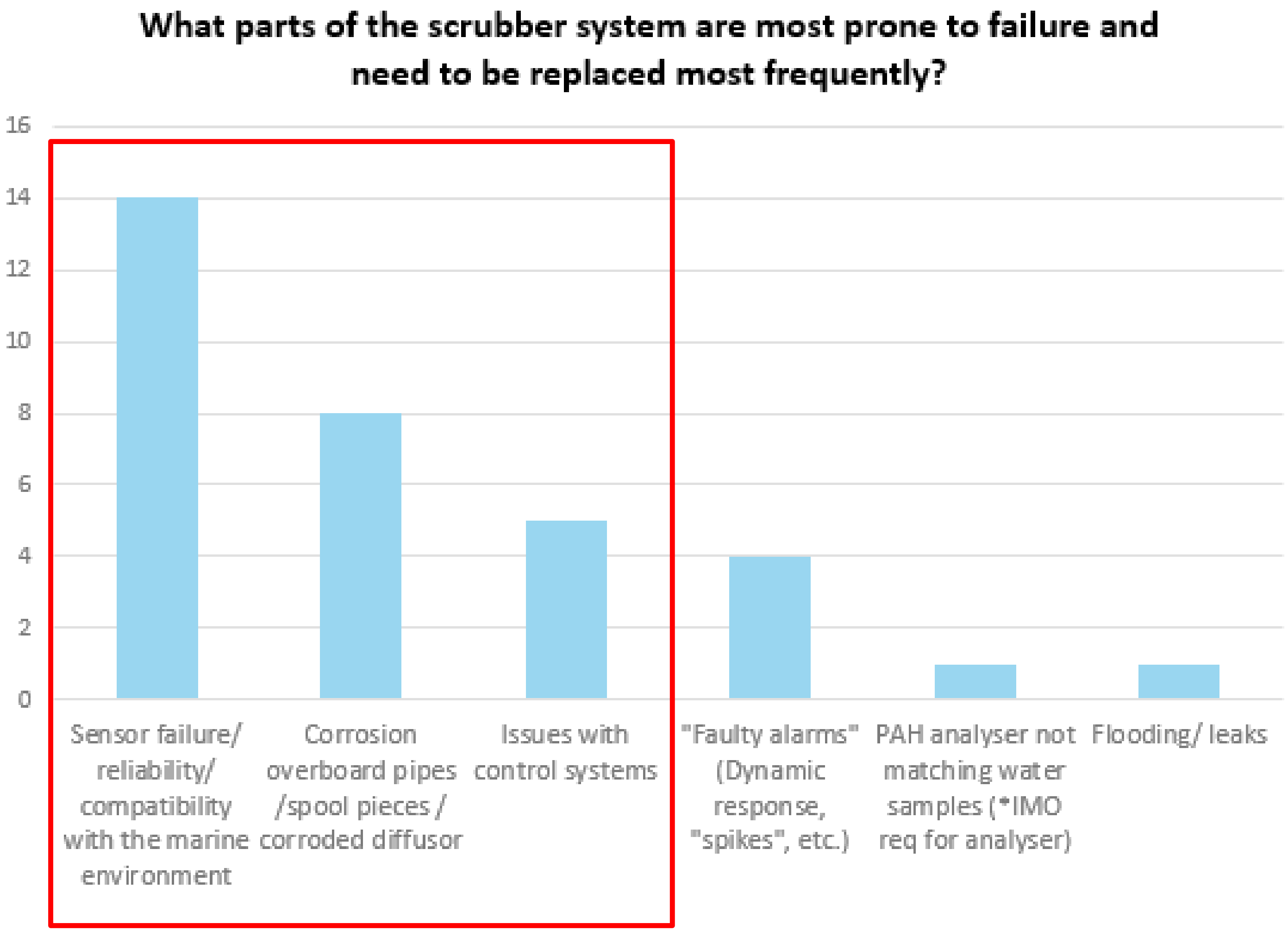
*"on an average **5.8** scrubber confirmed conversions per day for all classes"* in 2019

DNV·GL

Experienced pain points by our clients

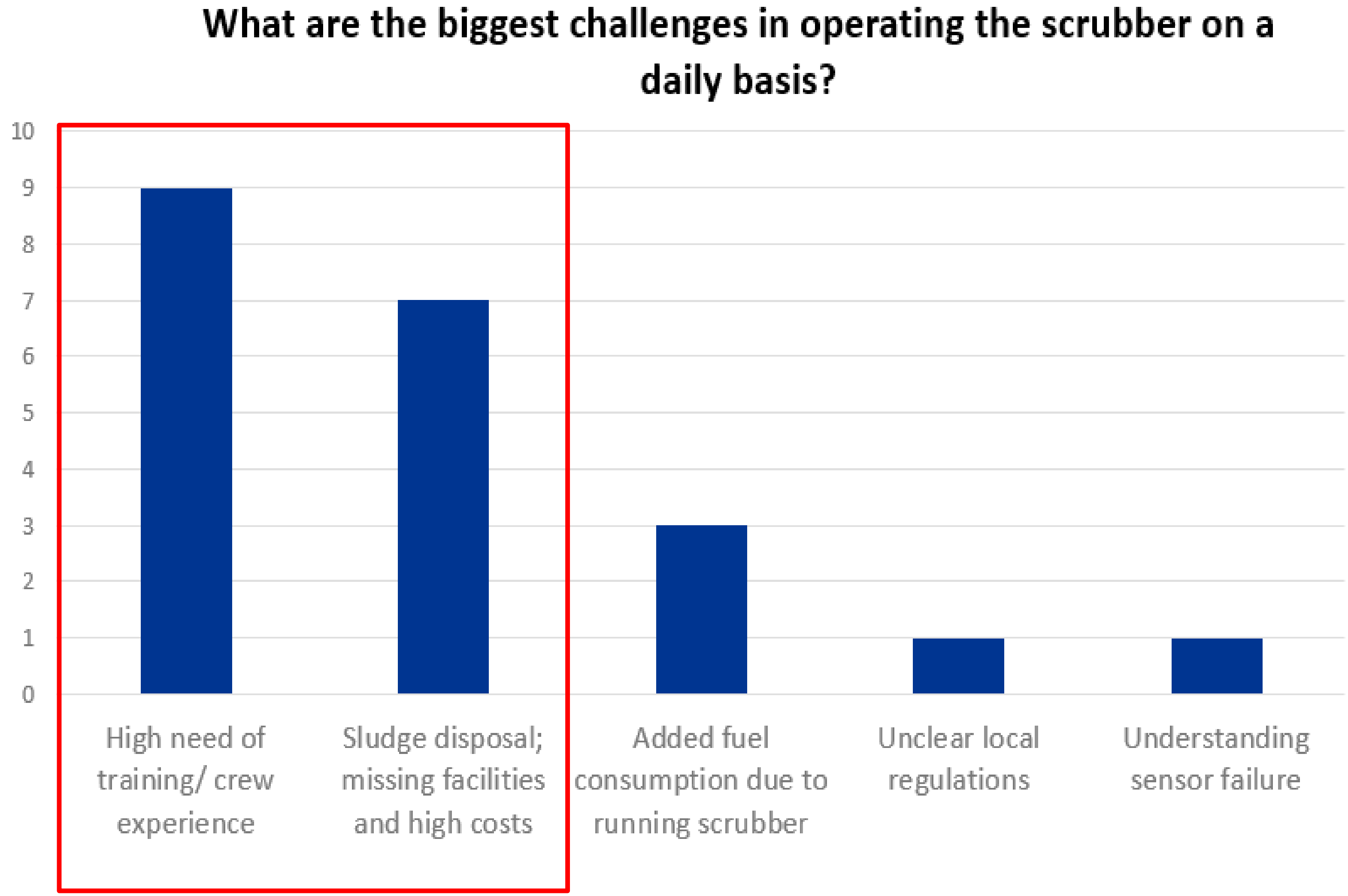


Operational challenges – what fails most often?

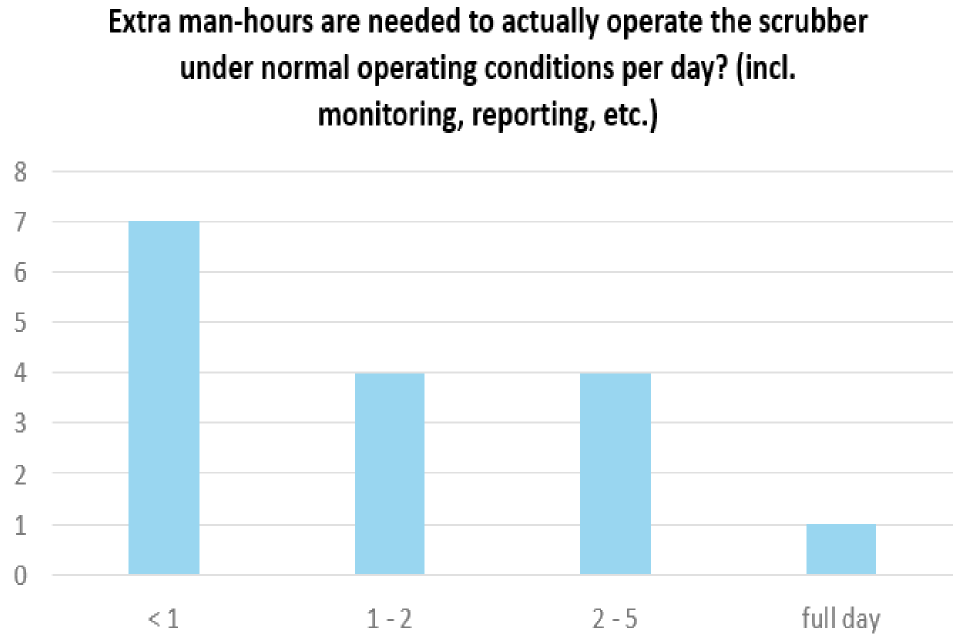


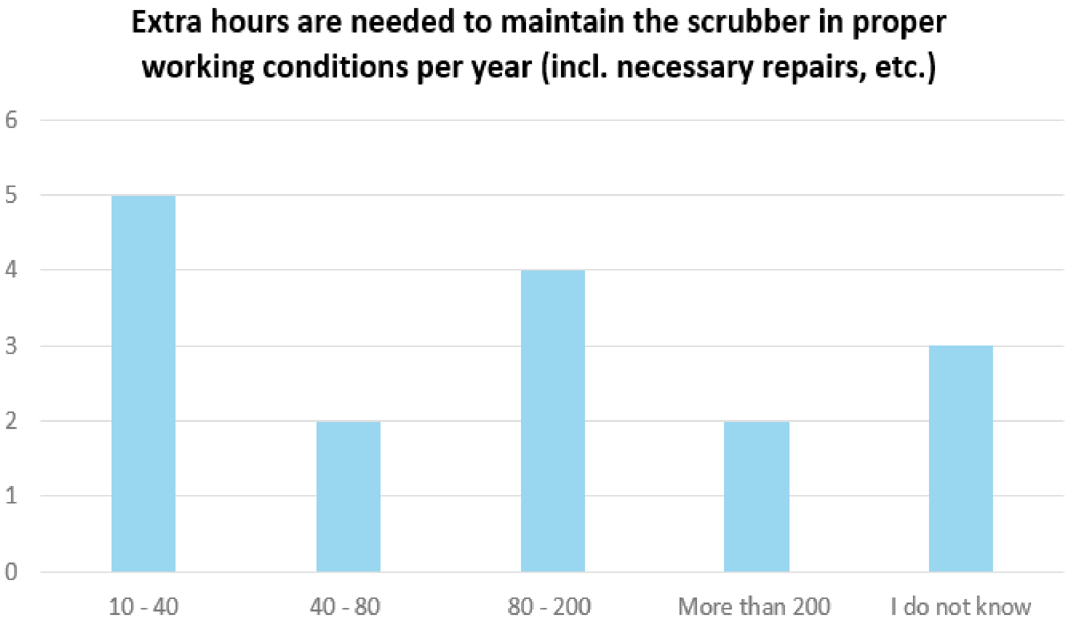
Overboard discharge pipe after 3 month of operation

Operational challenges – daily operation



Daily operational challenges – high need of training/crew experience


Extra man-hours are needed to actually operate the scrubber under normal operating conditions per day? (incl. monitoring, reporting, etc.)


Extra hours are needed to maintain the scrubber in proper working conditions per year (incl. necessary repairs, etc.)

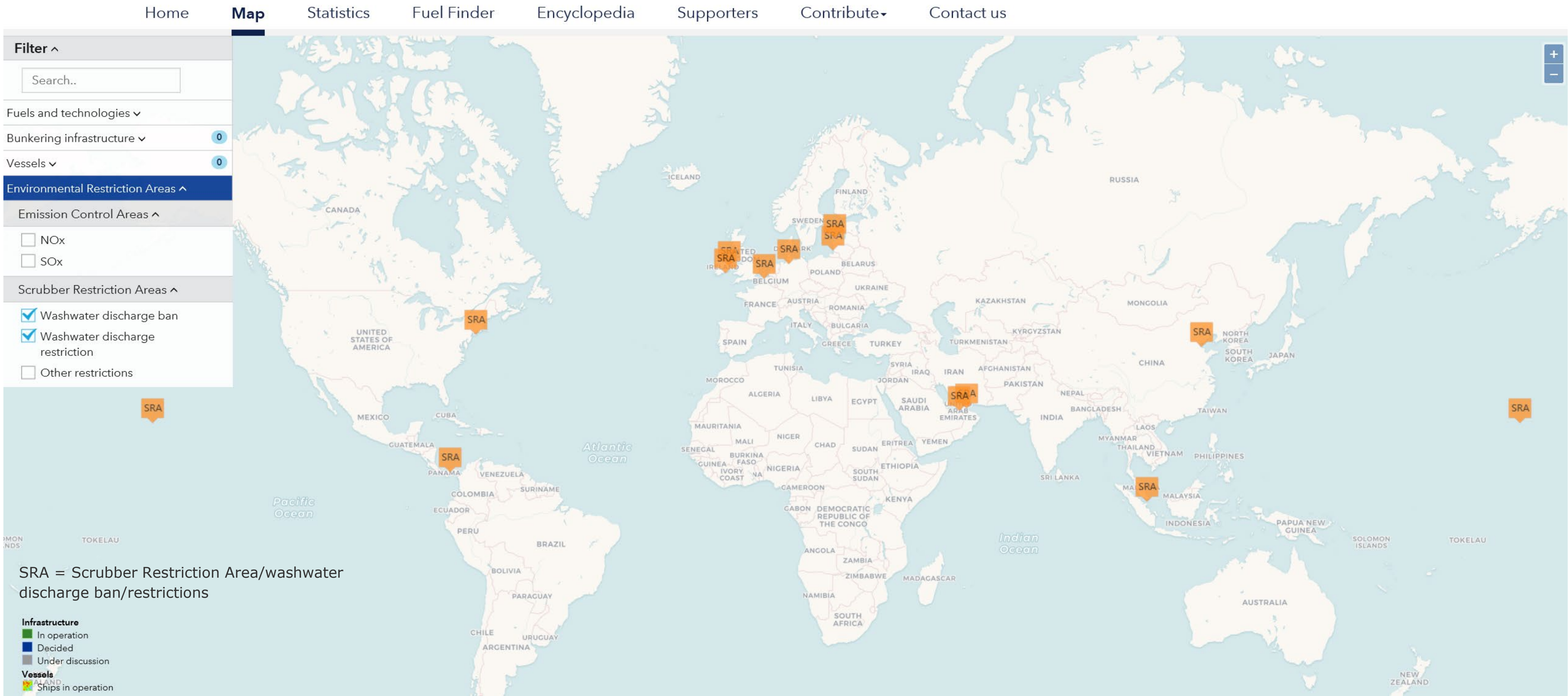
2

hrs/day

4

hrs/week

Restrictions on scrubber washwater disposal – still manageable…



Filter

Search..

Fuels and technologies

Bunkering infrastructure 0

Vessels 0

Environmental Restriction Areas

Emission Control Areas

☐ NOx

☐ SOx

Scrubber Restriction Areas

☑ Washwater discharge ban

☑ Washwater discharge restriction

☐ Other restrictions

SRA = Scrubber Restriction Area/washwater discharge ban/restrictions

Infrastructure

🟩 In operation

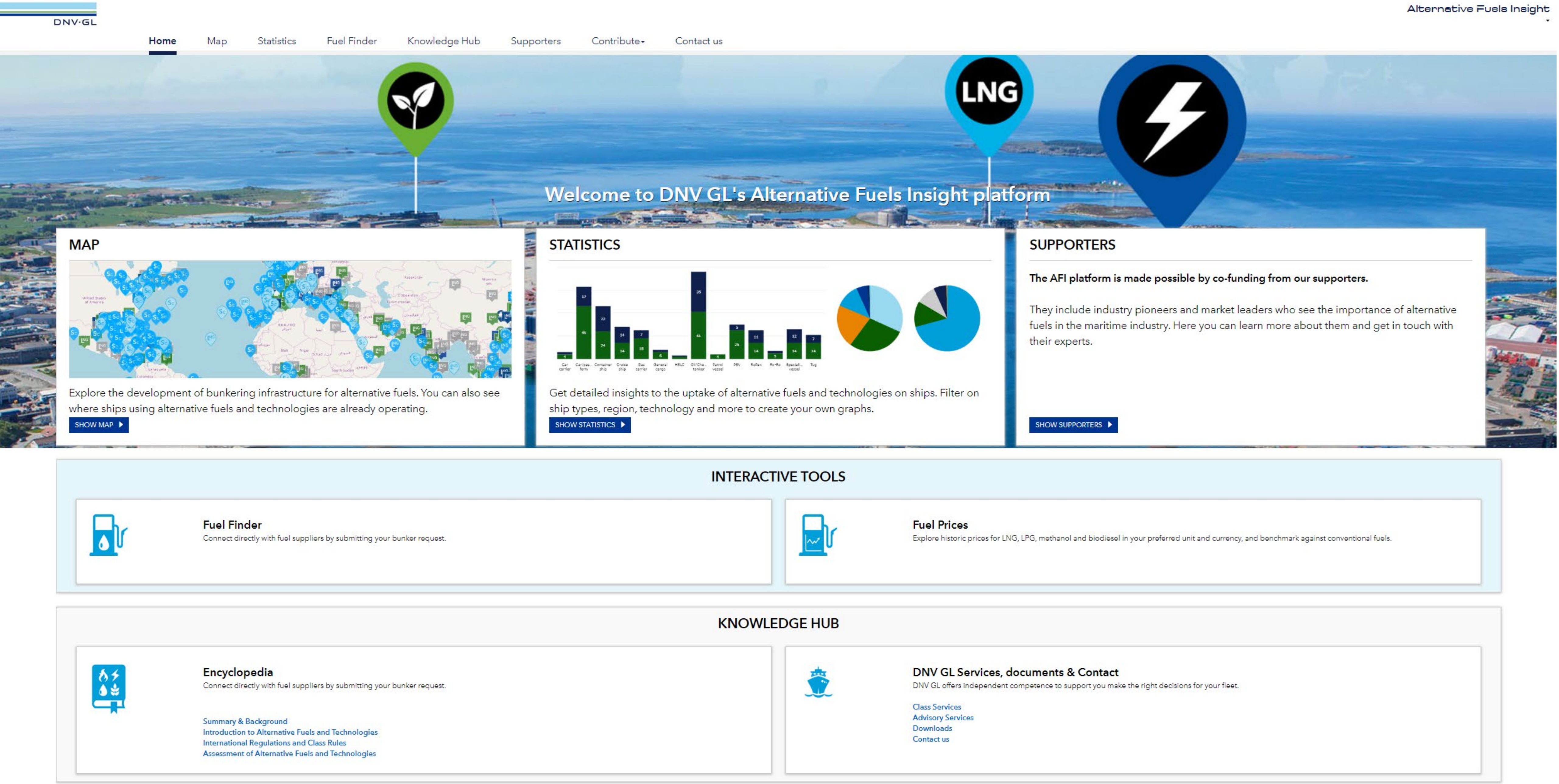
🟦 Decided

⬜ Under discussion

Vessels

Ships in operation

Source: afi.dnvgl.com



Welcome to DNV GL's Alternative Fuels Insight platform

MAP

Explore the development of bunkering infrastructure for alternative fuels. You can also see where ships using alternative fuels and technologies are already operating.

SHOW MAP

STATISTICS

Get detailed insights to the uptake of alternative fuels and technologies on ships. Filter on ship types, region, technology and more to create your own graphs.

SHOW STATISTICS

SUPPORTERS

The AFI platform is made possible by co-funding from our supporters.

They include industry pioneers and market leaders who see the importance of alternative fuels in the maritime industry. Here you can learn more about them and get in touch with their experts.

