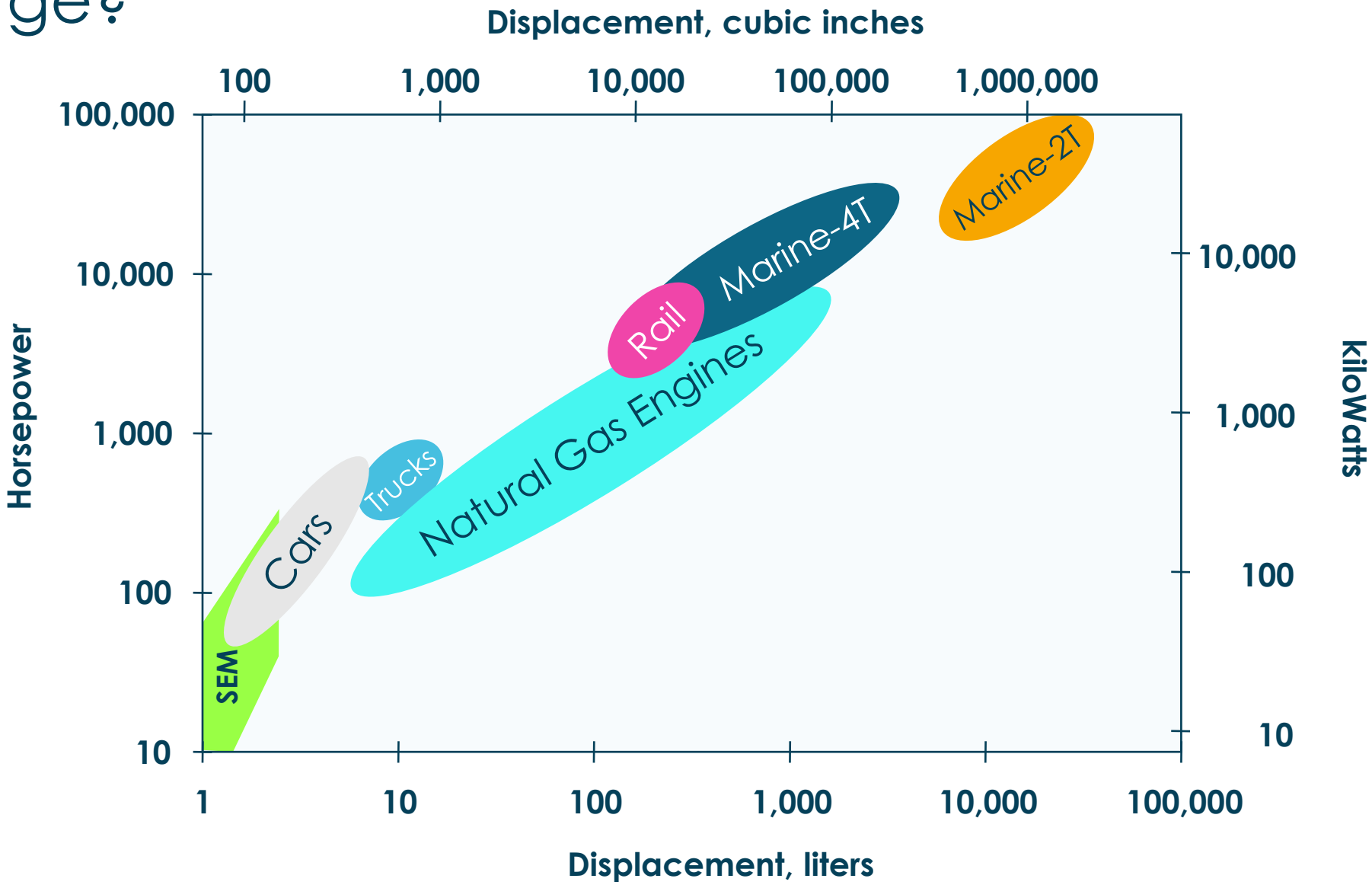
Infineum

Large Engine Lubricants

Outline

1. **Types of Large Engines:**
   Natural gas • Railroad & inland marine • Marine
2. **What Makes Them Different?**
   Fuels • Design features • Applications
3. **Lubrication Requirements:**
   Comparison with other engine oils
4. **What's New and Exciting?**

How Large?



Large engines – Common Concerns

Safety

Emissions

- Necessary to stay in business
- Target of increasing legislative pressure

SPECIFIC LIMITS NOT REVIEWED HERE

Fuel Economy

- Reduce cost

Reliability

- Generate revenue
- Minimize down-time
- Lives could depend on it

Durability

- Minimize maintenance costs
- Extend Time Between Overhaul and Oil Drain Interval
- Lengthen profitable life of asset

Large Engine Oils – Common Systems

No ‘Categories’ or formal industry rules

Although most circumstances follow similar procedures

Some OEMs have formal approval processes

Performance is demonstrated by field test

Under actual operating conditions

No special modifications to increase or decrease severity

Field Test typical procedure:

- Sign contracts and warranties
- Install pre-measured parts
- Run for required duration (typically one year)
- Oil analysis and engine operation monitoring
- Remove, measure, and rate parts