SHOW SUPPORTERS

INTERACTIVE TOOLS

Fuel Finder

Connect directly with fuel suppliers by submitting your bunker request.

Fuel Prices

Explore historic prices for LNG, LPG, methanol and biodiesel in your preferred unit and currency, and benchmark against conventional fuels.

KNOWLEDGE HUB

Encyclopedia

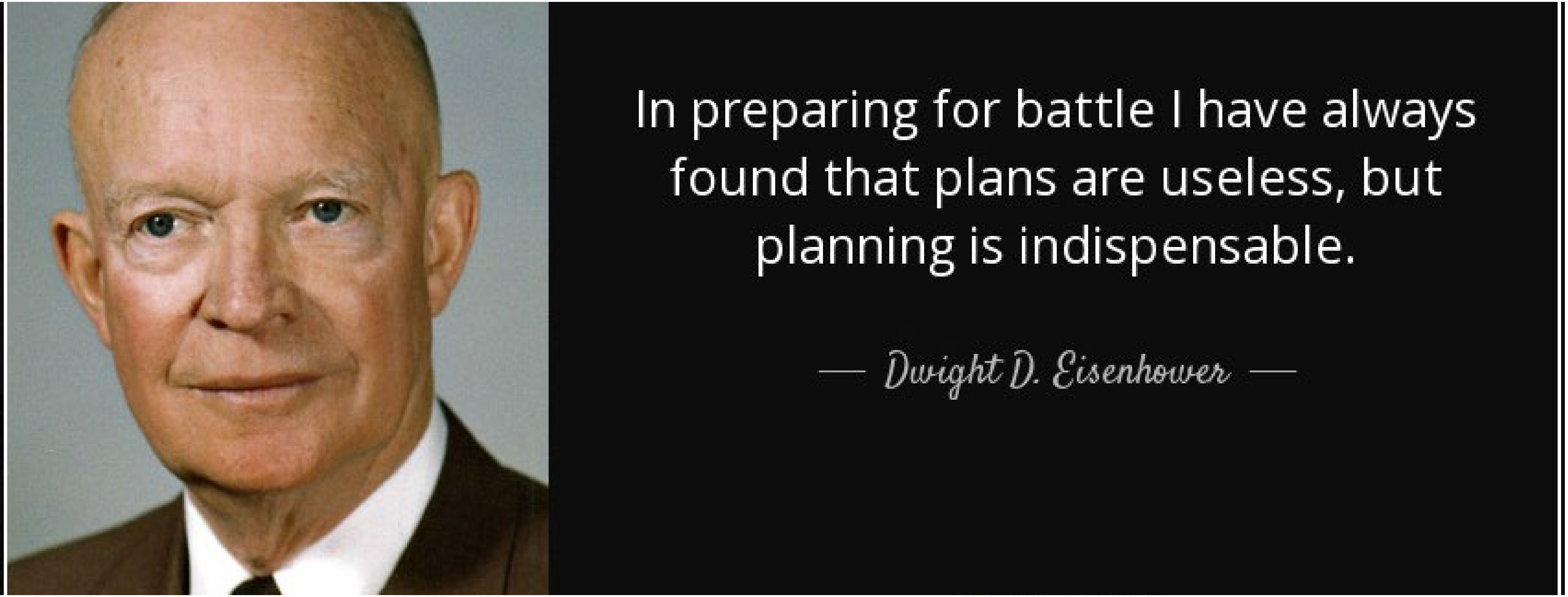
Connect directly with fuel suppliers by submitting your bunker request.

- Summary & Background
- Introduction to Alternative Fuels and Technologies
- International Regulations and Class Rules
- Assessment of Alternative Fuels and Technologies

DNV GL Services, documents & Contact

DNV GL offers independent competence to support you make the right decisions for your fleet.

- Class Services
- Advisory Services
- Downloads
- Contact us



In preparing for battle I have always found that plans are useless, but planning is indispensable.

— Dwight D. Eisenhower —

Thank you for your attention

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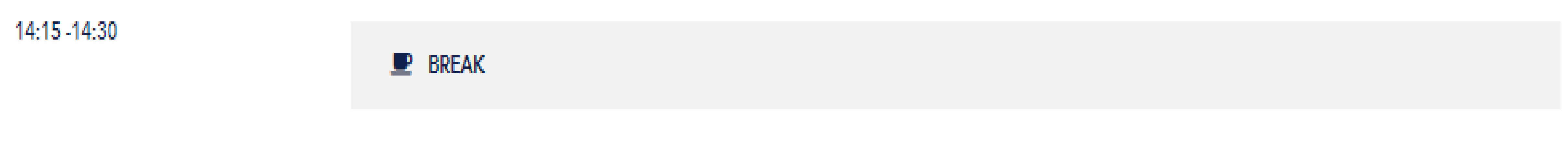
LNG Day Program Agenda



14:15 -14:30	☕ BREAK

LNG Day Program Agenda

14:30 -15:15	Alternative Fuels for the Maritime Industry what are they?	Speaker **Anthony Teo** DNV GL, Technology and LNG Business Development Director

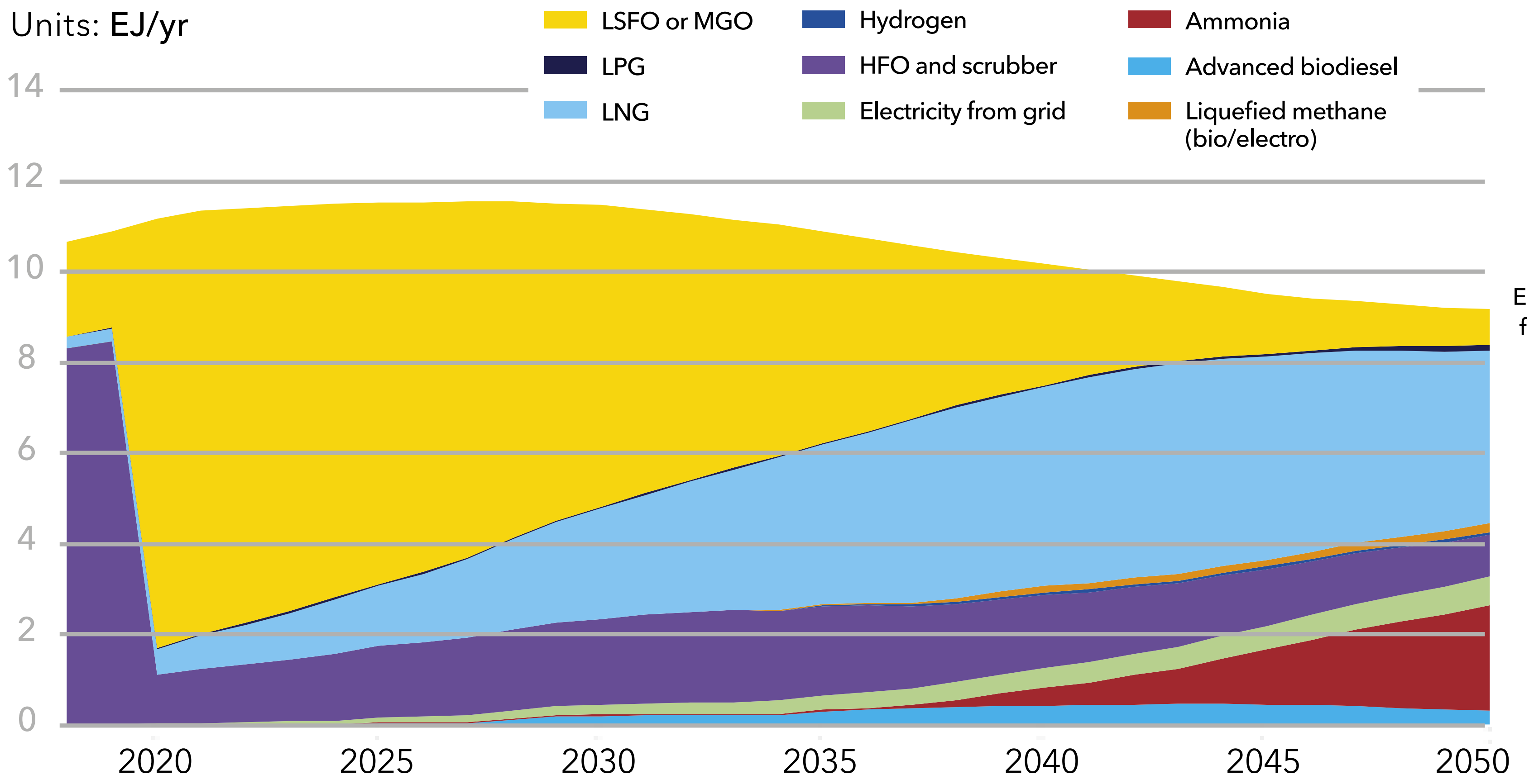
DNV·GL

LNG Day @ Technology Week

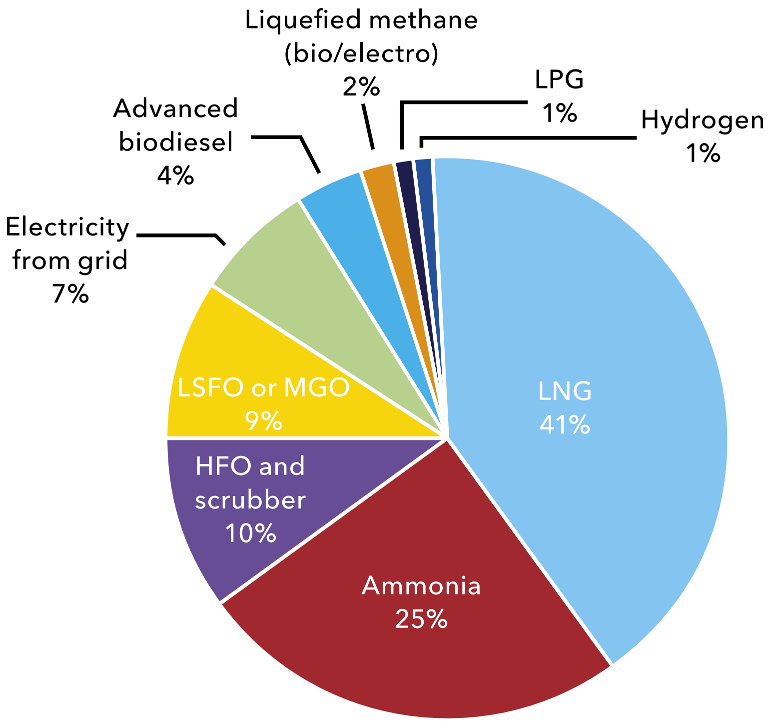
Alternative Fuels for the Maritime Industry what are they?

Anthony Teo

Maritime Fuel mix towards 2050 ('Design requirements' pathway)



In 2050



In all three pathways modelled, liquefied methane (both fossil and non-fossil) ends up dominating the fuel mix.

Summary

Energy source		Fossil (without CCS)					Bio			Renewable[3]		
Fuel		HFO + scrubber	Low sulphur fuels	LNG	Methanol	LPG	HVO (Synthetic diesel)	LBG[6]	Bio-diesel (FAME)[6]	Ammonia	Hydrogen	Fully-electric
High priority parameters												
• Energy density		🟢	🟢	🟩	🟩	🟩	🟢	🟩	🟢	🟡	🟧	🔴
• Technological maturity		🟩	🟩	🟩	🟡	🟡	🟢	🟩	🟢	🟧	🟧	🟡
• Local emissions		🟠	🟠	🟩	🟩	🟩	🟠	🟩	🟧	🟡	🟢	🟢
• GHG emissions		🔴	🔴	🟧 [2]	🟧	🟧	🟩	🟢	🟩	🟢	🟢	🟢
• Energy cost		🟢	🟩	🟢	🟡	🟩	🟧	🟠	🟠	🔴	🔴	🌈 [4]
• Capital cost	Converter	🟩	🟢	🟩	🟩	🟩	🟢	🟩	🟢	🟩	🔴	🟢
	Storage	🟢	🟢	🟡	🟩	🟩	🟢	🟡	🟢	🟩	🔴	🔴
• Bunkering availability		🟢	🟢	🟩	🟡	🟡	🔴	🔴	🔴	🟧	🔴	🟧
Commercial readiness [1]		🟢	🟢	🟢	🟩	🟩	🟡	🟡	🟡	🟧	🔴	🌈 [5]
Other key parameters												
• Flammability		🟢	🟢	🟢	🟩	🟢	🟢	🟢	🟢	🟠	🔴	🟢
• Toxicity		🟢	🟢	🟢	🟡	🟢	🟢	🟢	🟢	🔴	🟢	🟢
• Regulations and guidelines		🟢	🟢	🟢	🟩	🟡	🟢	🟢	🟩	🟡	🔴	🟩
• Global production capacity and locations		🟢	🟢	🟢	🟡	🟩	🟧	🟠	🟠	🟡	🟡	🔴

[1] Taking into account maturity and availability of technology and fuel.

[2] GHG benefits for LNG, methanol and LPG will increase proportionally with the fraction of corresponding bio- or synthetic energy carrier used as a drop-in fuel.

[3] Results for ammonia, hydrogen and fully-electric shown only from renewable energy sources since this represents long term solutions with potential for decarbonizing shipping. Production from fossil energy sources without CCS (mainly the case today) will have a significant adverse effect on the results.

[4] Large regional variations.

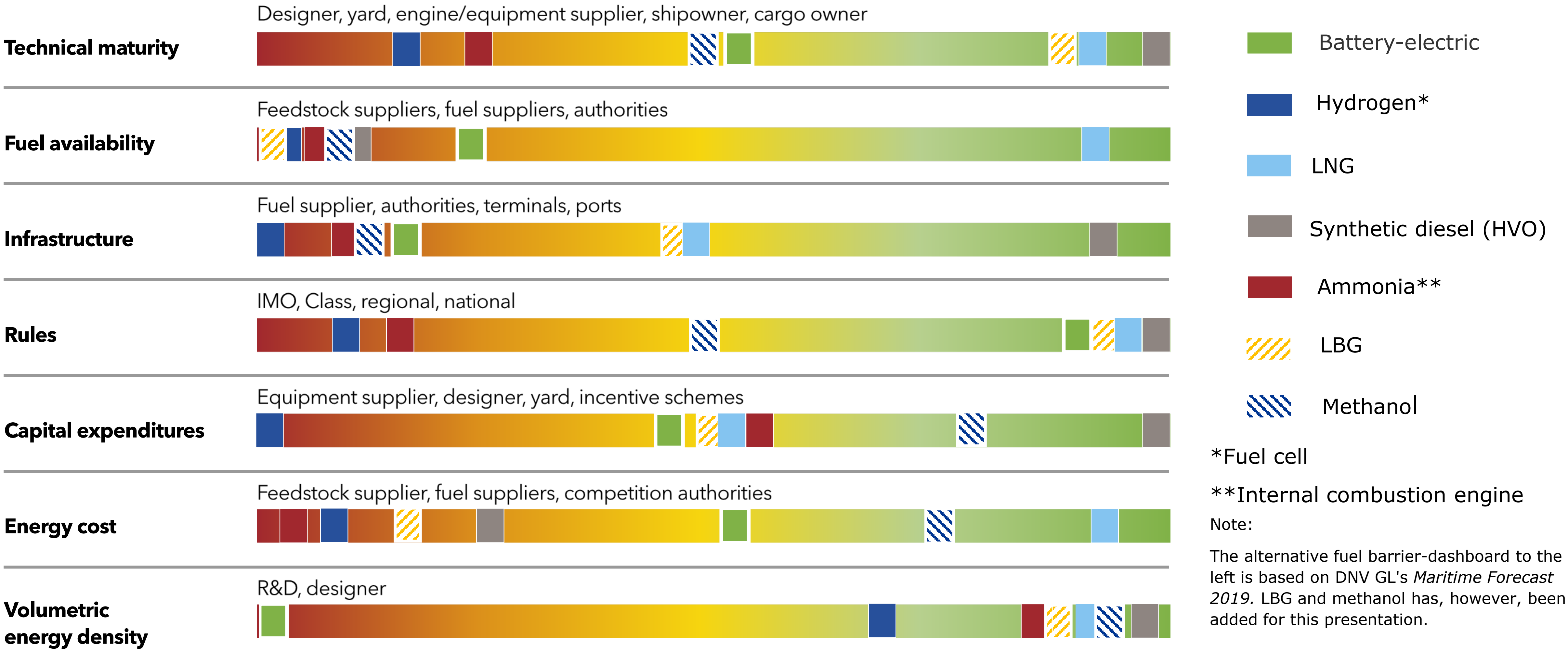
[5] Needs to be evaluated case-by-case. Not applicable for deep-sea shipping.

[6] Not part of *DNV GL Comparison of Alternative Marine Fuels*, but included here on a qualitative basis

- The summary to the left is based on a study conducted by DNV GL (*Comparison of Alternative Marine Fuels),* however, Liquefied Biogas (LBG) and biodiesel (FAME) has been added on a qualitative basis
- The table indicates the relative performances of different alternative fuels when it comes to a variety of different parameters **today**
- The colour green is indicative of high performance, red represents low performance and multi colour can represent either dependant on the case

Source: DNV GL Comparison of Alternative Marine Fuels, 2019

Status of key barriers to uptake of alternative fuels



*Fuel cell

**Internal combustion engine

Note:

The alternative fuel barrier-dashboard to the left is based on DNV GL's *Maritime Forecast 2019.* LBG and methanol has, however, been added for this presentation.

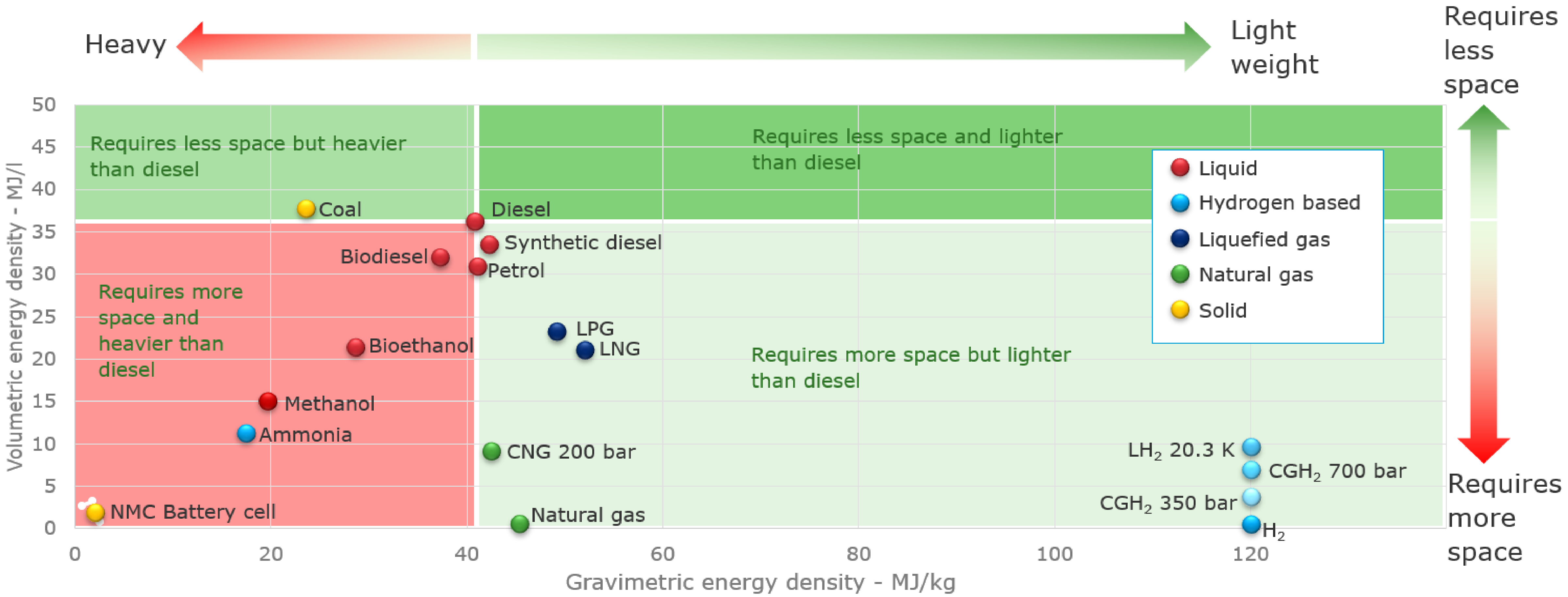
Source: DNV GL Maritime Forecast 2019

Overview of Alternative Fuels

Fuels covered:

- LNG
- LPG
- LBG
- Ammonia
- Hydrogen
- Methanol
- Biodiesel (FAME)
- Synthetic diesel

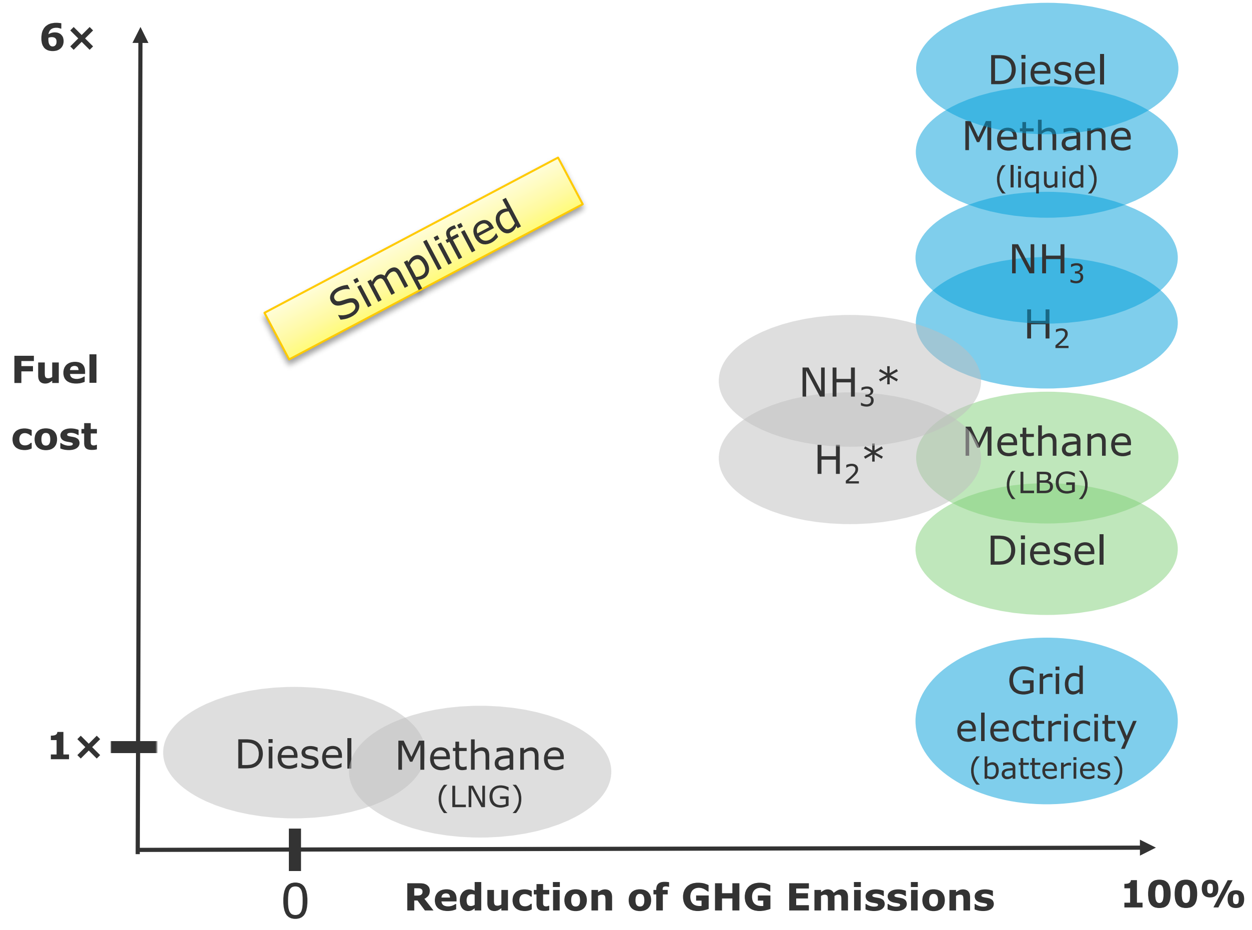
Energy Density



*The above figure does not take into account the mass and volume of the storage system associated with each fuel

Source: DNV GL Comparison of Alternative Marine Fuels, 2019

Fuel costs



- Future alternative fuel prices are highly dependent on technological progress and market developments. The figure to the left gives indicative fuel-cost of alternative fuels **based on current production-costs**.

⚪ **Fossil-based**

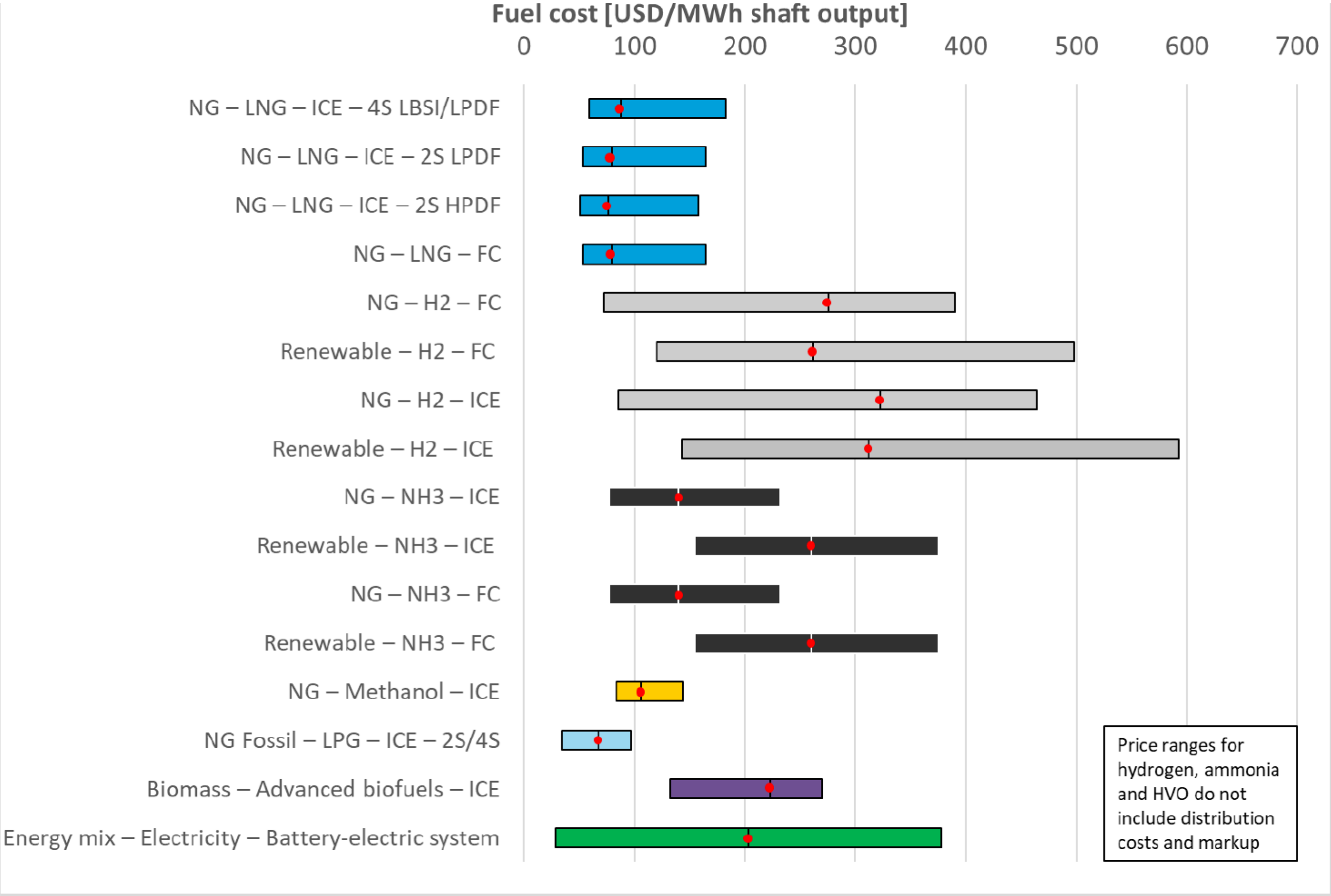
🔵 **Electricity-based****

🟢 **Bio-based**

*Assuming CCS

** from renewable sources; CO_2 for electro-fuels need to be captured from the atmosphere

Energy cost



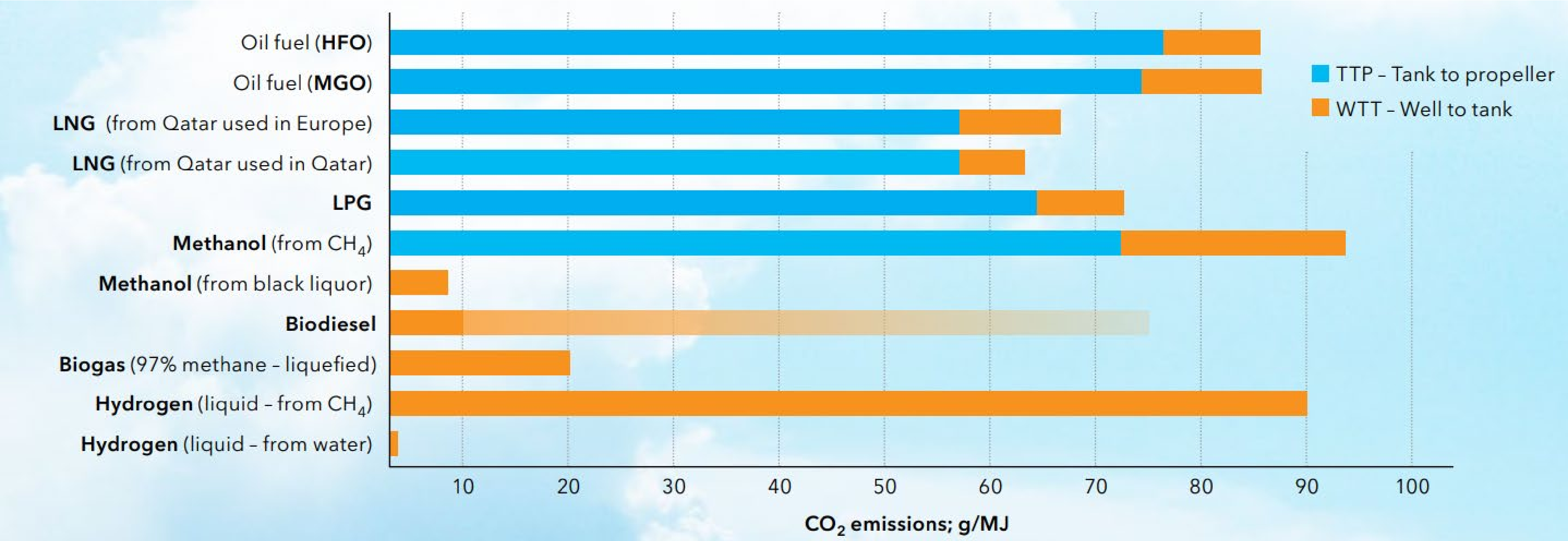
Price ranges for hydrogen, ammonia and HVO do not include distribution costs and markup

- The cost ranges to the left are from *DNV GL Comparison of Alternative Marine Fuels*
- The costs are only applicable for the given fuel production pathway, and takes into account the energy content of the fuel and the efficiency of the propulsion system on board the ship

NG: Natural Gas
LNG: Liquefied Natural Gas
ICE: Internal Combustion Engine
4S: 4-stroke
LBSI: Lean-burn Spark-ignition
LPDF: Low Pressure Dual Fuel
2S: 2-stroke
HPDF: High-pressure Dual Fuel
H2: Hydrogen
FC: Fuel Cell
NH3: Ammonia
LPG: Liquefied Petroleum Gas
HVO: Hydrotreated Vegetable Oil

Source: DNV GL Comparison of Alternative Marine Fuels, 2019

CO_2 Emissions

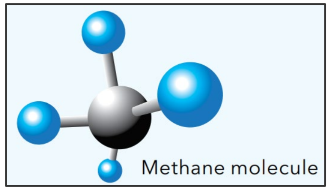


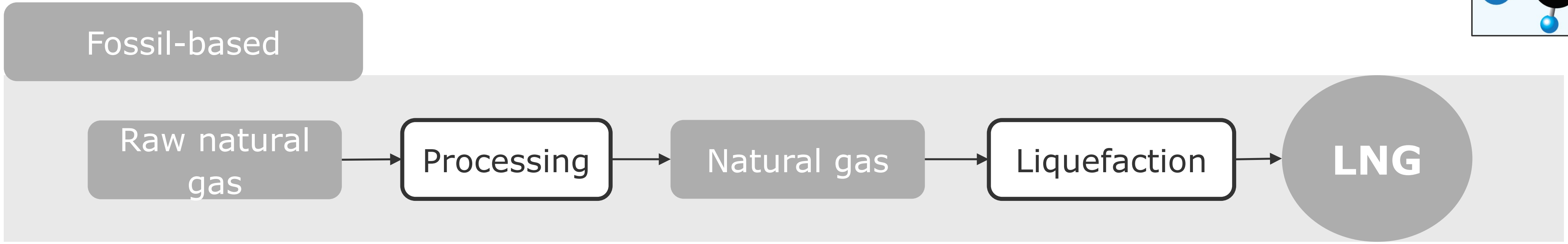
Source: DNV GL calculations; Bio diesel: emissions depend on the production method. Graphic uses data from the European Renewable Energy Directive (Council of the European Union, Interinstitutional File: 2016/0382 (COD), Brussels, 21 June 2018)

- The above figure is taken from *DNV GL Comparison of Alternative Marine Fuels*, and is based on given production pathways. Potential methane emissions are not included in this graph.

Source: DNV GL Comparison of Alternative Marine Fuels

LNG – production pathways





Fossil-based

Raw natural gas → Processing → Natural gas → Liquefaction → LNG

General

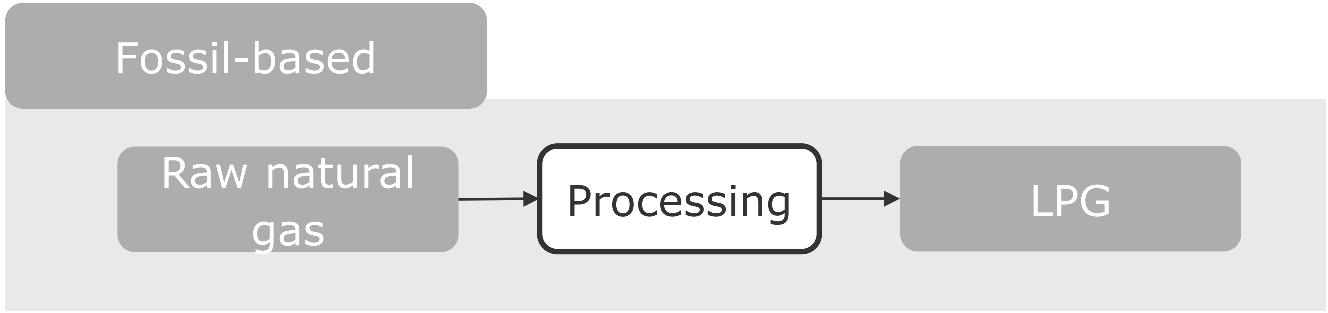
The main component of liquefied natural gas (LNG) is methane (CH_4), the hydrocarbon fuel with the lowest carbon content and therefore with the highest potential to reduce CO_2 emissions. Ethane, is the other major component of LNG. LNG has more or less the same composition as natural gas used in households, for power generation and by the industry. LNG, as its name implies, only has one production pathway, which is the liquefaction of natural gas from a natural gas processing plant.

LNG - key characteristics

Availability	In principle, LNG is available worldwide (large scale import and export terminals), and investments in bunkering infrastructure are being made globally. Currently, a large share of LNG bunkering as well as LNG distribution to bunkering locations is still taking place by road. However, 2017 and 2018 saw several LNG bunkering vessels being delivered for operation in key areas including the North Sea, coast of Florida, and Rotterdam. Within the next few years, other areas such as the Western Mediterranean, Gulf of Mexico, and Singapore will be serviced by LNG bunkering vessels currently under construction.
Storage	LNG is stored in insulated tanks at a very low temperature of approximately -162°C, at atmospheric pressure. Inevitably, boil-off natural gas is generated inside LNG fuel tanks due to ambient heat ingress. Consequently, a system for handling boil-off gas must be in place. When taking into account the entire fuel storage system, LNG has a relatively low volumetric fuel density (less than half that of MGO/HFO). As a result, more space must be allocated on board ships for storage of LNG, when compared to conventional marine fuels.
Application	LNG may applied as a fuel in ICEs, FCs or steam turbines. Different types of ICEs available on the market are capable of running on LNG. Engine-types include 2-stroke Dual Fuel ICEs (high- and low pressure), and 4-stroke dual-fuel and mono-fuel ICEs. Less commonly, is the application of LNG in gas turbines. LNG may also be applied directly in high-temperature FCs such as SOFCs.
Technological maturity	Gas engines, gas turbines and LNG storage and processing systems have been available for land installations for decades. Sea transport of LNG by LNG carriers also has a long history going back several decades. Developments to use LNG fuel in the general shipping fleet, with the exception of LNG carriers, began early in the current century. Today, the technology required for using LNG as ship fuel is readily available on the market. ICEs including piston engines and gas turbines, several LNG storage tank types as well as process equipment are also commercially available. Application of LNG in high-temperature fuel cell systems such as SOFCs is still relatively immature, and pilot projects are taking place to explore its usage on ships.
Environmental performance	Due to the low sulphur-content of LNG, it is associated with virtually zero emissions of SOx when consumed on board ships. NOx emissions are also lower than those that result from combustion of HFO or MGO. Methane-slip must, however, be considered when evaluating the GHG reduction potential of LNG. Assuming no methane-slip occurs, LNG has the potential to reduce GHG emissions by a maximum of 26 per cent, compared to conventional ship propulsion systems run on HFO.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

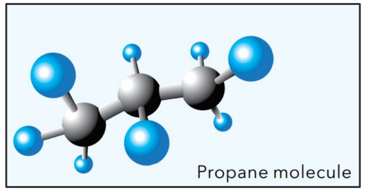
LPG – production pathways

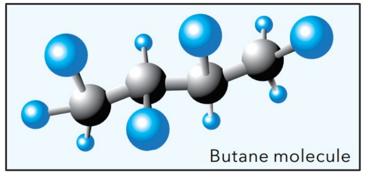

Fossil-based

Raw natural gas

Processing

LPG


Propane molecule


Butane molecule

General

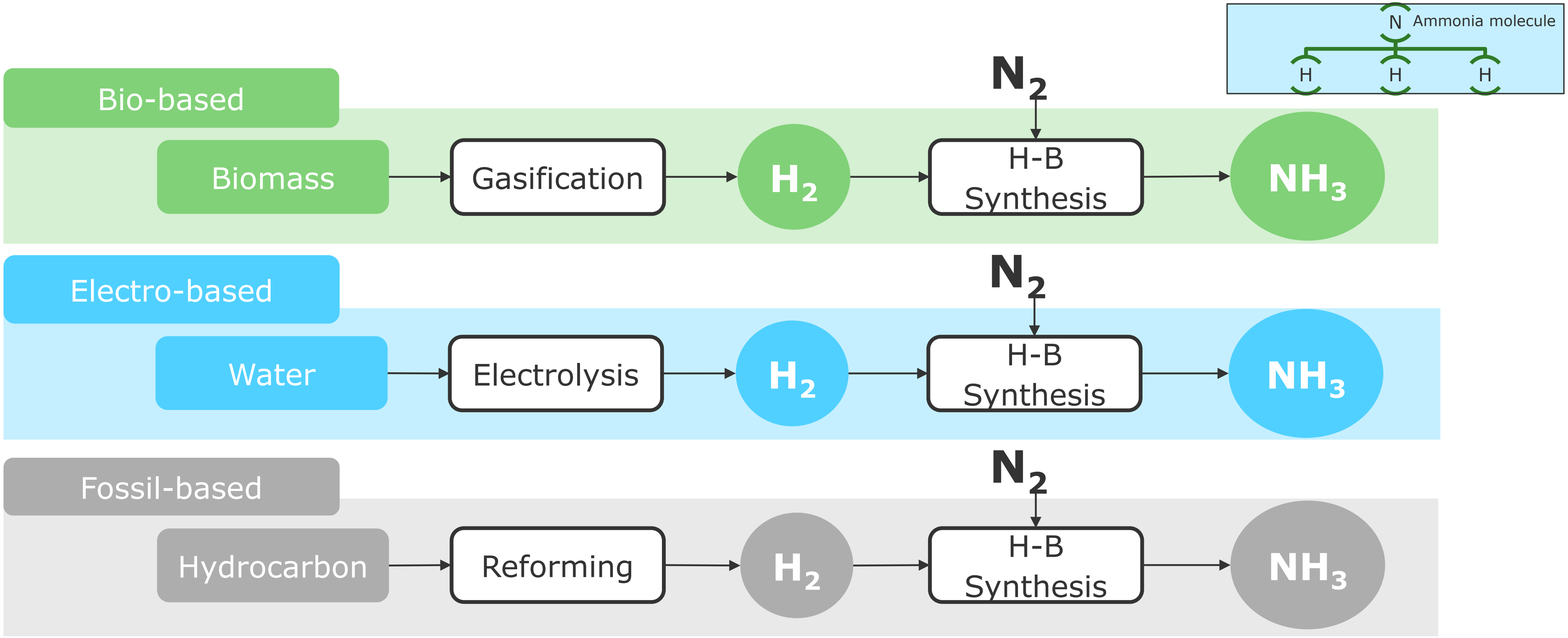
Liquefied petroleum gas (LPG) is by definition any mixture of propane and butane in liquid form. In the USA, the term LPG is generally associated with propane. Specific mixtures of butane and propane are used to achieve desired saturation, pressure and temperature characteristics.