Every customer may want their own demonstration

Even for the same formulation

No industry categories. **Success is earned through field performance.**

Natural Gas Engine Oils

Gas Engine Intro Video

Gas Engine Applications

Gas Compression

- Also called transmission, gathering, or pumping
- "Free" fuel

Recycling

- Landfill and Biogas
- Decomposition of organic material → methane

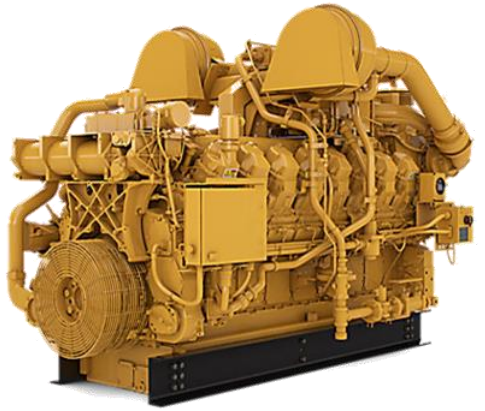
Power Generation (electricity)

- Co-Generation = use heat from exhaust and coolant
- Also called Combined Heat and Power (CHP)
- Electricity, heating, and cooling = Tri-Generation

Transportation

- City buses, airport shuttles, taxis, etc.
- "Clean air technology"

Agriculture, irrigation, etc.



Gas Engine Design Overview

Reciprocating internal combustion engines:

Same as heavy duty diesel and passenger car engines

Key difference: operates on gaseous fuel - normally methane:

Defines unique lubrication challenges

Two- or four-stroke cycle:

2T: older, larger, medium-speed engines (400 - <1000 rpm)

4T: newer, smaller, high-speed engines (~1000-1800 rpm)

Spark-ignited, dual-fuel

Air:Fuel Ratio:

Stoichiometric - Common in mobile applications

Mathematically "correct" mixture

Lean burn - Common in stationary applications

More air than fuel – for NOx emission control

Power outputs -

~50 to ~20k kW
(~70 to ~27k hp)

May or may not have exhaust catalysts/other after treatment to meet emissions standards