LPG - key characteristics

Availability	There is an extensive network of LPG import and export terminals worldwide. It is reported that there are more than 1,000 import and secondary terminals for pressurized LPG. Recently more LPG export terminals have been developed in the US to cover the increased demand for competitively priced LPG products. It is relatively easy to develop bunkering infrastructure at existing LPG storage locations or terminals by simply adding distribution installations. Distribution to ships can occur either from dedicated facilities or from special bunker vessels.
Storage	LPG is mostly stored in three different states; fully refrigerated (~-50ºC, ~1 bar), semi-pressurized (~-10ºC, ~5 bar), or fully pressurized (~20ºC, ~17 bar). When taking into account the entire storage system, storage of LPG will take up significantly more space than HFO or MGO. However, the volumetric density is higher than that of LNG.
Application	ICEs are considered to be the LPG energy-converter of choice on ships. Different engine concepts for combustion of LPG exist, including diesel-cycle 2-stroke engines, and otto cycle, lean-burn, 4-stroke engines (currently only available for stationary power plants). Gas turbines, compatible with LPG, are also available for marine propulsion.
Technological maturity	Engines fueled by LPG has recently been developed for the marine market and is commercially available. The first major ships fueled by LPG are set to enter operation in 2020. To date (January 2020) LPG has no operational track-record on board ships as a fuel.
Environmental performance	LPG combustion results in GHG emissions that are approximately 16 per cent lower than those of HFO. When accounting for the complete lifecycle, including fuel production, the GHG savings amount to roughly 17 per cent. The global warming potential of propane and butane as greenhouse gases is three to four times higher than that of CO_2. This has to be taken into consideration when addressing the issue of unburned LPG potentially escaping into the atmosphere (LPG slip). At the same time, using LPG virtually eliminates Sulphur emissions. LPG is also expected to reduce particulate matter (PM) emissions significantly. The reduction of NOx emissions depends on the ICE technology applied.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL LPG as a Marine Fuel

Ammonia – production pathways



General

Ammonia is a compound consisting of nitrogen and hydrogen, with chemical formula NH_3. Currently, the vast majority of ammonia is produced via reforming of natural gas, followed by Haber-Bosch synthesis. In the future however, other production routes based on electricity (electro-based) or biomass (bio-based) are considered.

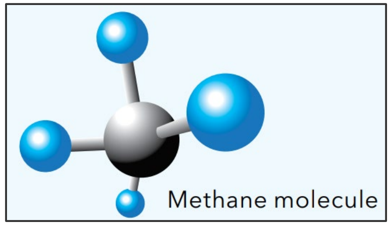
Ammonia - key characteristics

Availability	Production of ammonia from hydrogen (derived from hydrocarbons) and nitrogen through H-B synthesis is a well-known commercial process, with total production of ammonia equivalent to approximately 76 Mtoe per year. The largest producers are China with 32% of global production, Russia (9%), and India (8%). Infrastructure for transport and handling of ammonia exists, due to its use in production of fertilizers. However, bunkering infrastructure for ships is currently non-existent and needs to be developed.
Storage	Ammonia is stored as a liquid, primarily in three different states: i) fully-pressurised (~18 bar, 20°C). ii) semi-pressurised (~5 bar, ~-10°C), or iii) fully refrigerated (1 bar,~-33°C), depending on the quantity stored. For use as fuel on ships, fully pressurised or semi-refrigerated storage is the most applicable. Liquid ammonia has a significantly lower volumetric energy density compared to conventional fuels like HFO. Consequently, significantly more space is needed relative to MGO/HFO, but less than other alternative fuels such as liquefied hydrogen.
Application	Ammonia may technically be applied as a fuel in both ICEs and FCs. As far as FCs are concerned, ammonia may be consumed directly in high-temperature fuel cells such as SOFCs, or after being cracked into hydrogen and purified for traces of ammonia for use in low-temperature fuel cells such as PEMFCs.
Technological maturity	No ammonia-fuelled propulsion systems are currently available on the market. However, given the similarity of ammonia-fuelled ICEs with current commercially-available engine-designs, there is reason to believe that ammonia-fuelled ICEs could be available within the next few years. Notably, the engine manufacturer MAN ES is developing a concept for applying ammonia as a fuel in two-stroke dual fuel engines[1]. Research efforts are being made with respect to the application of ammonia in FCs, however, there is still a long time before the technology is expected to be commercially available.
Environmental performance	The end-use of ammonia in ICEs or FCs does not cause any GHG- or SOx emissions. For use in ICEs, depending on the choice of engine-technology, emissions of NOx will be generated. Considering a well-to-tank perspective, regardless of the selected production pathway, ammonia has the potential to be carbon-neutral. However, that is only valid under the given assumption that fossil-based production is supplemented by CCS, or that the electricity-input in electro-based ammonia is produced from carbon-neutral sources.

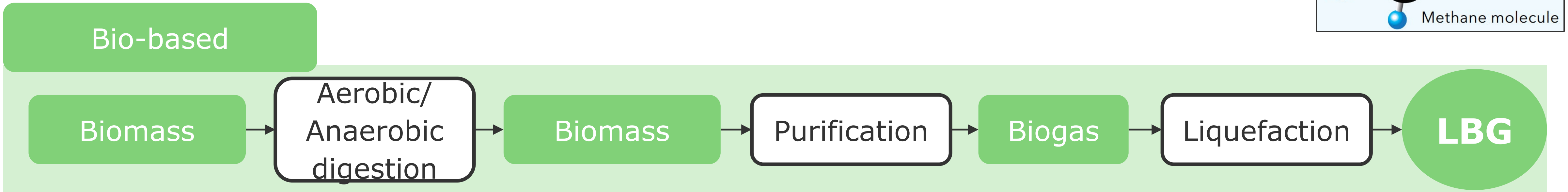
[1] (MAN ES, 2019), *Engineering the future two-stroke green-ammonia engine*

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies, DNV GL Maritime Forecast to 2050

LBG – production pathways



Methane molecule



General

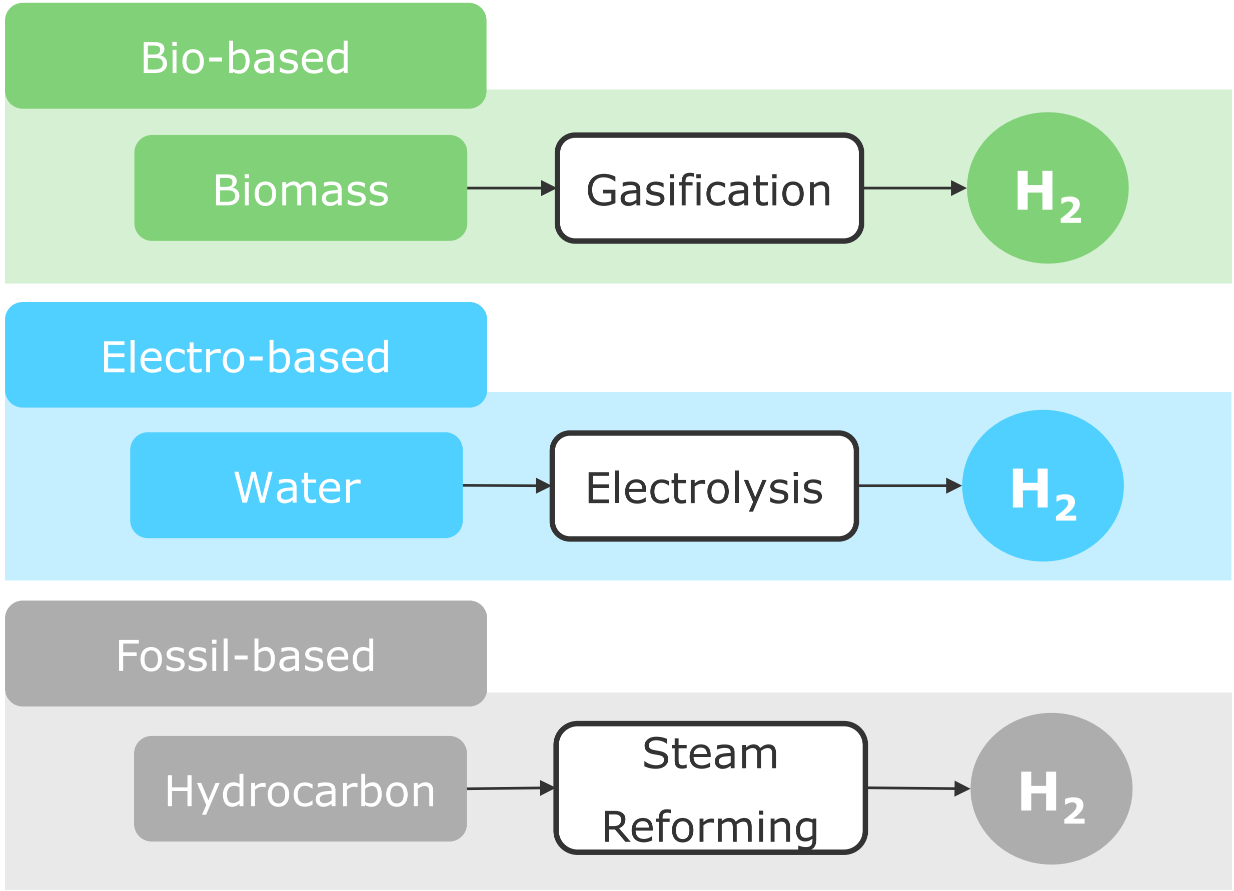
Liquefied biogas (LBG) is practically identical to liquefied natural gas (LBG), and is most commonly produced via aerobic/anaerobic digestion of waste from agriculture, as well as municipal waste. Even though biogas is, technically, a mixture of methane, CO$_2$, and other impurities, LBG refers to liquefied biomethane. Hence, biogas needs to be purified and liquefied before it may be defined as LBG.

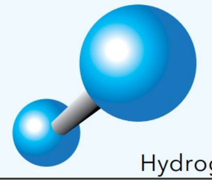
LBG (cont.)

Availability	In 2018, total production of LBG made up less than 0.2 Mtoe. Considering that the total fuel consumption of the world fleet was approximately 274 Mtoe in 2018, a massive upscale of LBG production is needed if it is to serve as a marine fuel. Since LBG is practically identical to LNG, it may use infrastructure including bunkering stations already built to serve the LNG-market.
Storage	Reference is made to section on LNG. LBG is stored in isolated tanks at a very low temperature of approximately -162°C, at atmospheric pressure. Inevitably, boil-off natural gas is generated inside LBG fuel tanks due to ambient heat ingress. Consequently, a system for handling boil-off gas must be in place. When taking into account the entire fuel storage system, LBG has a relatively low volumetric fuel density (less than half that of MGO/HFO). As a result, more space must be allocated on board ships for storage of LBG, when compared to conventional fuels.
Application	Reference is made to section on LNG. LBG may applied as a fuel in ICEs, FCs or steam turbines. Different types of ICEs available on the market are capable of running on LBG. Engine-types include 2-stroke Dual Fuel ICEs (high- and low pressure), and 4-stroke Dual-fuel and Mono-fuel ICEs. Less commonly, is the application of LBG in gas turbines. LBG may also be applied directly in high-temperature FCs such as SOFCs.
Technological maturity	Reference is made to section on LNG. Gas engines, gas turbines and LNG/LBG storage and processing systems have been available for land installations for decades. Sea transport of LNG by LNG carriers also has a long history going back several decades. Developments to use LNG/LBG fuel in the general shipping fleet, with the exception of LNG carriers, began early in the current century. Today, the technology required for using LBG as ship fuel is readily commercially available. ICEs including piston engines and gas turbines, several LNG/LBG storage tank types as well as process equipment are also commercially available. Application of LNG/LBG in FC systems such as SOFCs is still relatively immature, and pilot projects are taking place to explore its usage on ships.
Environmental performance	Although combustion of LBG produces GHG comparable in magnitude with those resulting from combustion of LNG, the overall net lifecycle GHG emissions has the potential to be zero since it is produced from biomass derived from feedstock which absorbs CO_2 from the atmosphere when growing. If LBG is produced from biomass derived from waste sources such as municipal solid waste, carbon-negativity is possible to achieve, preventing methane resulting natural decomposition of waste to escape to the atmosphere.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

Hydrogen – production pathways




Hydrogen molecule

General

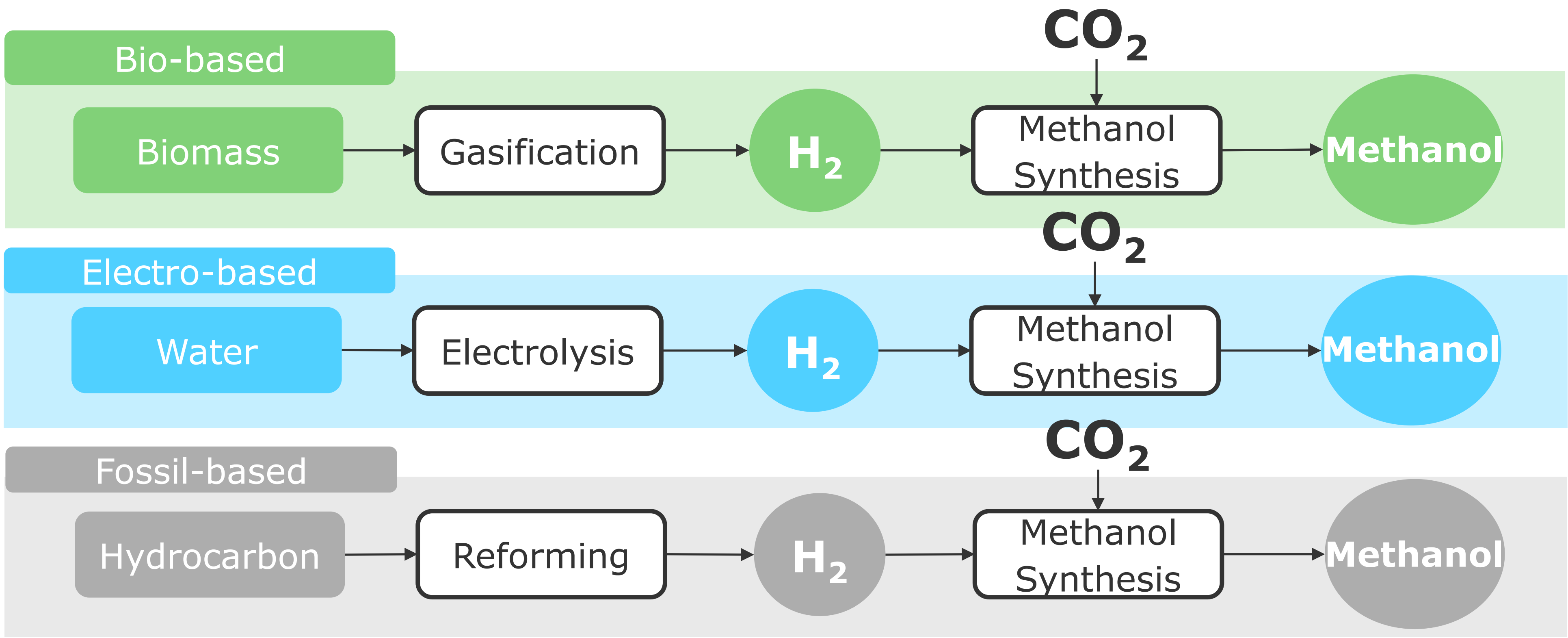
Hydrogen (H_2) is a colourless, odourless and non-toxic gas. Hydrogen is an energy carrier and a widely used chemical commodity. It can be produced from various energy sources, such as by electrolysis of renewables, or by reforming natural gas. Today, 95 per cent of hydrogen is produced from fossil fuels, mainly natural gas. Five per cent of current hydrogen production uses electrolysis, and is hence electro-based.

Hydrogen - key characteristics

Availability	Currently, infrastructure and bunkering facilities are not developed. Hydrogen production from electrolysis is a well-known and commercially available technology suitable for local production of hydrogen, e.g. in port as long as an adequate supply of electricity is available. This would eliminate the need for long-distance distribution infrastructure. In the future, liquid hydrogen might be transported to ports from storage sites where hydrogen is produced from surplus renewable energy, such as wind power, whenever energy production exceeds grid demand. Hydrogen can also be produced from natural gas, which is globally available.
Storage	For use on ships, hydrogen can either be stored as a cryogenic liquid (at ~-253°C), as compressed gas (200 – 700 bar). Hydrogen storage as a liquefied gas achieves a significantly higher energy-density than that of compressed hydrogen. Due to the very low boiling point of hydrogen, super-insulated pressure vessels are used for storage in liquid (cryogenic) form. Boil-off is unavoidable, and the boil-off rate, which depends on the relationship between tank surface area and volume, can be 0.3 to 0.5 per cent per day depending on technology and conditions. A major barrier to the implementation of hydrogen as a fuel on larger ocean-going ships is its volumetric energy density, which is much less than that of HFO/LNG.
Application	Fuel cells is considered the key technology for hydrogen, however, other applications are also under consideration, including gas turbines and internal combustion engines in stand-alone operation or in arrangements incorporating fuel cells. The first major hydrogen-fueled ferry is set to enter operation in 2021 with low-temperature PEMFCs.
Technological maturity	Currently, the usage of hydrogen as fuel for ships has been restricted to large-scale piloting. Developments are, however, fast-paced with a hydrogen-fuelled ferry with capacity of 299 passengers set to enter operation in Norway in 2021. In the past, hydrogen has been used as a fuel for fuel cells in niche applications such as for some submarines. Developments of hydrogen-fuelled vessels has so far favoured its use in PEMFCs, with its application in other fuel cells and in ICEs at a less mature stage.
Environmental performance	Electro-, bio-, or fossil-based hydrogen may be produced environmental-friendly in different ways. Notably, current development initiatives explore hydrogen production from natural gas while safely capturing and storing the resulting CO_2 (CCS). Hydrogen used in fuel cells as energy converters does not produce any CO_2 emissions and could eliminate NOx, SOx and particulate matter (PM) emissions from ships, resulting in zero-emission. Hydrogen-fuelled internal combustion engines for marine applications could also minimize greenhouse gas (GHG) emissions, while NOx emissions cannot be avoided when using combustion engines.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

Methanol – production pathways



Bio-based

Biomass → Gasification → H_2 → Methanol Synthesis → Methanol

CO_2

Electro-based

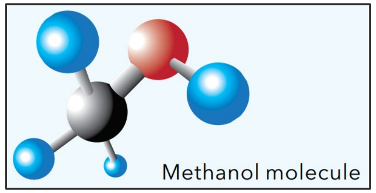
Water → Electrolysis → H_2 → Methanol Synthesis → Methanol

CO_2

Fossil-based

Hydrocarbon → Reforming → H_2 → Methanol Synthesis → Methanol

CO_2



Methanol molecule

General

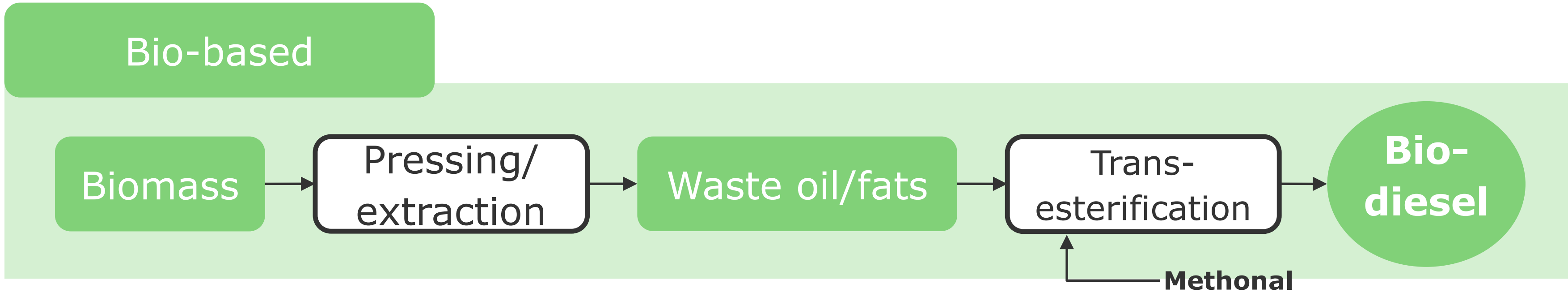
With its chemical structure CH_3OH, methanol is the simplest alcohol with the lowest carbon content and highest hydrogen content of any liquid fuel. Methanol is a basic building block for hundreds of essential chemical commodities and is also used as a fuel for transport. It can be produced in three primary ways, from biomass, hydrocarbons, or electrolysis of water. In each case, a source of CO_2 is required for methanol synthesis.