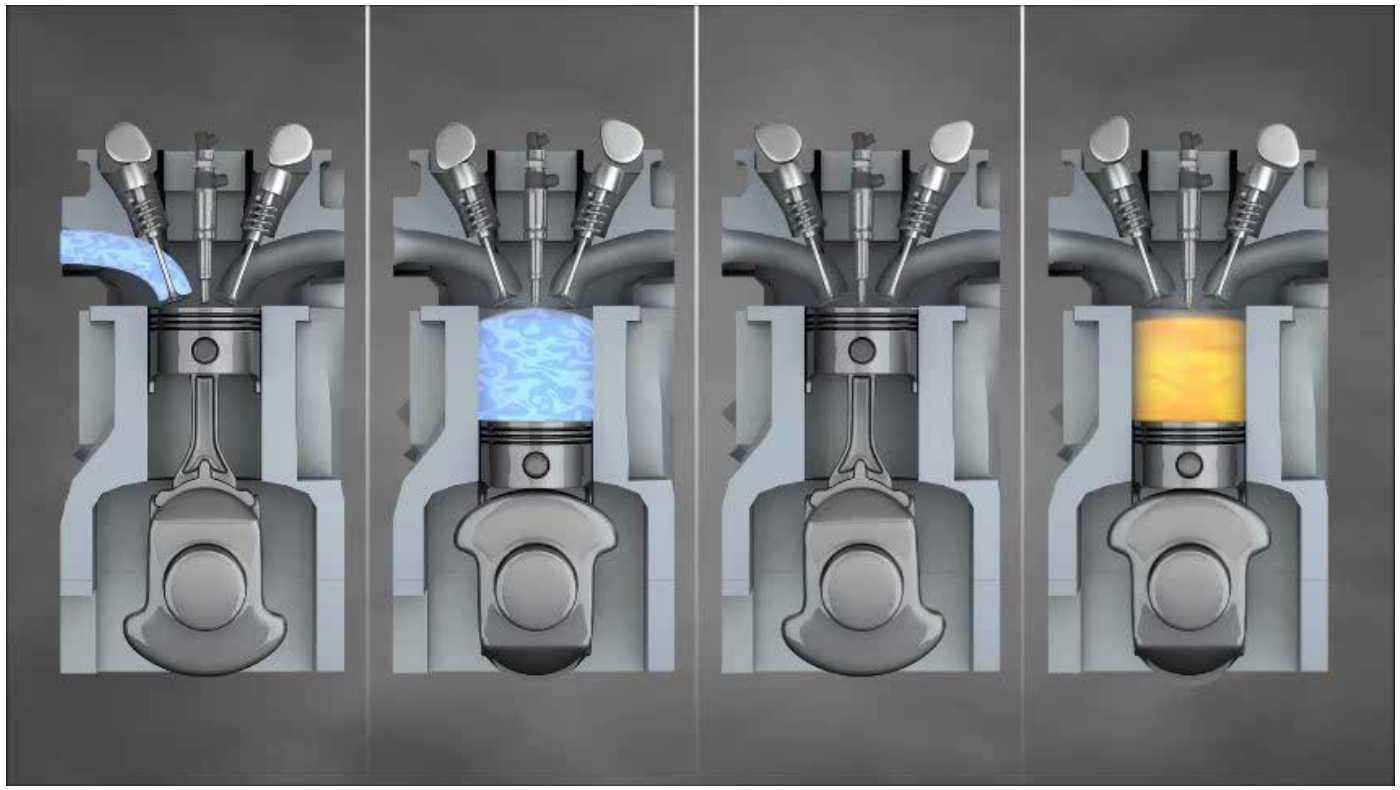
2T (Two Stroke) Engine

Two-stroke Cycle = Two Stroke = Two Cycle = 2T

- Older, larger, medium-speed engines
- Two stroke engines mix oil with the fuel and consume the oil
- In gas engine applications, 2T OEMs recommend Ashless gas engine oils.

4T (Four Stroke) Engine

Four-stroke Cycle = Four-stroke = Four Cycle = 4T



- Newer, smaller, high-speed engines
- The sump is oil filled and the oil recirculates
- In gas engine applications, 4T OEMs recommend Low-Medium gas engine oils.

Fuel Gases for Stationary Natural Gas Engines

Wide fuel flexibility: gas engines can utilize a broad range of calorific gases

Natural gas:
Clean or sweet gas

Contains >90% methane (CH_4) with few contaminants and low S

Main sources: pipeline, compressed natural gas (CNG), liquified natural gas (LNG)

Waste gas:
Anaerobic, waste, sour gas

Lower methane content (as low as 35%), also containing CO_2 and N_2 content up to 50%, etc.

Landfill gas: anaerobic breakdown of waste, high siloxane content, halogens and high S

Biogas: anaerobic decomposition of biological matter (e.g., sewage and food waste) – high levels of H_2S common

Nonconventional gases:
Syngas, furnace gas, coal gas

Least common fuel source

Flammable gases from industrial processes

Contains mixtures of hydrogen, carbon monoxide, as well as methane and higher hydrocarbons, e.g., propane

Typical Gas Engine Parameters

Engine Type:	4T			2T
Manufacturer	Caterpillar	Waukesha	Jenbacher	Ingersoll-Rand
Model	G3516	VHP L7044	Type 6	KVR
Ignition / Breathing / Cylinders	Spark / Turbo / 16	Spark / Turbo / 12	Spark / Turbo / 16	Spark / Turbo / 16
Bore, mm (in)	170 (6.7)	238 (9.4)	190 (7.5)	432 (17)
Stroke, mm (in)	190 (7.5)	216 (8.5)	220 (8.7)	559 (22)
Displacement, L (cu in)	69 (4211)	115 (7037)	100 (6090)	1309 (79,897)
Weight, kg (k lbs)	7550 (17)	9525 (21)	23,600 (52)	140,000 (310)
Speed, rpm	1400	1200	1500	330
Power, kW (Hp)	1030 (1380)	1250 (1680)	2188 (2934)	4480 (6000)
Torque, N-m (ft-lb)	7020 (5180)	9970 (7350)	13,900 (10,270)	122k (90k)

Common Challenges – Now and Future

Challenge	Lubricant Impact	Future Trend
Oxidation due to lean burn, high temps., NOx	Visc. Increase, varnish, sludge, shortened ODI	Higher efficiency engines → higher severity, robust AO
Deposits from high thermal load, oil degradation	Ring sticking, oil consumption, reduced heat transfer	Hotter piston zones → greater deposit control
Valve train stress	SASH balance	Lower SASH requirements compete with valve protection
Corrosive due to acids, halogens, moisture	BN depletion, corrosive wear	Growing renewable gas → robust BN retention
Pre-ignition	Deposit and ash control critical	Higher BMEP engines → tighter combustion margins

New generation of engines are providing a more hostile / severe environment for the lubricant than previously encountered

Gas Engine Oils – Typical Segmentation

Segmentation by Ash (Sulphated ASH = SASH)

Ashless	< 0.1 SASH	Older 2-stroke
Low ash	0.1 – 0.5 SASH (≤ 0.6)	**Most common**
Medium ash	0.5 – 1.0 SASH	High sulfur gas / some OEMs
High ash	> 1.0 SASH	Very high sulfur gas