Methanol - key characteristics

Availability	The global methanol demand was approximately 80 million tonnes in 2016, twice the 2006 amount. The production capacity is more than 110 million tonnes. Most methanol is currently consumed in Asia (more than 60 per cent of global demand), where demand has been increasing for the last few years. Methanol is one of the top five chemical commodities shipped around the world each year. It is readily available through existing global terminal infrastructure and well positioned to reliably supply the global marine industry. However, dedicated bunkering infrastructure for ships is currently limited. Distribution to ships can be accomplished either by truck or by bunker vessel.
Storage	Methanol is a liquid between –93°C and 65°C at atmospheric pressure, which entails that it is more easily stored on board ships than some other alternative fuels such as LNG. It may be stored in standard fuel tanks with minor modifications. Its volumetric energy density is, however, significantly lower than conventional fuels. Therefore, when compared to a conventional fuel like MGO, approximately twice as much volume is needed to store the same amount of energy on board ships.
Application	There are two main options for using methanol as fuel in conventional ship engines; in a two-stroke diesel-cycle engine or in a four-stroke, lean-burn Otto-cycle engine. Both options has seen real-life operation for extended periods of time on board ships, and use pilot fuel oil ignition. Another possibility would be to use methanol in fuel cells, which is in a less mature technical stage.
Technological Maturity	For the time being, only methanol-fuelled two-stroke dual fuel diesel engines, as part of the MAN ME-LGI series, is commercially available on the marine propulsion market. Wärtsilä 4-stroke engines are, however, in operation on board the passenger ferry Stena Germanica, fuelled by methanol. Use of methanol as a fuel on major ships has a relatively short track-record (first ship retrofitted in 2015), and so far it has largely been restricted to the niche market of methanol tankers.
Environmental performance	Methanol-combustion in an internal combustion engine reduces CO_2 emissions (tank-to-propeller) by approximately 10 per cent compared to oil. The exact value may differ depending on whether methanol is compared with HFO or distillate fuel. When considering the complete life cycle (well-to-tank and tank-to-propeller) including the production of the fuel from natural gas (without CCS), the total GHG emissions are equivalent to or slightly higher (in the order of 5 per cent) than the corresponding emissions of oil-based fuels. The well-to-tank emissions of bio-based or electro-based methanol have the potential to be carbon-neutral. If used along with a CCS system, fossil-based methanol also has a large potential for GHG reduction. Using methanol as a marine fuel virtually eliminates sulfur oxide emissions. It is also expected that particulate matter (PM) emissions will be significantly lower. The reduction of NOx emissions depends on the engine-technology used.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

Biodiesel (FAME) – production pathways



Bio-based

Biomass

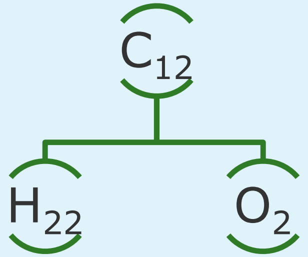
Pressing/ extraction

Waste oil/fats

Trans-esterification

Bio-diesel

Methonal



C_{12}

H_{22}

O_2

Biodiesel (FAME) molecular formula

General

Fatty-Acid Methyl Ester (FAME), also commonly referred to as biodiesel, is produced from a variety of different oils and fats through a process called transesterification. Properties of FAME depends on the type of vegetable oil or animal fat used for production. Generally, its properties resemble those of fossil diesel, however, there are significant differences. FAME is consequently not categorised as a drop-in biofuel, unlike synthetic diesel (ref. to previous slides). FAME is usually referred to as biodiesel since it is commonly blended in fossil diesel to create a cleaner fuel for road-transport in many countries. Production of FAME is commercial, and it is the biofuel with the second-highest production (after ethanol).

Biodiesel (FAME) - key characteristics

Availability

In 2018, the total production of FAME amounted to approximately 27 Mtoe. The biggest producers of FAME are based in the USA, Brazil, and the EU. The main feedstocks used for production are vegetable oils such as pal, soy and canola oils, depending on where FAME is produced. Some animal fats are also used for production. The vast majority of FAME is applied in road-transportation, and the availability of FAME for shipping is low.

Storage

FAME is a liquid in atmospheric temperature and pressure, an may be stored in standard tanks. Long-term storage of FAME (>2 months) is not recommended due to the fact that it may degrade as a fuel. The extent of this problem is higher for blends with higher concentrations of FAME. FAME has a slightly lower volumetric energy-density when than MGO, but higher than many other alternative fuels such as ammonia.

Application

FAME is only used as a fuel in ICEs. FAME, on account of not being a hydrocarbon, is not as compatible with existing marine energy converters as the synthetic diesels (HVO and F-T). It is theoretically possible to run engines on 100% FAME, however, this requires engine-adjustments and approval from engine manufacturers. This is the reason why FAME is usually blended with fossil diesels for use in engines, with the ISO 8217 standard, specifying that no more than 7% FAME blended with fossil diesel is to be used for on-spec marine fuel.

Technological maturity

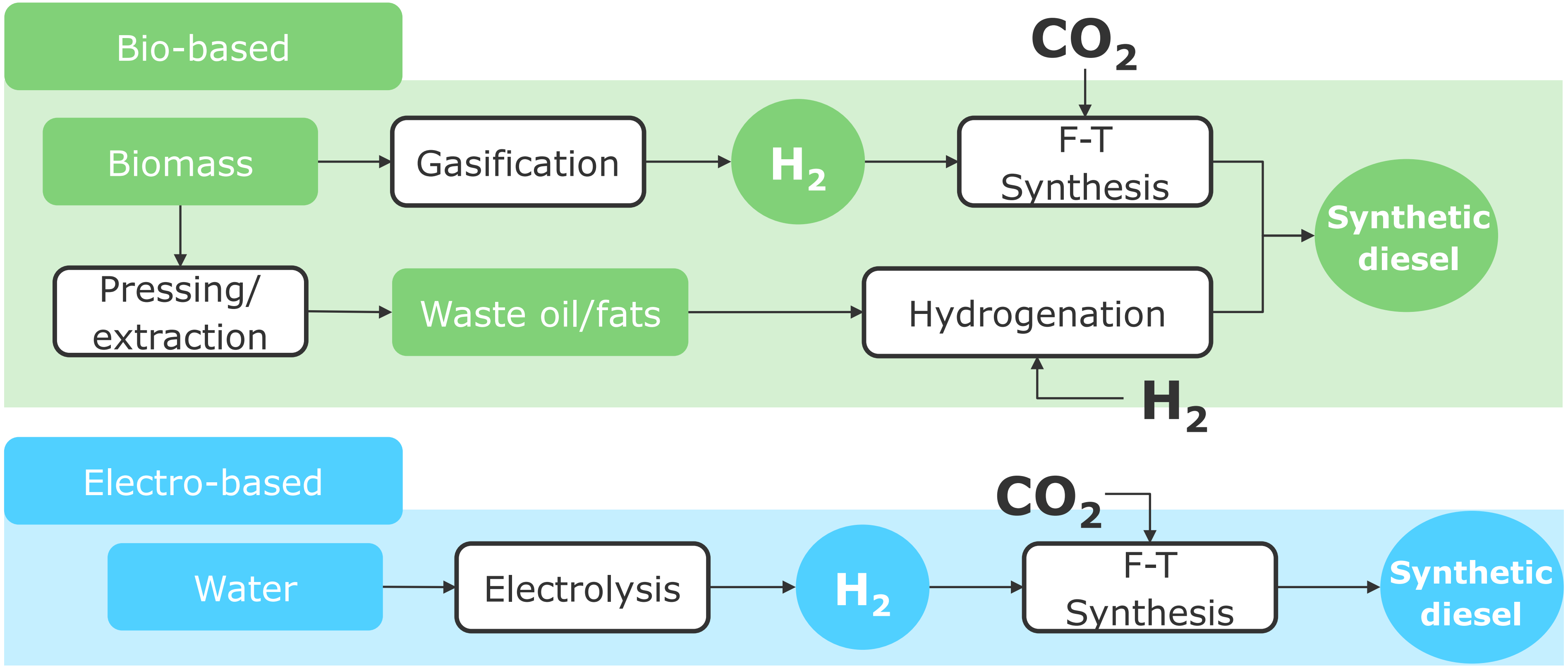
Since FAME, to a large degree, may be used on existing marine engines and fuel storage systems, its technical maturity is high. Adjustments must be made to propulsion systems, however, to account for the differences between FAME and fossil diesel. For instance, use of FAME may lead to filter clogging in the engine due to its high cloud point. FAME also has the ability to dissolve certain non-metallic materials. Therefore, susceptible parts of the fuel supply system and engine must be changed prior to operation on FAME.

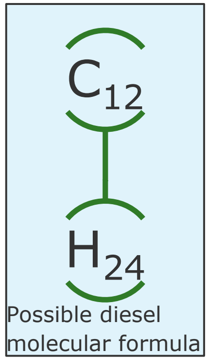
Environmental performance

The GHG reduction potentials for FAME is largely dependent on the source of biomass. Carbon neutrality is possible because biomass is derived from feedstock which absorbs CO_2 from the atmosphere when growing. However, in practice, taking a lifecycle approach, carbon-neutrality will depend on the type of biomass used for production of FAME. Effects such as indirect land-usage change must be taken into account, when evaluating the sustainability of FAME-production. SOx emissions are virtually extinguished when using FAME as a marine fuel, the fuel contains little (if any) sulphur. NOx emission will inherently still be present due to the use of ICEs for propulsion.

Source: DNV GL Internal Biofuel Study

Synthetic diesel (HVO) – production pathways





Possible diesel molecular formula

General

Synthetic diesel has two primary production pathways, bio-based or electro-based. Using biomass, synthetic diesel may be produced in different ways including hydrotreatment of waste oils and fats (known as hydrotreated vegetable oil) or from Fischer-Tropsch synthesis using hydrogen produced from gasification of biomass. As implied by its name, synthetic diesel is a hydrocarbon with equivalent properties to those of fossil-based conventional diesel.

Synthetic diesel (HVO)– - key characteristics

Availability	Synthetic diesel may be distributed using existing infrastructure in place for MGO or HFO. Unlike MGO and HFO, the current production of synthetic diesel is very limited. Bio-based synthetic diesel (more specifically hydrotreated vegetable oil (HVO)), is by far the largest production-pathway for synthetic diesel, and its production amounted to the equivalent of 5.8 Mtoe. When considering that the total consumption of marine fuel was at the level of approximately 274 Mtoe in 2018, a massive production-upscale is needed if synthetic diesel is to play a significant role in the future marine fuel-mix.
Storage	Synthetic diesel is, similarly to conventional diesel, stored as a liquid in standard tanks.
Application	Synthetic diesel may be applied on board ships compatible with HFO or MGO. This includes various slow-, medium-, and high-speed engines.
Technological maturity	The technical maturity of on board propulsion and energy storage systems for synthetic diesel is very high, owing to the fact that it is compatible with existing systems designed for use with MGO or HFO.
Environmental performance	The GHG reduction potentials for synthetic diesel is largely dependent on the production-pathway. For electro-based synthetic fuels, carbon-neutrality is possible assuming that renewable electricity is used for hydrogen production. For bio-based synthetic diesel, carbon neutrality is possible because biomass is derived from feedstock which absorbs CO_2 from the atmosphere when growing. However, in practice, taking a lifecycle approach, carbon-neutrality will depend on the type of biomass used for production of synthetic diesel. SOx emissions are virtually extinguished when using synthetic diesel as a marine fuel, the fuel contains little (if any) sulphur. NOx emission will inherently still be present due to the use of ICEs for propulsion.

Source: DNV GL Comparison of Alternative Marine Fuels, DNV GL Assessment of Alternative Fuels and Technologies

Thank You!

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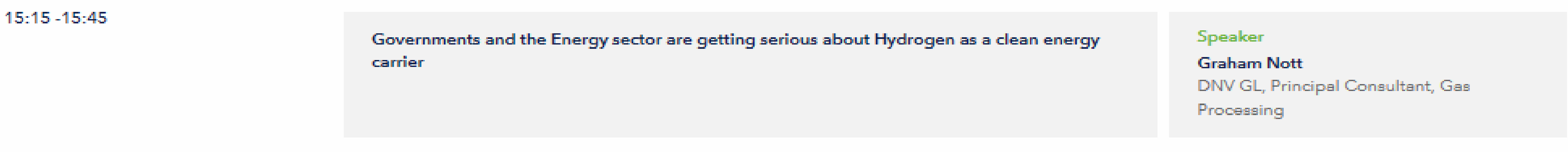
SAFER, SMARTER, GREENER

LNG Day Program Agenda



15:15 -15:45

Governments and the Energy sector are getting serious about Hydrogen as a clean energy carrier

Speaker

Graham Nott

DNV GL, Principal Consultant, Gas Processing

Hydrogen as an Enabler of Decarbonization

Ton van Wingerden
04 December 2019

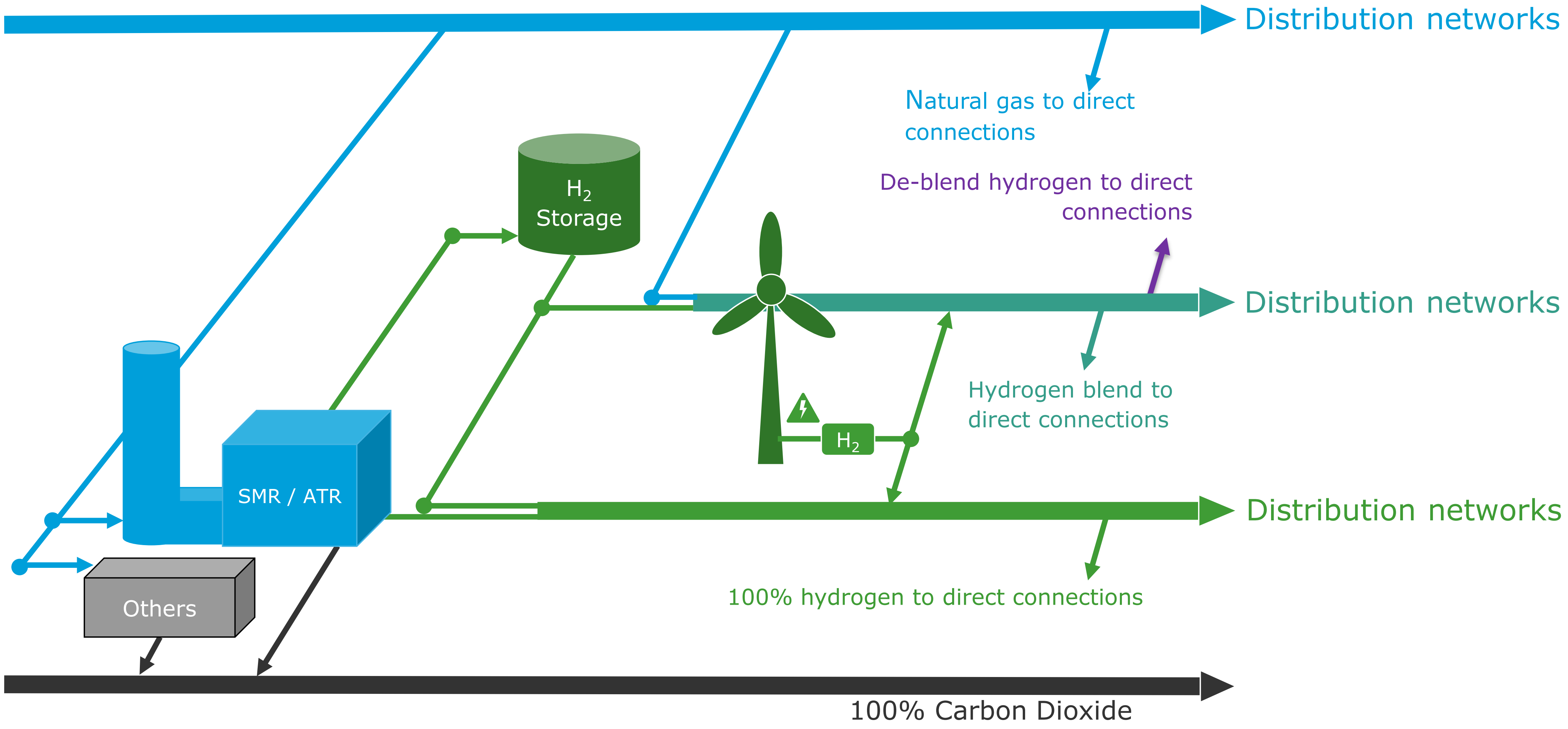
Role for hydrogen

Hydrogen – a common element of the future energy supply?

- Current momentum for hydrogen is unprecedented, with more and more policies, projects and plans by governments and companies - all over the world
- Hydrogen is expected to overcome many expected energy challenges
  - Integrate more renewables, including storage options and tapping their full potential
  - Decarbonize hard-to-abate sectors: steel , chemicals, trucks, ships and planes
  - Enhance energy security by diversifying the fuel mix and providing flexibility to balance grids
- Challenges
  - Costs need to fall for electrolysis
  - Infrastructure needs to be developed
  - Cleaner hydrogen is needed
  - Regulatory barriers persist

Source: IEA report: The Future of Hydrogen

Hydrogen in the On-Shore Gas Networks

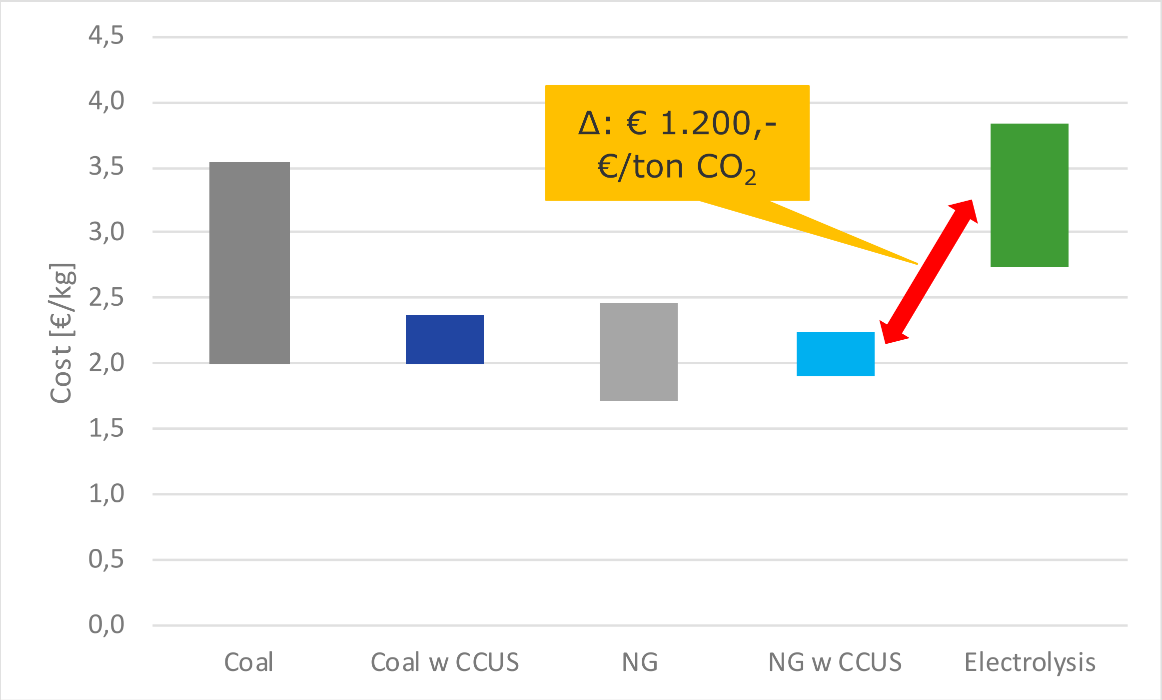


Three colours of hydrogen

- **GREY:** steam reforming from coal or natural gas: 8 – 10 kg CO_2/kg H_2

- **BLUE:** steam reforming with CCS: 0,8 – 1,0 kg CO_2/kg H_2

- **GREEN:** from green electricity or biomass: no CO_2

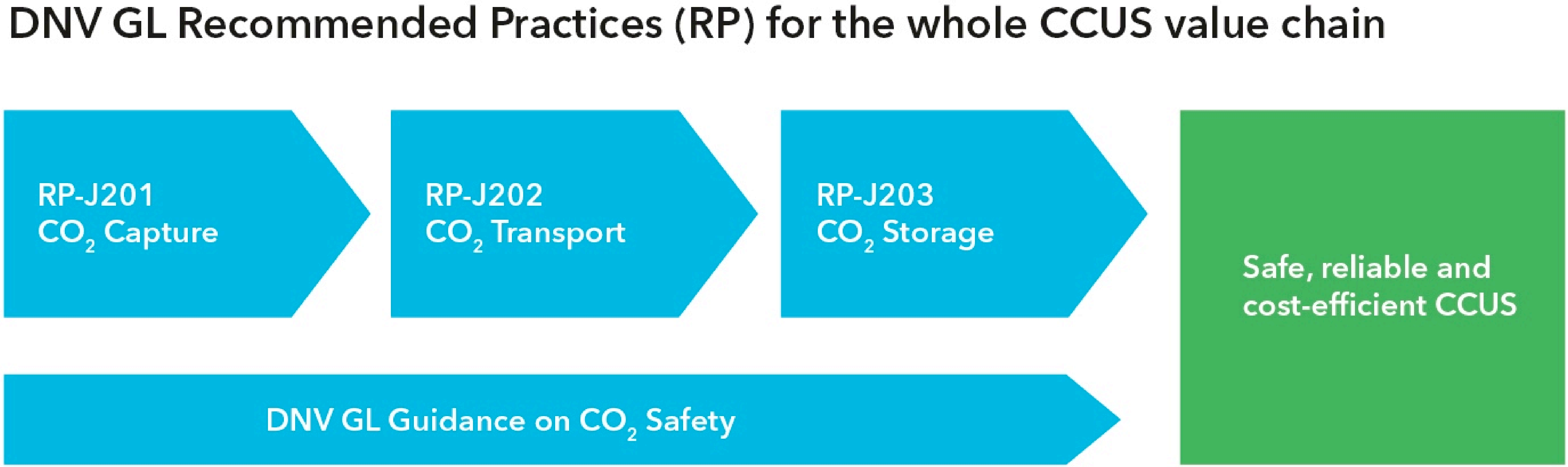


Source: IEA

Production cost for Europe

The hydrogen narrative for gas comes with CCS

1. **Reduce emissions:** Decarbonize existing hydrogen use in industry.
2. **Maintain role of gas:** Allow hydrogen from gas to be a low-carbon solution on par with green hydrogen and green electricity (i.e., allow cost competitiveness to decide).



DNV GL Recommended Practices (RP) for the whole CCUS value chain

RP-J201
CO_2 Capture

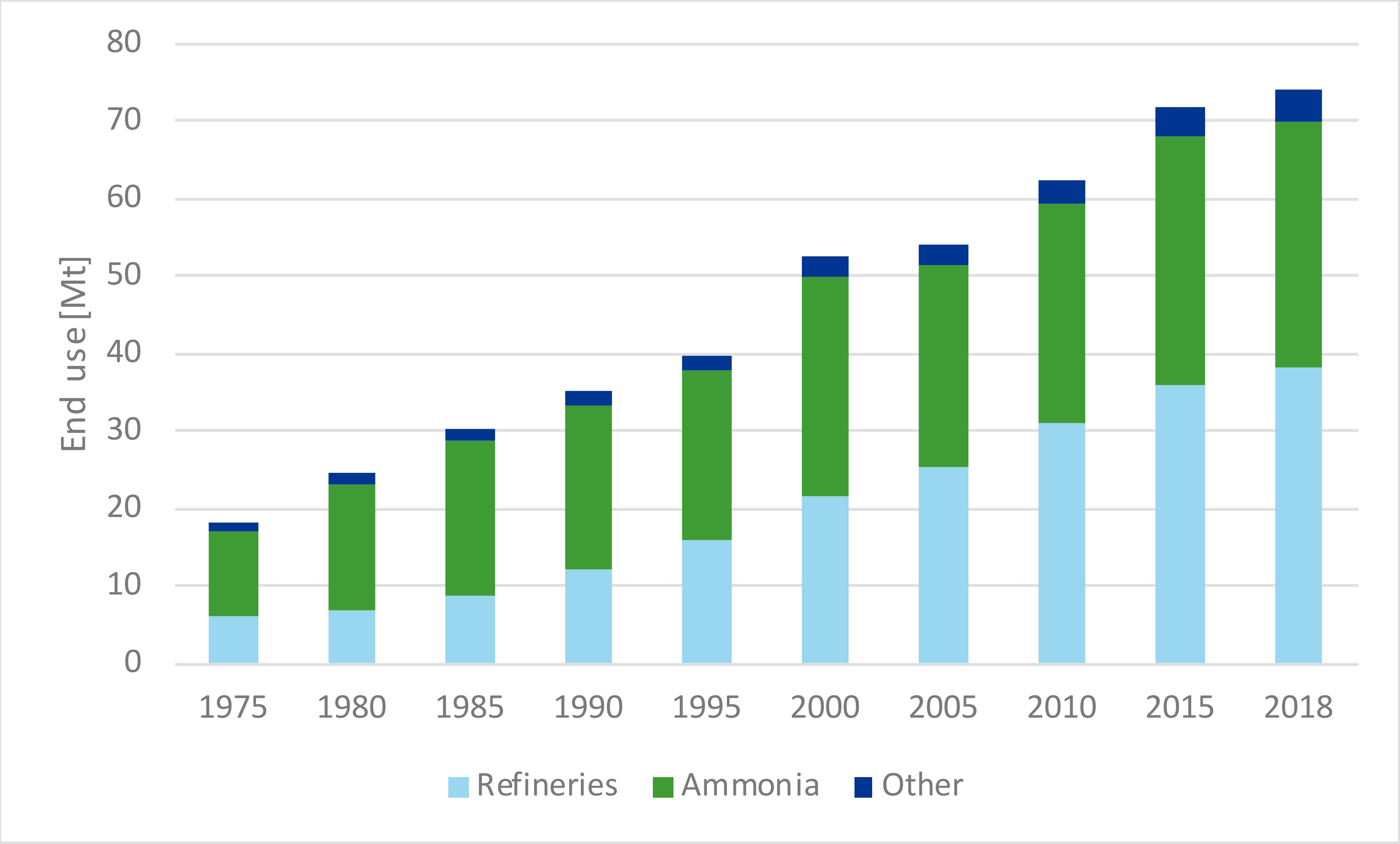
RP-J202
CO_2 Transport

RP-J203
CO_2 Storage

DNV GL Guidance on CO_2 Safety

Safe, reliable and cost-efficient CCUS

Global demand for pure hydrogen 1975 – 2018: grey



Source: IEA

Current research consortia

Welcome to HyStreet at Spadeadam

Europe, Asia, Canada and US – HyReady JIP

- No current guidelines for gas transmission and distribution operators
- Output
  - Practical guidelines for hydrogen injection
  - Mitigation measures
  - Up to 30% hydrogen blend
  - Phase one - gas networks
  - Phase two - compressors and end-users
- DNV GL
  - Program coordination and implementation
  - Building on NaturalHy and HIPS projects

PG&E

FORTIS BC

ENBRIDGE Life Takes Energy

SoCalGas

enagas

gasNatural fenosa

Gas Networks Ireland

GRTgaz

GAZ system

TERĒGA

gasunie

DBI GUT Gas- und Umwelttechnik GmbH

DNV·GL

GRDF GAZ RÉSEAU DISTRIBUTION FRANCE

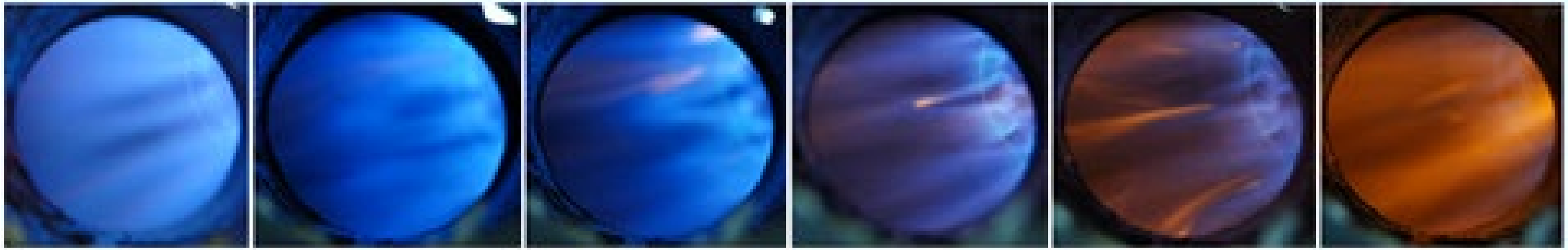
Hy4Heat

Objective: Demonstrate how 100% hydrogen can be safely delivered to domestic consumers.

DNV GL work: Aspects considered include:

- Required purity of hydrogen and if colourant needs to be added to make the flames visible.
- Development of hydrogen standards for industry.
- Experimental study to investigate how hydrogen leaks will disperse in homes and streets (using DNV GL's purpose-built terrace of test properties at Spadeadam known as HyStreet).
- https://www.hy4heat.info/

Europe – Burner Control System

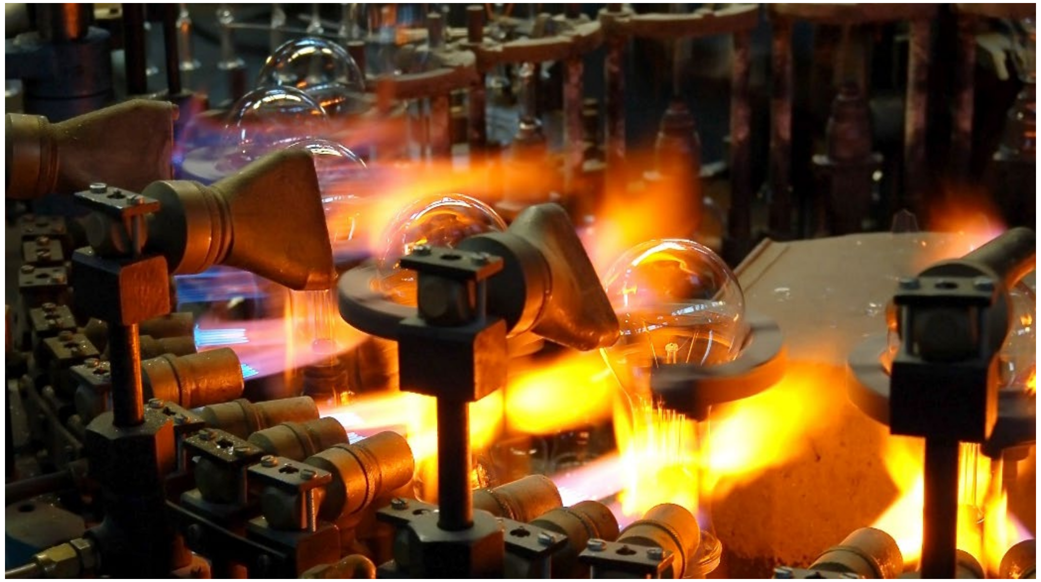


Natural Gas	100%	70%	40%	10%	5%	0%
Hydrogen	0%	30%	60%	90%	95%	100%

Full range fuel flexible burner control

Consortium of >25 companies (from ceramics industry and stakeholders)

- Hydrogen producers
- Gas transport/distribution companies
- Manufactures
- Suppliers of burners and control systems
- Boiler and oven manufacturers
- Industrial end-users
- Government



Netherlands - Rozenburg Apartment Complex

- Dutch Government running pilot projects
- 25 homes near Rotterdam
- Synthetic natural gas to hydrogen
  - 8% of heat demand (statutory limitation)
- DNV GL:
  - Burner engineering for hydrogen boilers
  - Life cycle emissions
  - Risk assessments
  - Verification of performance

Hydrogen for Heat

Production from green electricity

Gas grid operator Stedin

Rozenburg Boiler house

Zero-carbon comfort

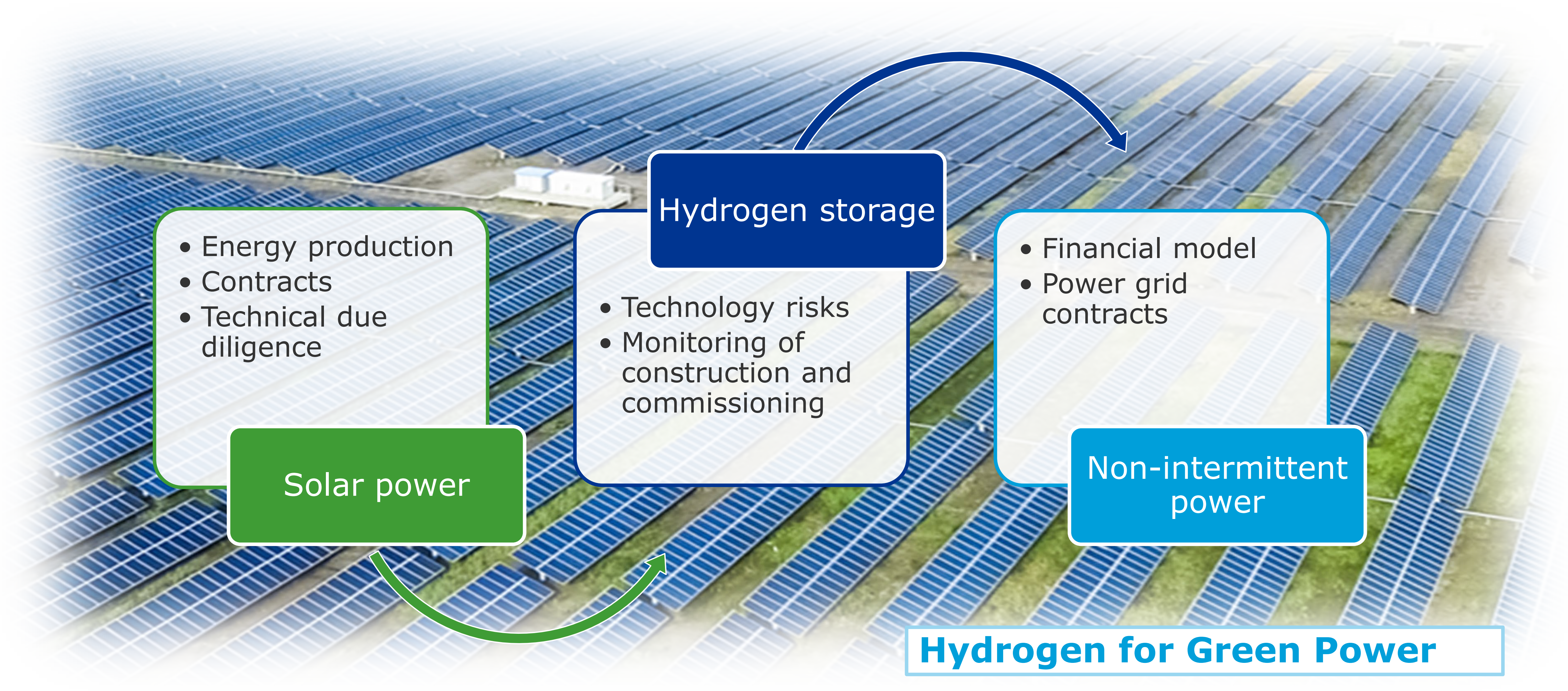
Equinor/Gassco Hydrogen Study: Hydrogen in UK Transport and Distribution System

Objective:

- Establish overview of materials used in the UK natural gas transmission and distribution pipeline system from import landfall station to the user.
- Evaluate gaps and possible risks of using existing natural gas system for transmission and distribution of hydrogen.

Contact person DNV GL: Bente H Leinum bente.Leinum@dnvgl.com

South America - Combined Solar and Hydrogen Storage



- Energy production
- Contracts
- Technical due diligence

Solar power

Hydrogen storage

- Technology risks
- Monitoring of construction and commissioning

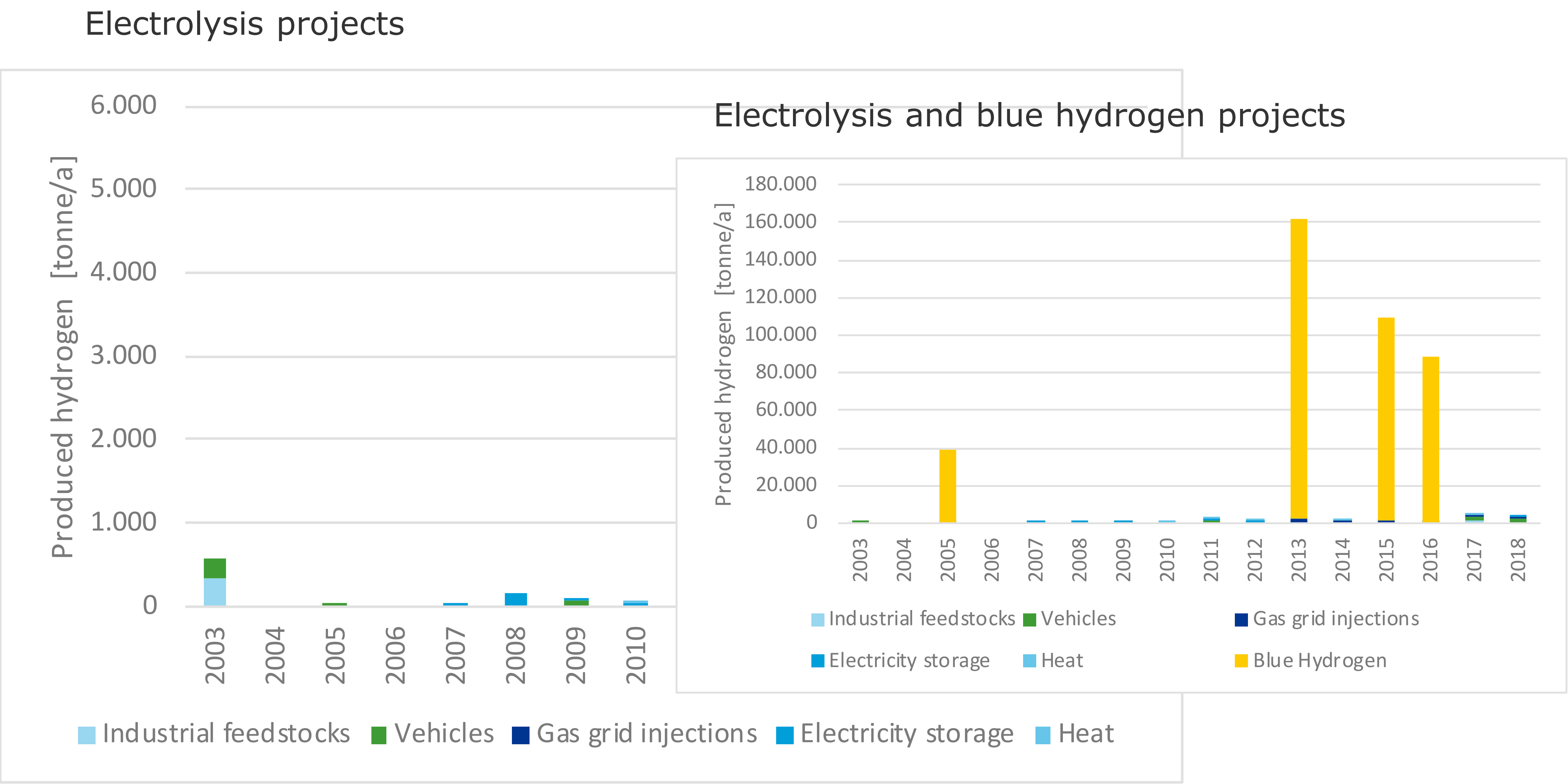
- Financial model
- Power grid contracts