Catalyst Compatible

<300 ppm phosphorus

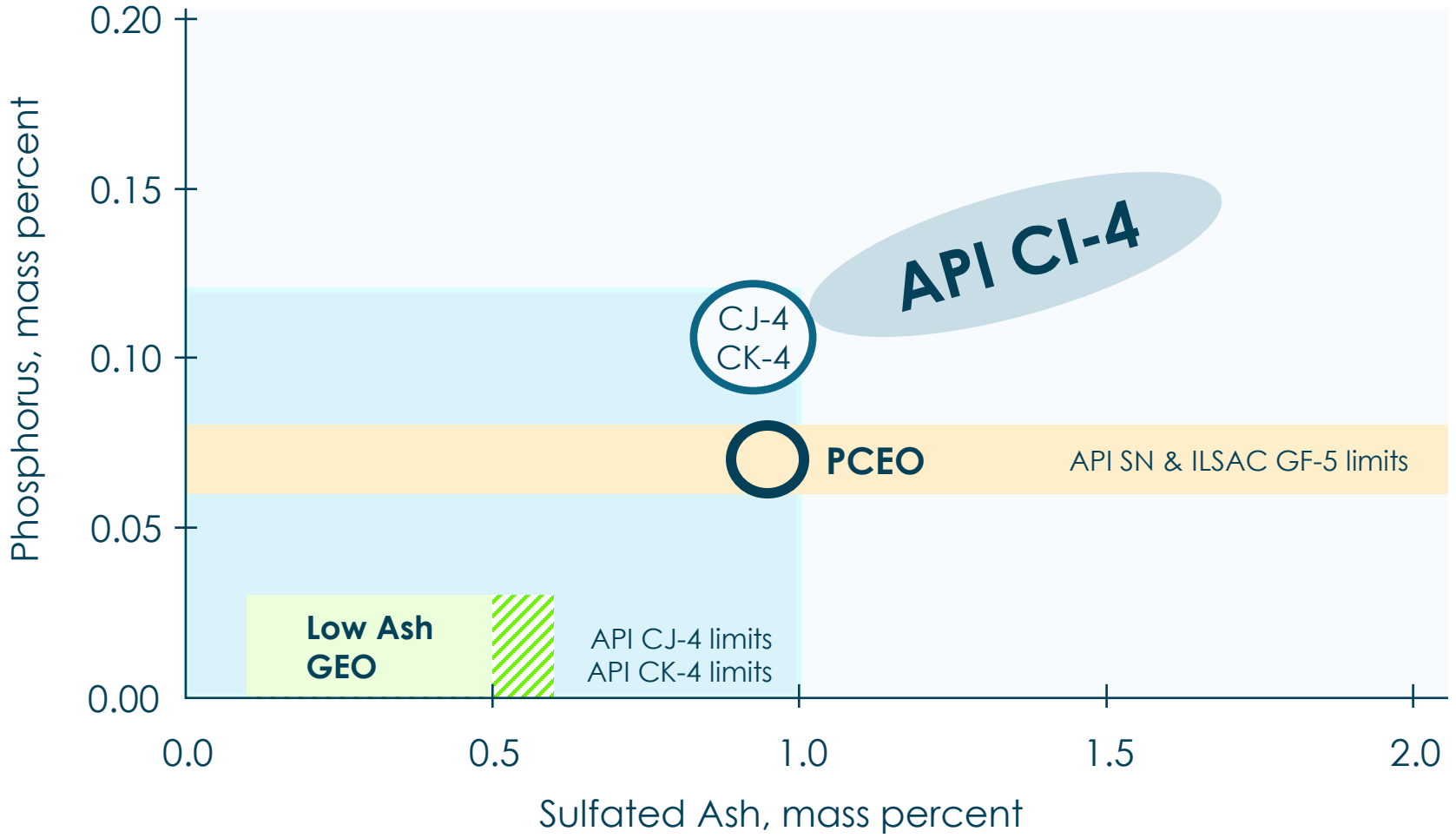
Viscosity Grades

SAE 40	**Most common**
SAE 30	Low temperature operation
SAE 15W-40	Buses, trucks, shuttles, on-highway

Comparison of Engine Oils

Gas Engine Oils are lower in ash and phosphorus

For deposit control and catalyst compatibility



What's New and Exciting?

Increasing use of natural gas

- New reservoirs
- Lower cost
- Better emissions

New engine design and higher power density

New engine materials and increased pressures and temperatures

Increased interest in gaseous fuels (LNG) for transportation

- Fleets with fixed re-fueling points: *Taxis, buses, local trucking, locomotives*
- Larger infrastructure projects considered

Emissions & After-Treatment

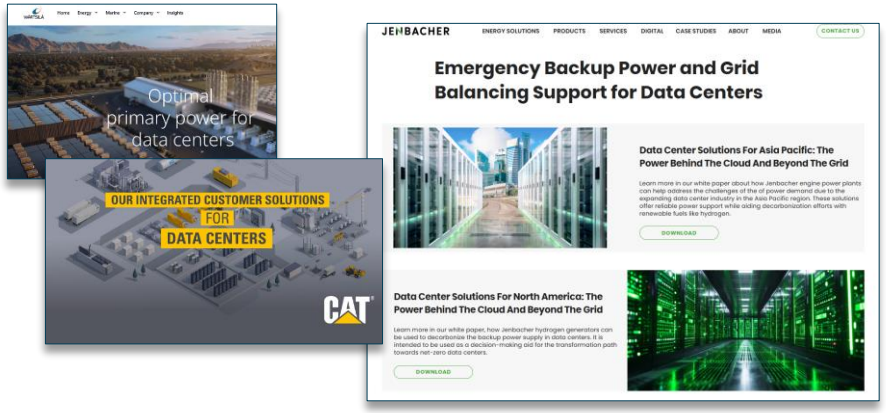
Learn Burn Engines (e.g. Caterpillar): Oxidation catalysts and SCR systems considering higher NO_x, lower CO/HC
Rich Burn Engines (e.g. Waukesha): Three-way catalysts (TWC) due to higher CO/HC, lower NO_x

Data Center Boom

Several stationary gas engines supporting generation of power for data centers.

Demand for Data Centers is Increasing

Data Center Solutions are a key industry trend, creating the need for decentralized power solutions. Several OEMs are offering solutions for data centers



Data Center growth is creating a new power paradigm – and a growth opportunity for Gas Engine Oil (GEO)

GEOs in Data Centers

ELECTRICITY GRID

Local grid capacity and interconnection timelines are not keeping pace with rapidly growing data center demand

Electricity

GEO Lubricant

Every on-site engine needs it

STATIONARY NATURAL GAS ENGINE*

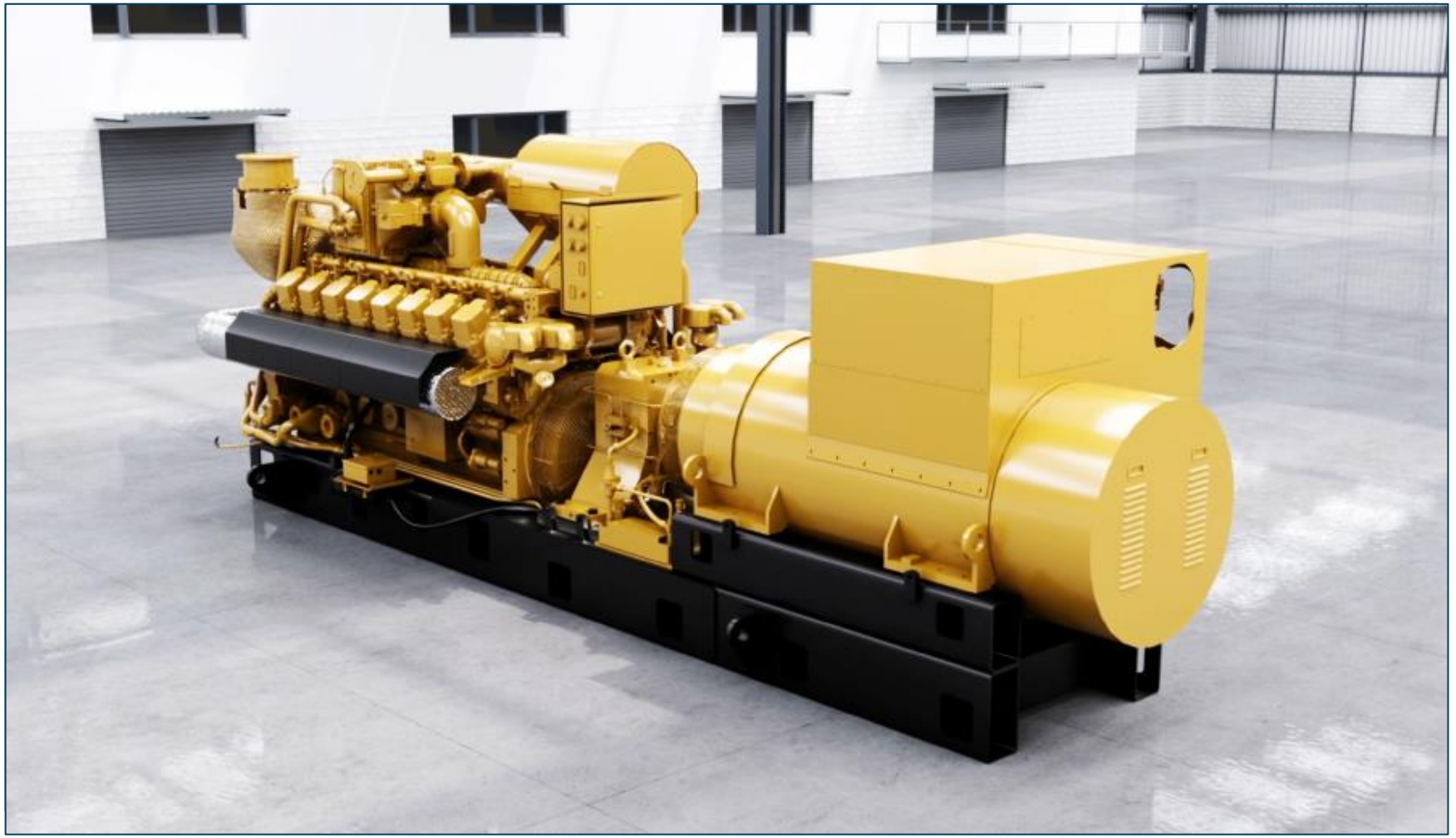
As a result, on-site power solutions are being deployed to secure reliable and timely electricity supply

DATA CENTERS

Electricity

* This mix includes gas engines/turbines, wind/solar renewables and battery storage, with gas engines being key for 24/7 reliability.

Gas Engine Fly Through Video



Railroad Engine Oils (and Inland Marine)

Railroad Summary

“Railroad” includes inland marine, power generation, etc.