Non-intermittent power

Hydrogen for Green Power

Hydrogen supply

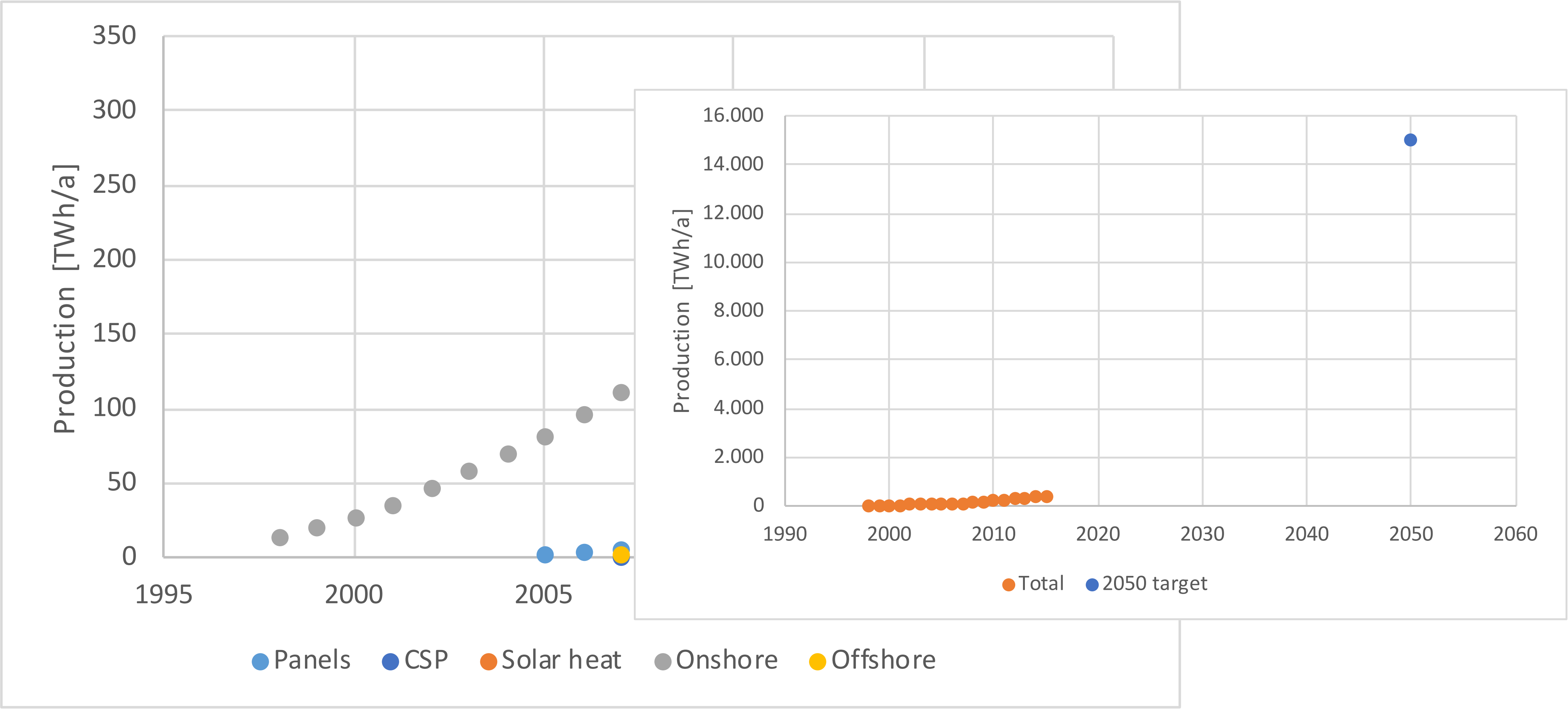
Capacity of new projects for hydrogen production



Source: IEA

The role of Hydrogen in the energy transition: Blue hydrogen will pave the way

Renewable energy in the EU is growing



Why blue hydrogen?

No need to wait for solar and wind: faster

Lower cost

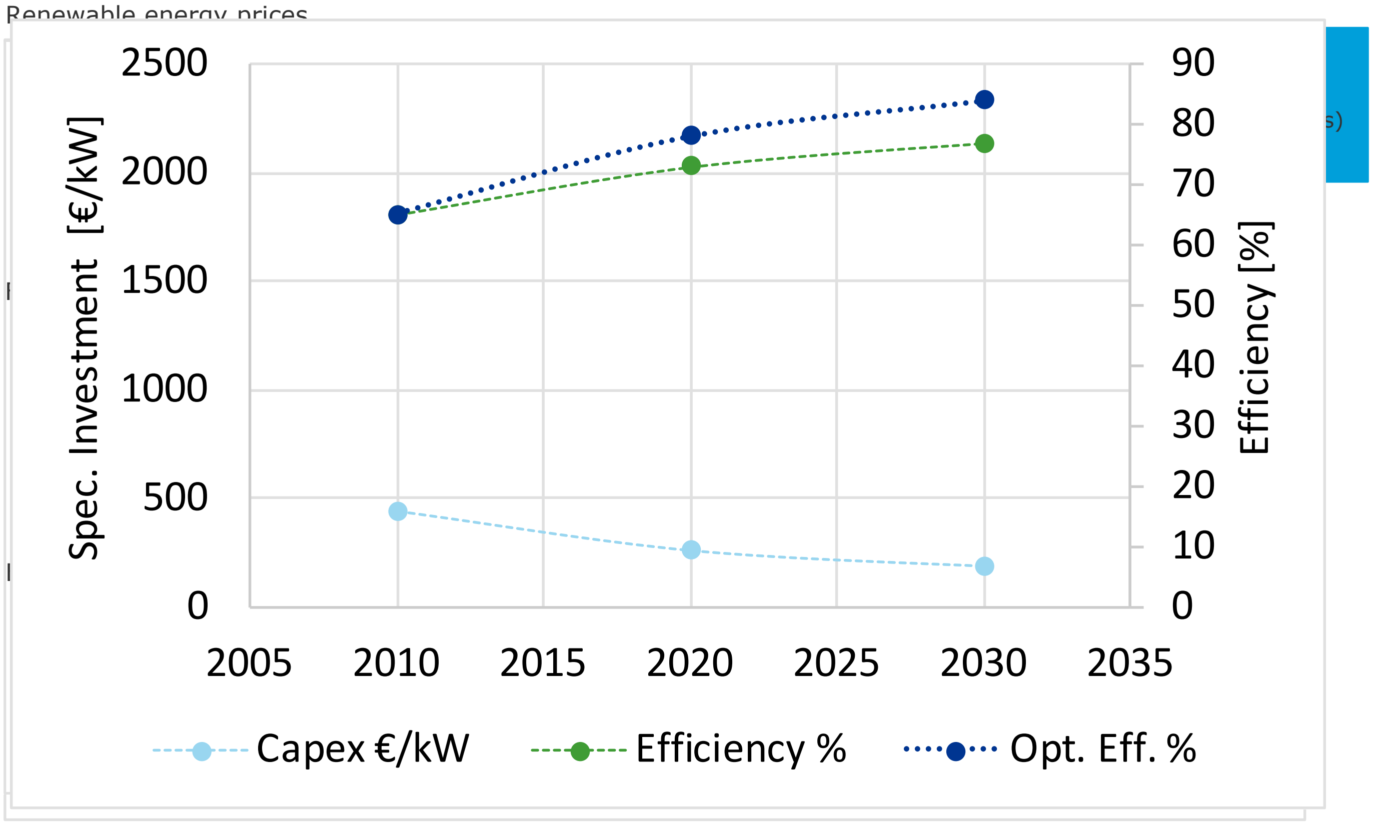
Involve oil companies

Market

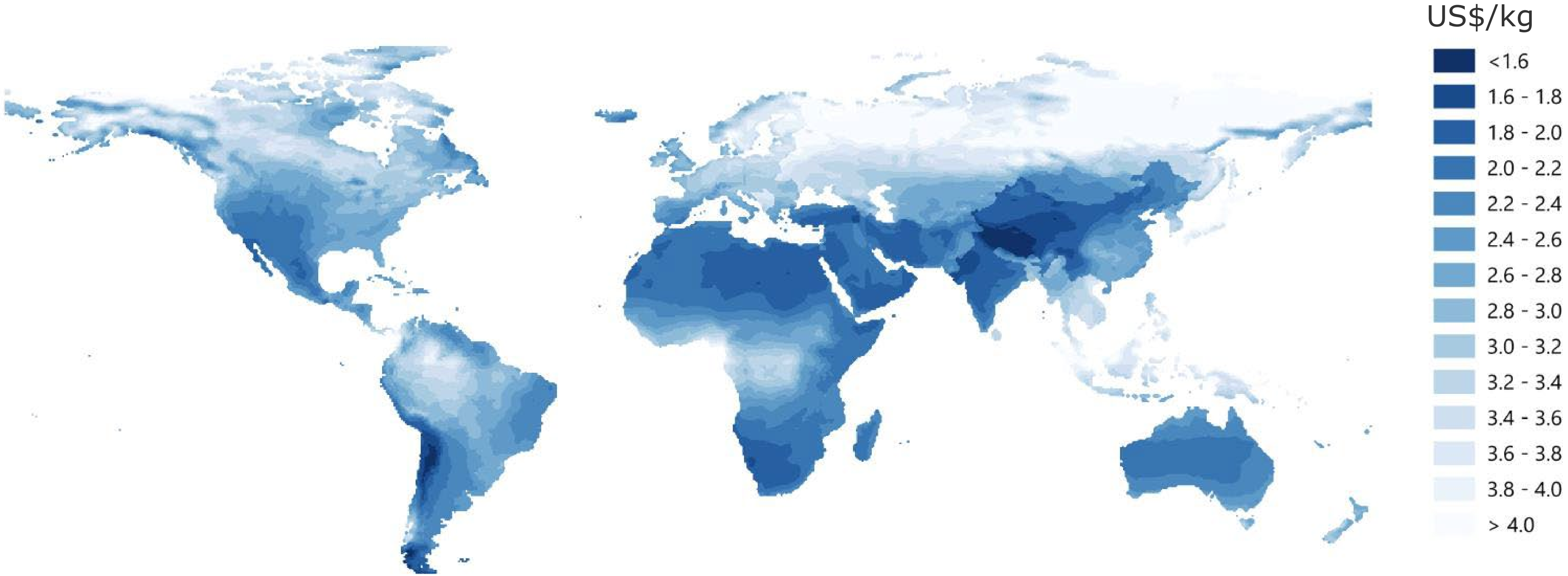
Balancing

Needs less storage

The role of Hydrogen in the energy transition: Prices are becoming competitive!



Long term hydrogen production cost from solar and wind systems

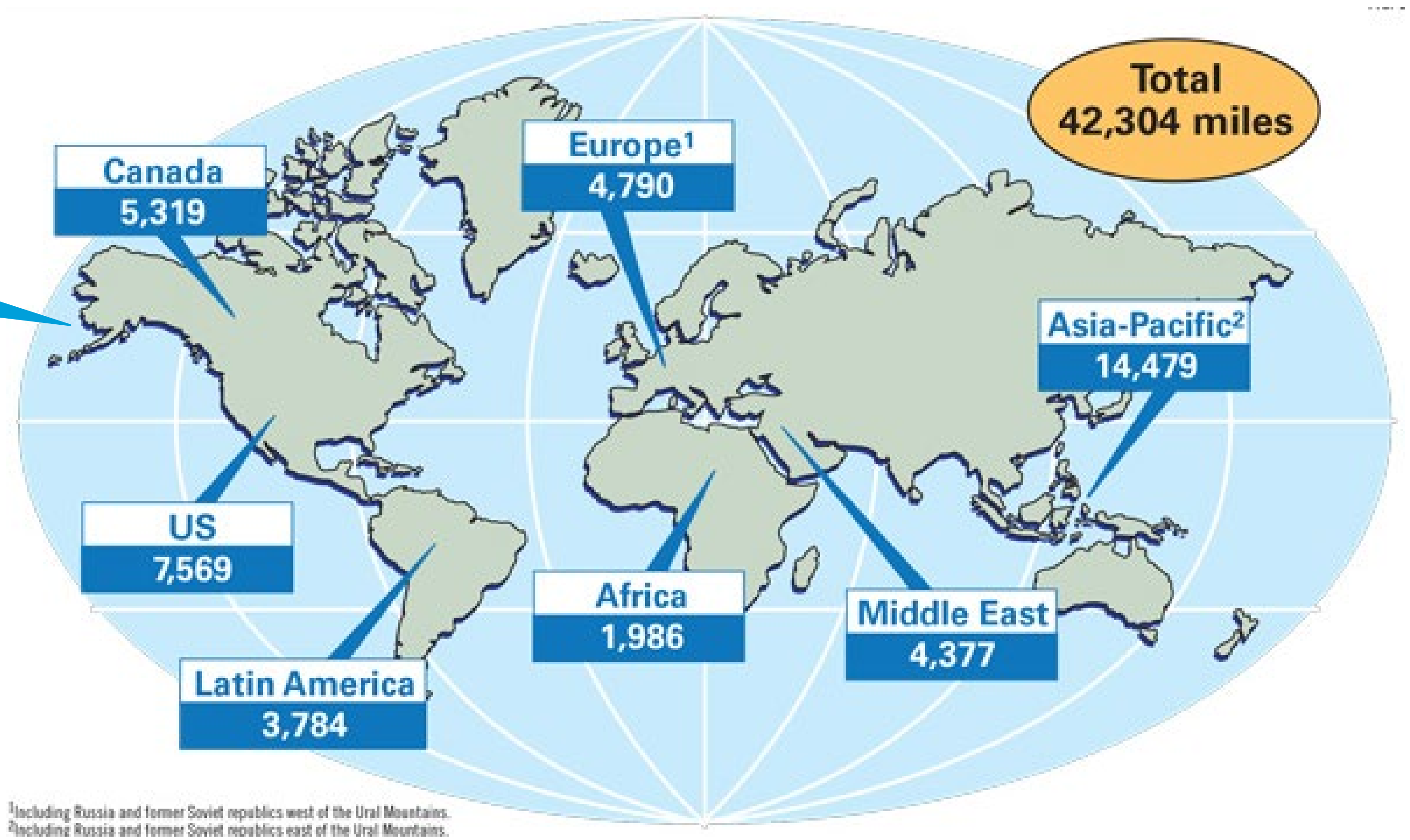


Source: IEA

Infrastructure

Forecast pipeline constructions

Hydrogen ready



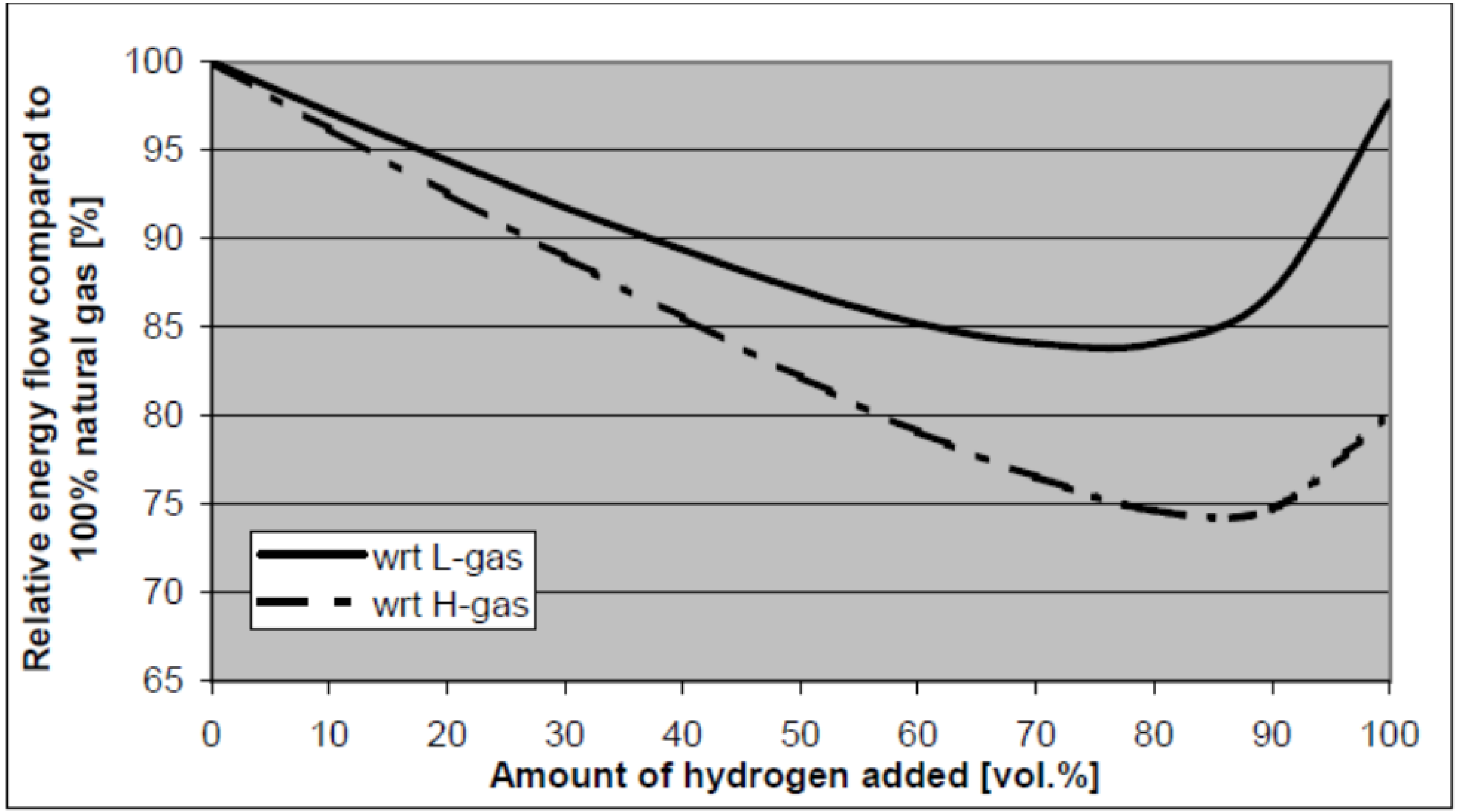
[1] Including Russia and former Soviet republics west of the Ural Mountains.
[2] Including Russia and former Soviet republics east of the Ural Mountains.

Source: Oil&Gas journal

Pipeline capacity

H_2 compared to CH_4:

- Energy/m³: $^1/_3$
- Density: $^1/_9$: velocity x3
- Energy flow ≈ similar



Note:

1. Pulsations and vibrations
2. Erosion

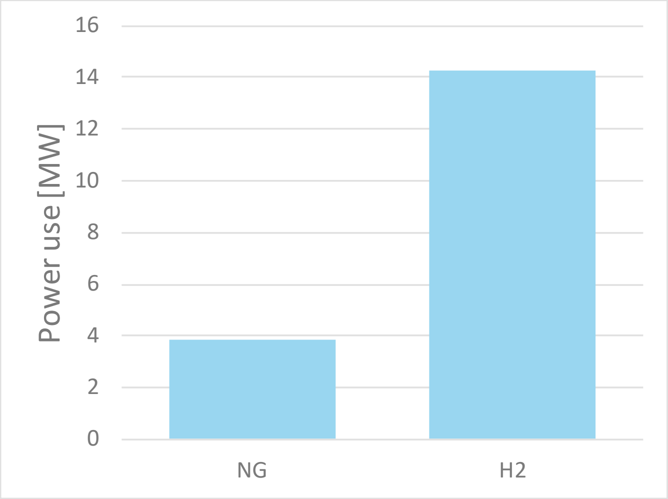
Compression: need to be replaced

Centrifugal

- 3 times larger volume:
  - 1.74 times higher rotation speed is required
- Energy need is 3-4 times higher
- two stages
- Large scale are being developed

Piston compressors

- More suitable
- Capital cost are lower
- Operation cost may be higher

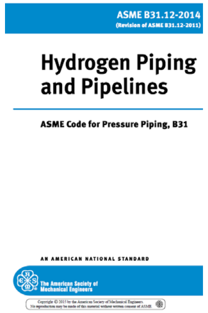


Material

- Transmission lines:
  1. Fatigue crack growth: Higher susceptibility hydrogen vs. natural gas, adjust operating parameters accordingly
  2. Crack propagation: Charpy V toughness should be 27J
  3. Hardness: ASME B31.12 for hydrogen transport requires hardness ≤ 250 HV. Not for natural gas

Codes for H2 pipelines:

- ASME B31.12-2014
- EIGA publication Hydrogen Transportation Pipelines

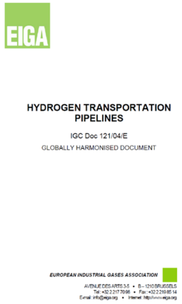

ASME B31.12-2014
(Revision of ASME B31.12-2011)