Anything using engines from ‘railroad’ engine manufacturers

Large Diesel Engines (~1500 → 4400 → 6000 Hp)
(1100 – 4500 kW)

Emissions (“Tier”) and engine designs
lag 9 – 14 years behind on-highway

Two Significant Manufacturers:

Progress Rail/EMD bought by Caterpillar in 2011

Mostly 2-stroke – older designs used silver bearings (not anymore)

Wabtec/GE

4-stroke

Engine oils must be approved by OEM (additive company arranges)

- ‘Full’ approval by field test
- Base Oil Interchange Guidelines (BOIG) by bench tests

Base Number

17 13	11	10 9
LMOA Generation 5	**LMOA Generation 7**	**LMOA Generation 6**
GE uses terminology Generation 4 Long Life		

Engine Oils Must be Zinc-Free for Backwards Compatibility with silver bearings

- Otherwise, similar types of additives to on-highway diesel engine oils
- Oil quality referenced as “Generation” (currently Gen 5, 6, or 7)

  “Generation” matched to fuel sulfur and engine design

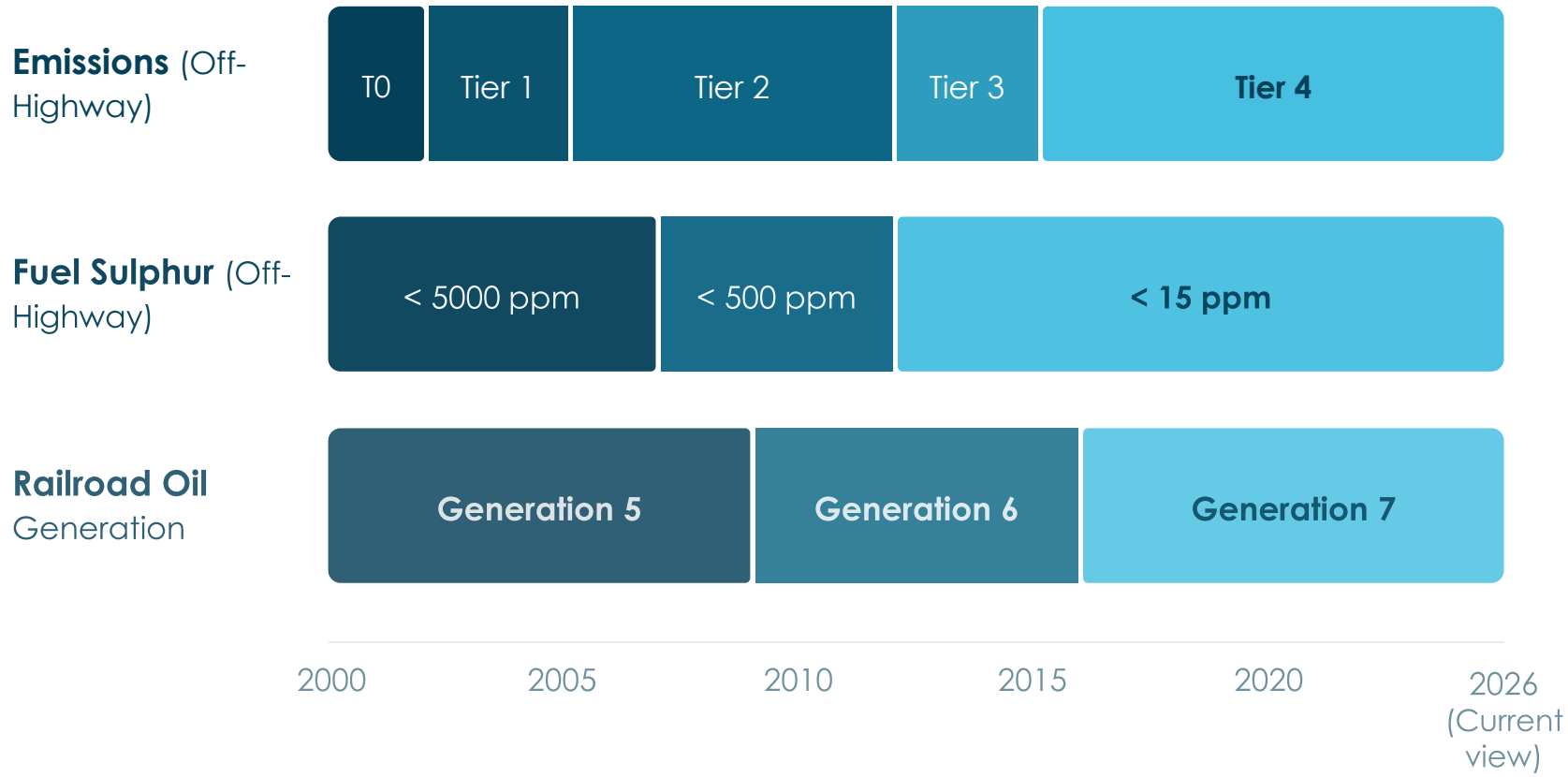
Railroad Timelines (North America)

"Generations" resulted from fuel changes and emissions regulations

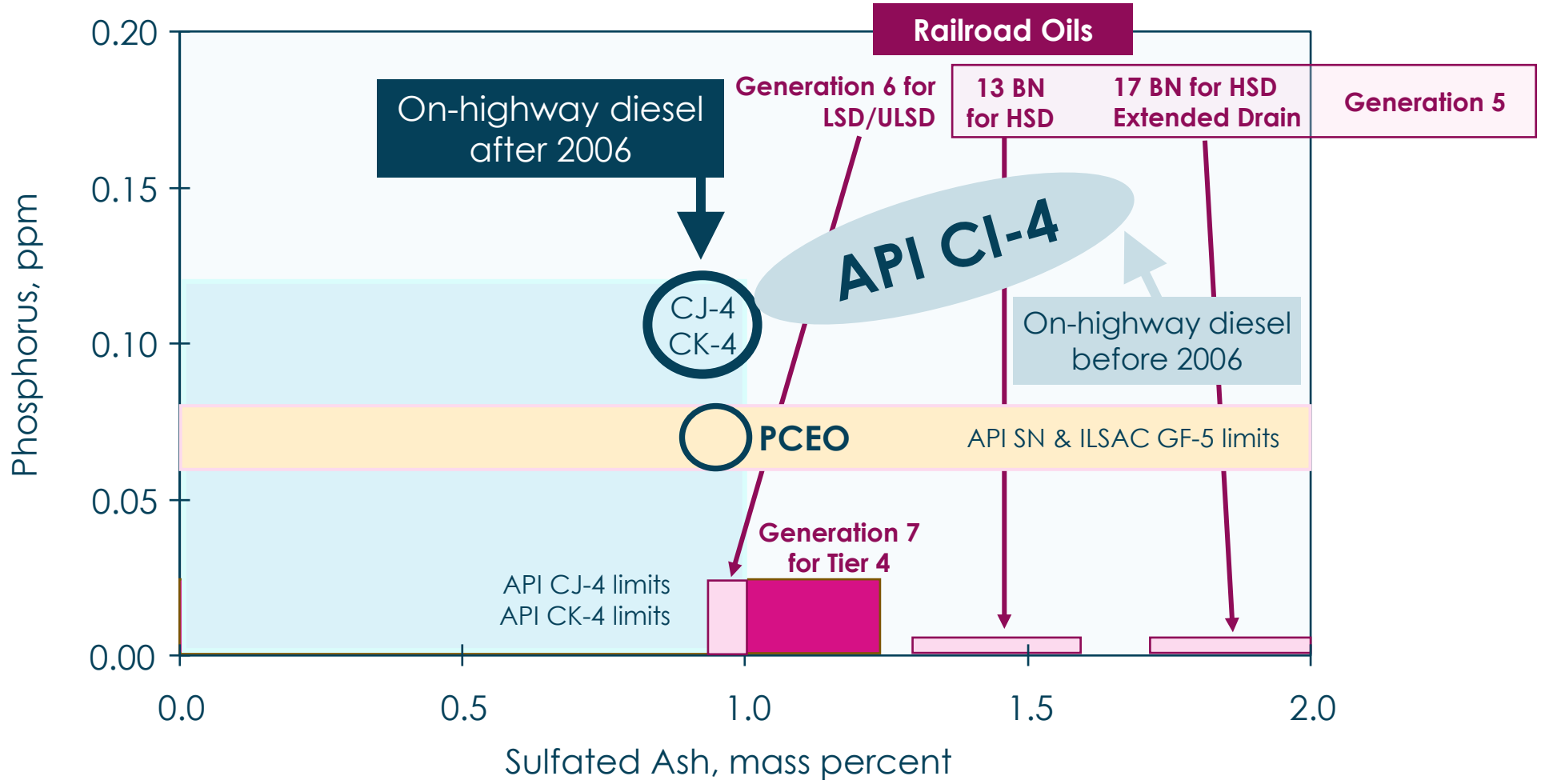
"Generation" is roughly the equivalent of on-highway "Category"

- Defined by field performance, not by engine test

Not always synchronized



Comparison of Engine Oils



Typical Railroad Engine Parameters

Engine Type:	Pre-Tier 4		Tier 4	
Manufacturer	Progress Rail/EMD	Wabtec/GE	Progress Rail/EMD	Wabtec/GE
Model	16-710G3C-T2	GEVO	12-1010J	GEVO-12 T4
Ignition / Breathing / Cylinders	Compression / Turbo-charged / 16	Compression / Turbo-charged / 12	Compression / Turbo-charged / 12	Compression / Turbo-charged + EGR / 12
Cycle	2T	4T	4T	4T
Bore, mm (in)	230 (9.06)	250 (9.8)	265 (10.4)	250 (9.8)
Stroke, mm (in)	279 (11)	320 (12.6)	300 (11.8)	320 (12.6)
Displacement, L (cu in)	186 (11,353)	188 (11,503)	199 (12,120)	188 (11,503)
Weight, kg (lb)	18,000 (40,000)	19,000 (42,000)	--	19,000 (42,000)
Sump, L (gal)	1650 (436)	1440 (380)	--	1440 (380)
Speed, rpm	900	1050	--	1050
Power, kW (Hp)	3280 (4400)	3280 (4400)	3360 (4500)	3360 (4500)

$1,000,000 – $2,500,000

— = not published in public sources

Past and Future: Railroad Engine Evolution

PAST Regulation-driven compliance | 2012–2016

2012

ULSD required in many regions

Reduces need for lubricant base number.

2015

Latest emissions reduction effective

Reductions in NO_x and particulates.