Hydrogen Piping and Pipelines

ASME Code for Pressure Piping, B31

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers


EIGA

HYDROGEN TRANSPORTATION PIPELINES

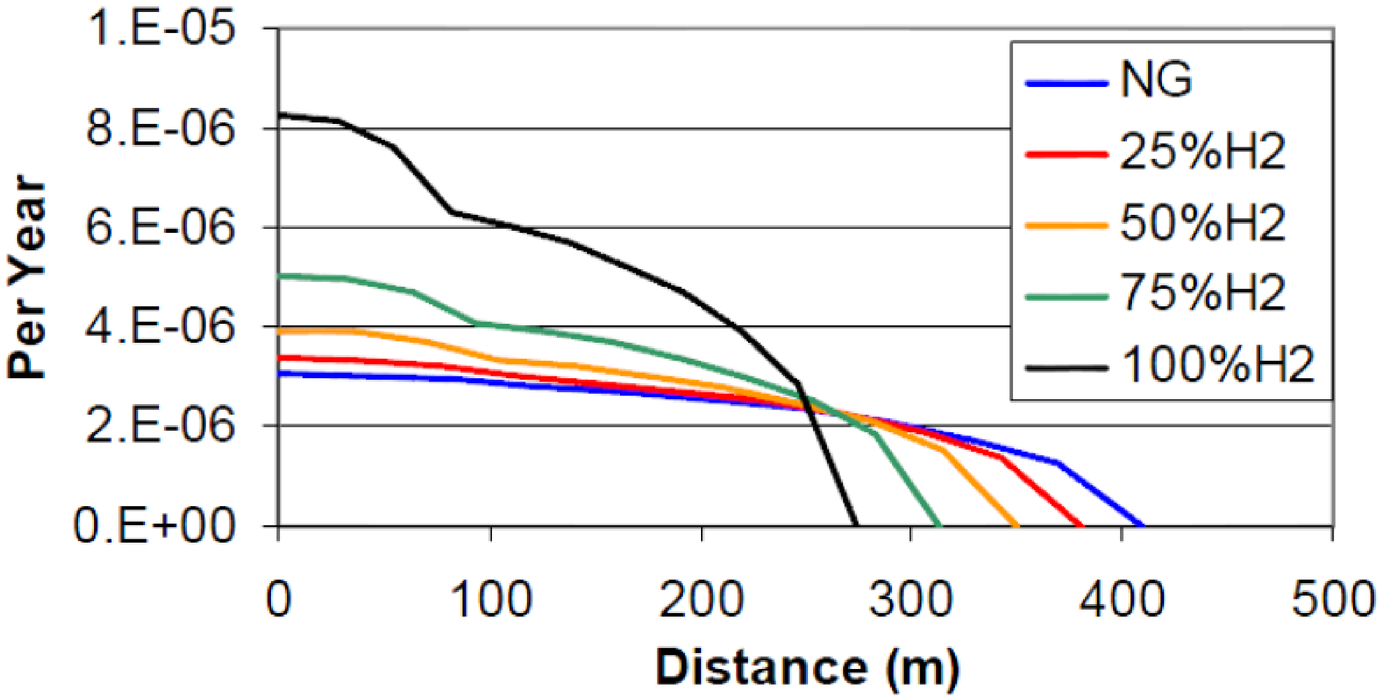
IGC Doc 121/04/E

GLOBALLY HARMONISED DOCUMENT

EUROPEAN INDUSTRIAL GASES ASSOCIATION

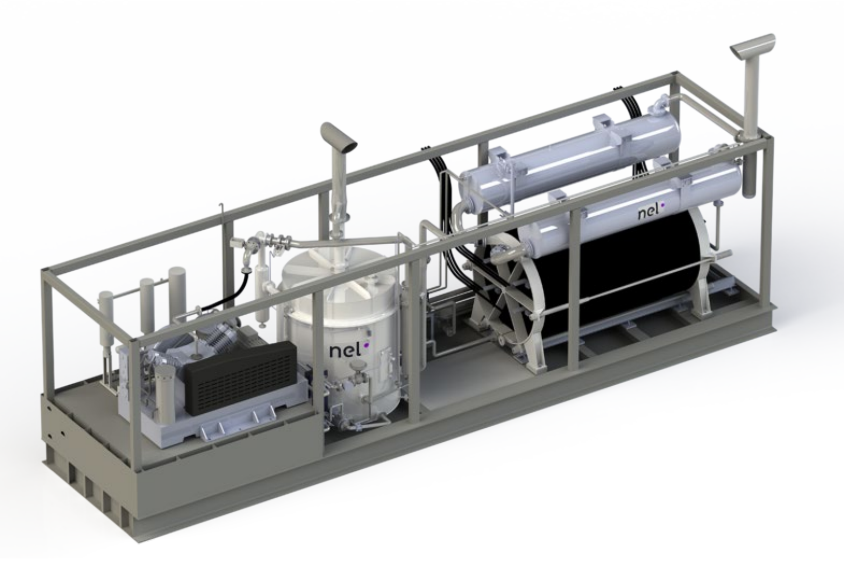
Safety distances

- Safety analysis from NaturalHy project for 36”, X65, 70 bar in rural area
- Individual risk



Technical Challenges and Safety Issues

Overview



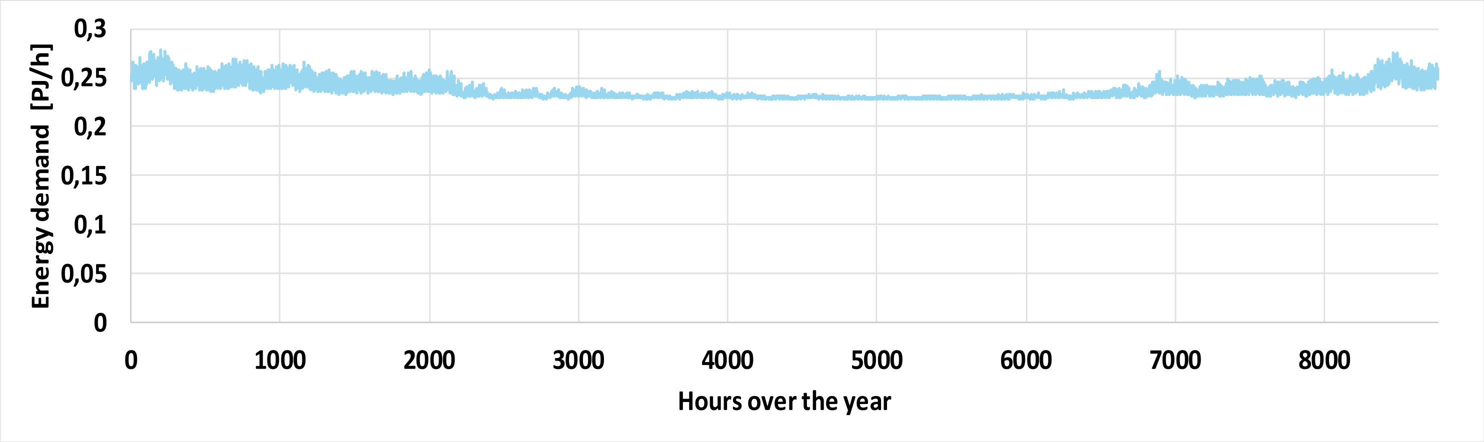
Electrolysis

Hydrogen storage

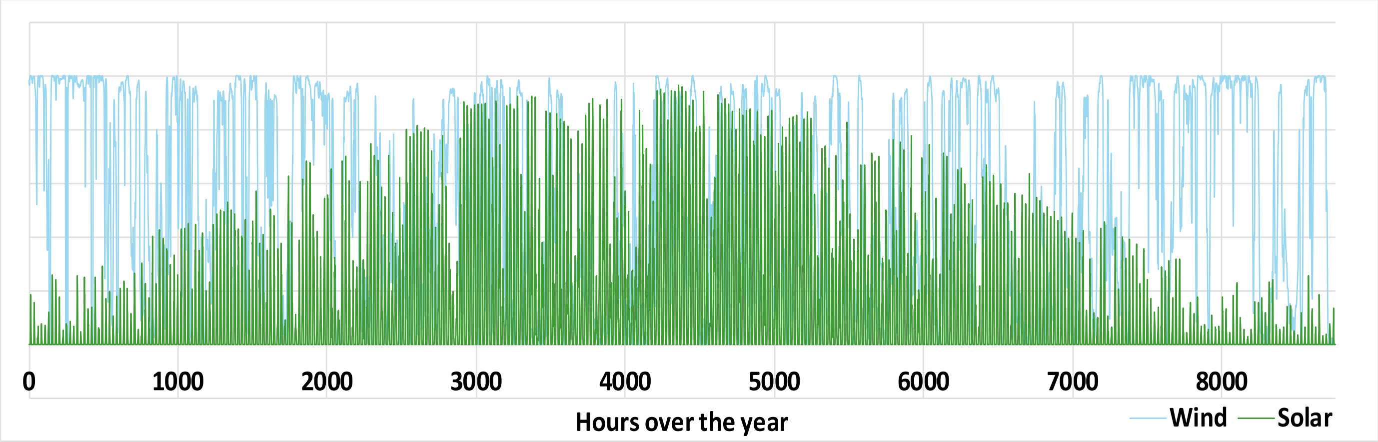
Safety

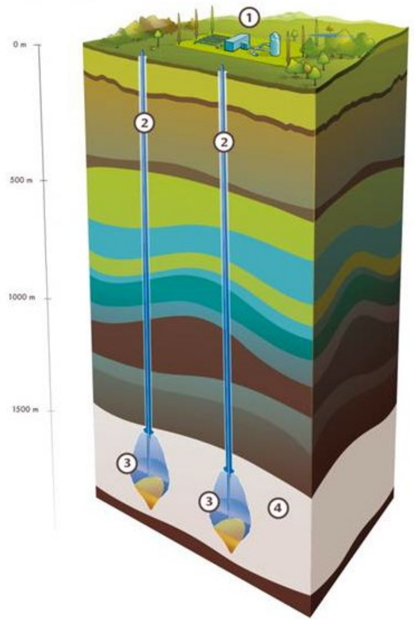
Storage

Sustainable energy supply

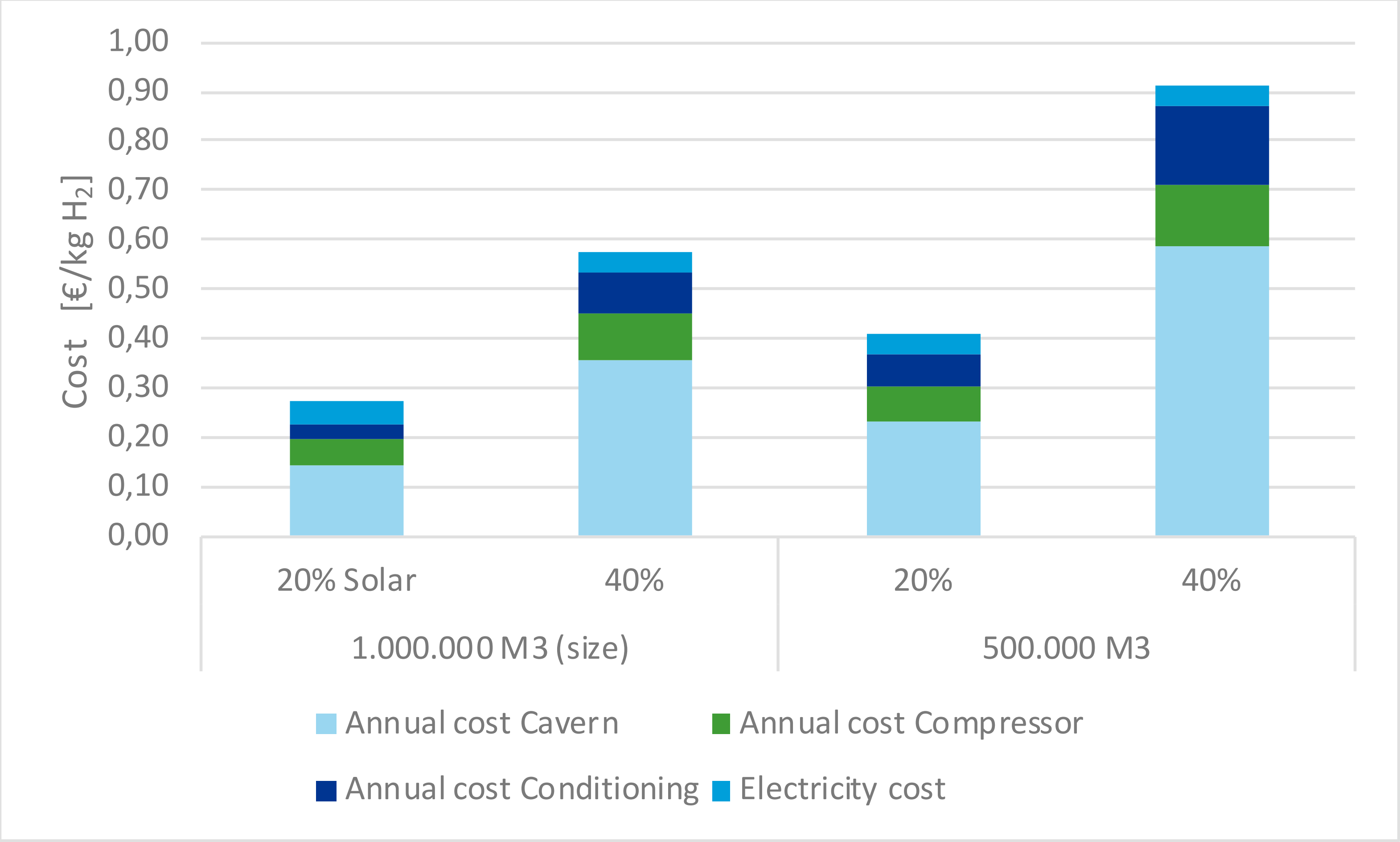


Fit with storage: H_2





Storage cost [€/kg stored H_2]

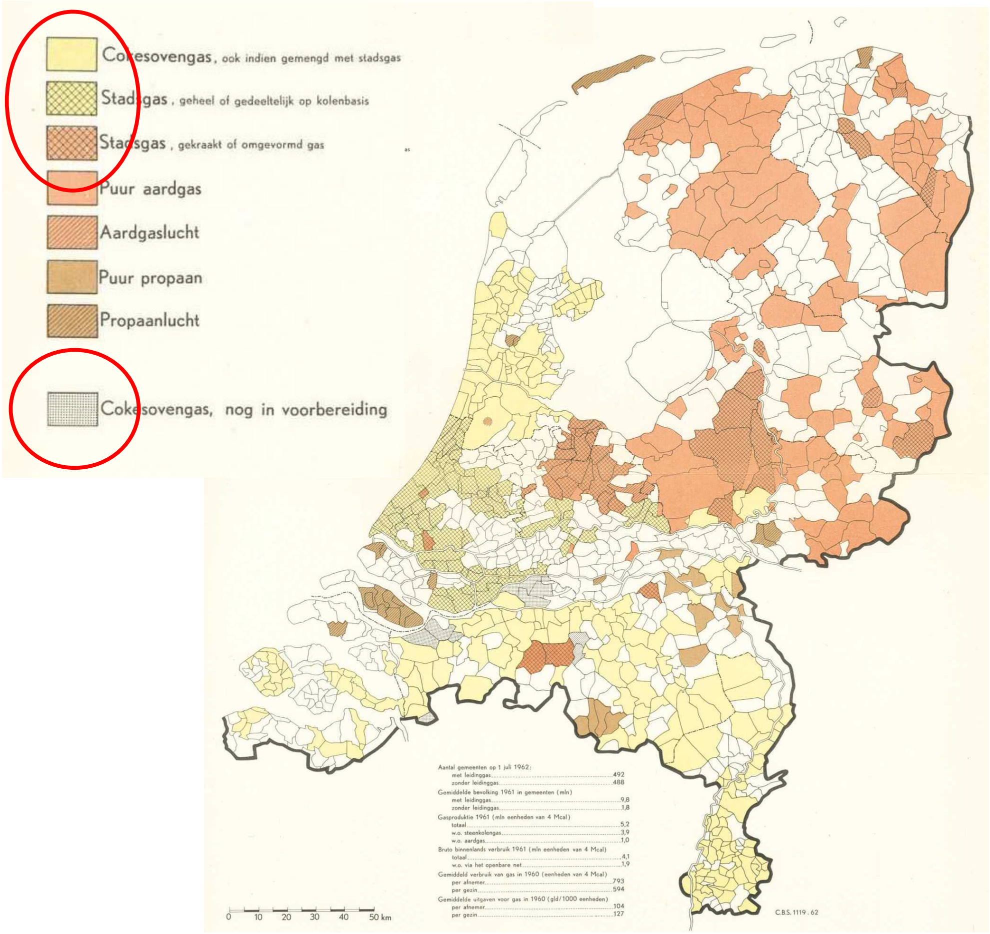


Conclusions storage

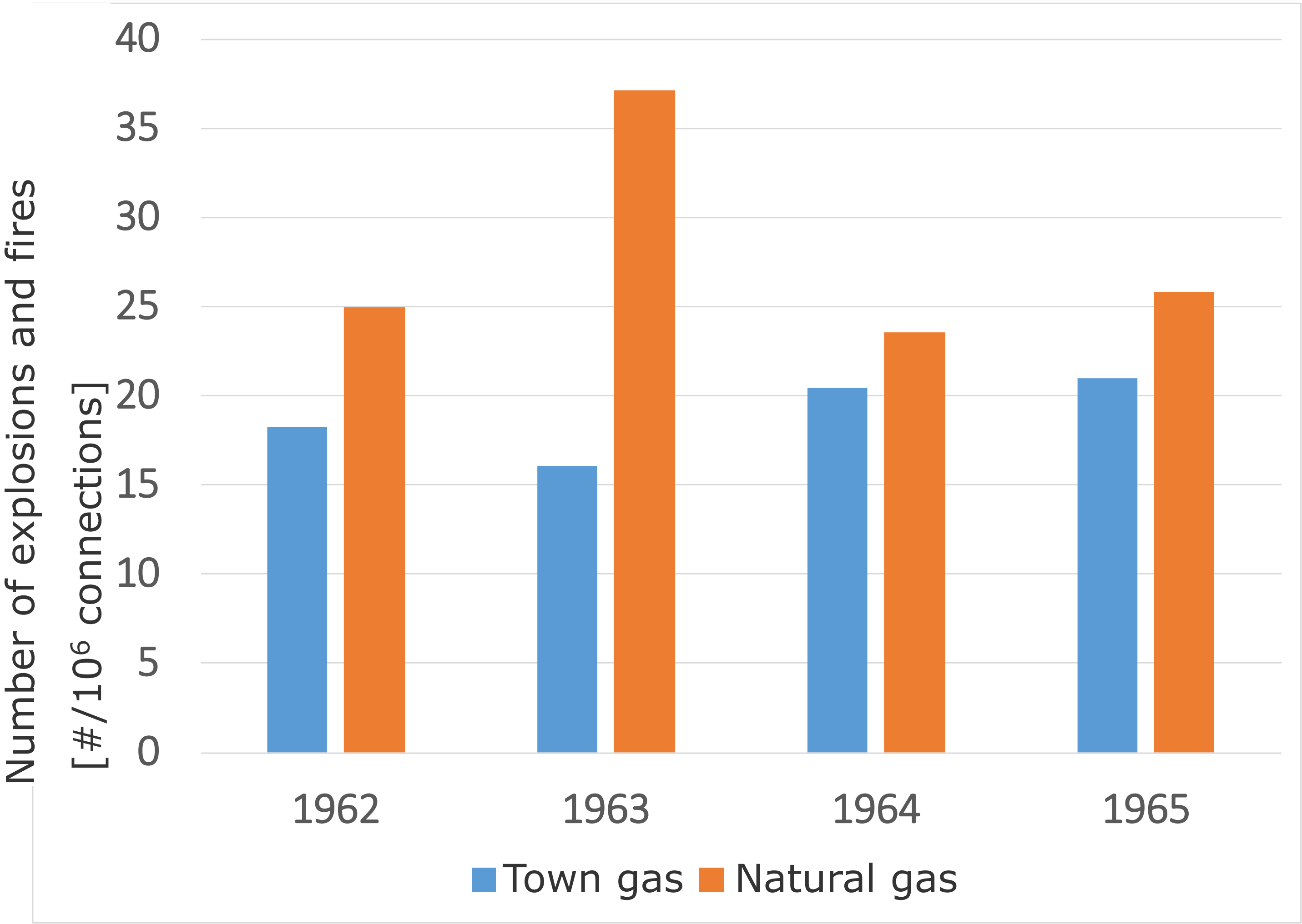
- Storage of blue hydrogen is more cost effective
- Blue hydrogen will pave the way
- Green hydrogen storage fits best for around 20% of solar power
- Storage adds 25 to 40 €ct/kg to the stored hydrogen price
- Overall prices are 7 to 11 €ct/kg for green H2
  2 to 4 €ct/kg for blue H2

Safety

Town gas statistics



Town gas 1962 The Netherlands



Thank you!

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SAFER, SMARTER, GREENER

LNG Day Program Agenda

15:45 -16:00

Session wrap-up/Adjourned

Speaker

Graeme Pirie

DNV GL, Vice President, Oil & Gas - Session Moderator

Thank You for Attending LNG Day

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