Design

New engine designs added emissions technologies

EGR; DOC/DPF; Miller Cycle valve timing and combustion optimization; SCR rarely used.

2016

Generation 7 engine oil specification

Issued by industry body; more compatible with EGR while controlling ash for DOC and DPF.

Transition

FUTURE New fuel pathways and industry trends

Liquefied Natural Gas (LNG)

Alternative fuel pathway under consideration.

Biofuels

Renewable / lower-carbon liquid fuel option.

Diesel vs. Electrification Trends

Initiatives in fuel consumption reduction, tightening emissions regulations, and decarb goals.

Other Changes

Industry consolidation, safety, automation and AI

Future Generation?

Marine Engine Oils

Marine Engines

Marine Engine Designs:

Trunk piston engines	Crosshead engines
Four-stroke	**Two-stroke**
Medium speed 300-700RPM ~3500 – 22,000 Hp	**Slow speed** 60-100rpm ~12,000 – 110,000 Hp
Trunk Piston Engine Oil (TPEO) for high sulfur residual fuels and low sulfur distillate fuels	**Marine Diesel Cylinder Lubricant (MDCL)** for upper part of engine
	System Oil for lower part of engine

Marine Lubricant Filter Systems:

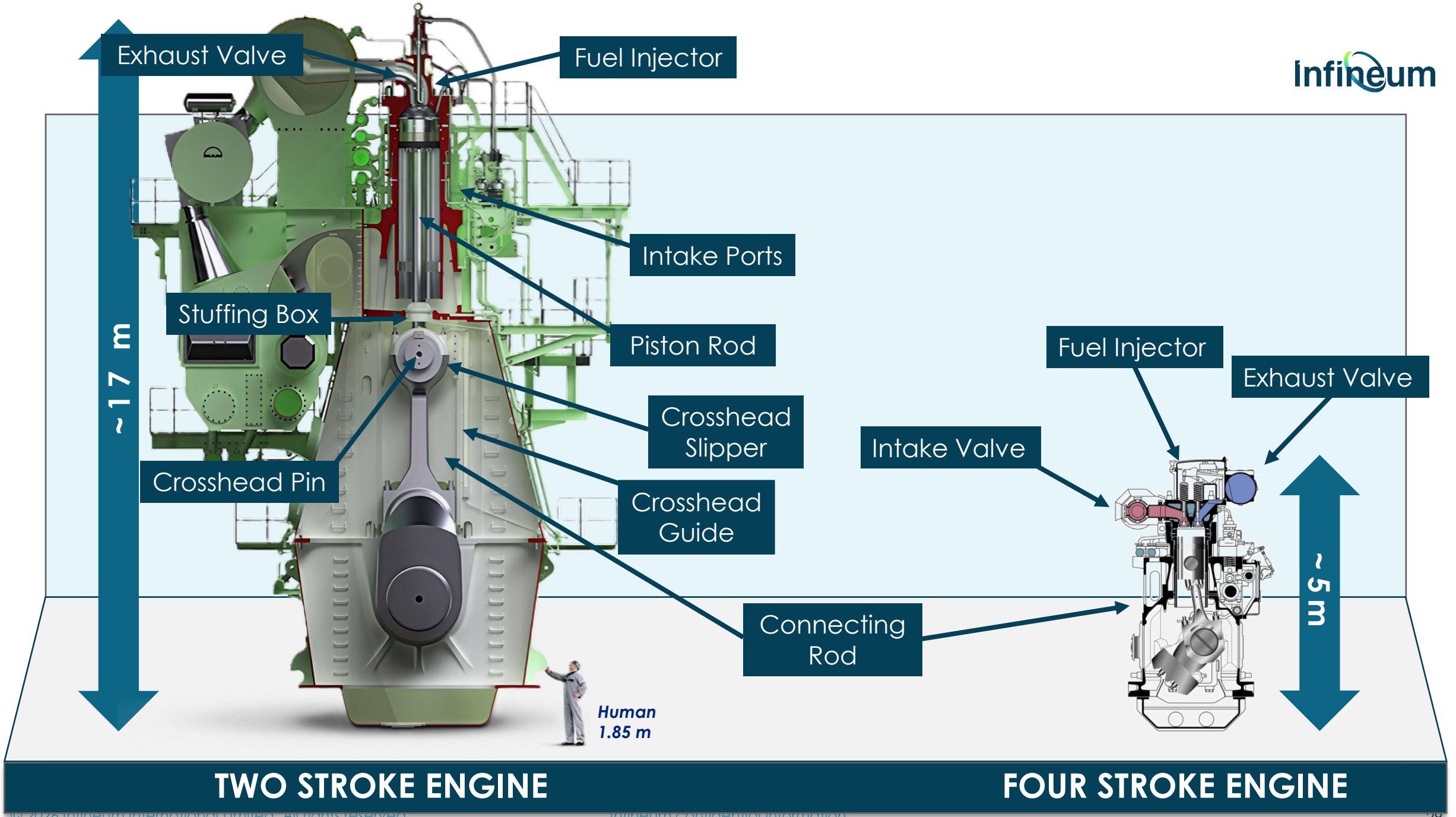
- Centrifugal Purifiers ← **Requires good water-handling properties**

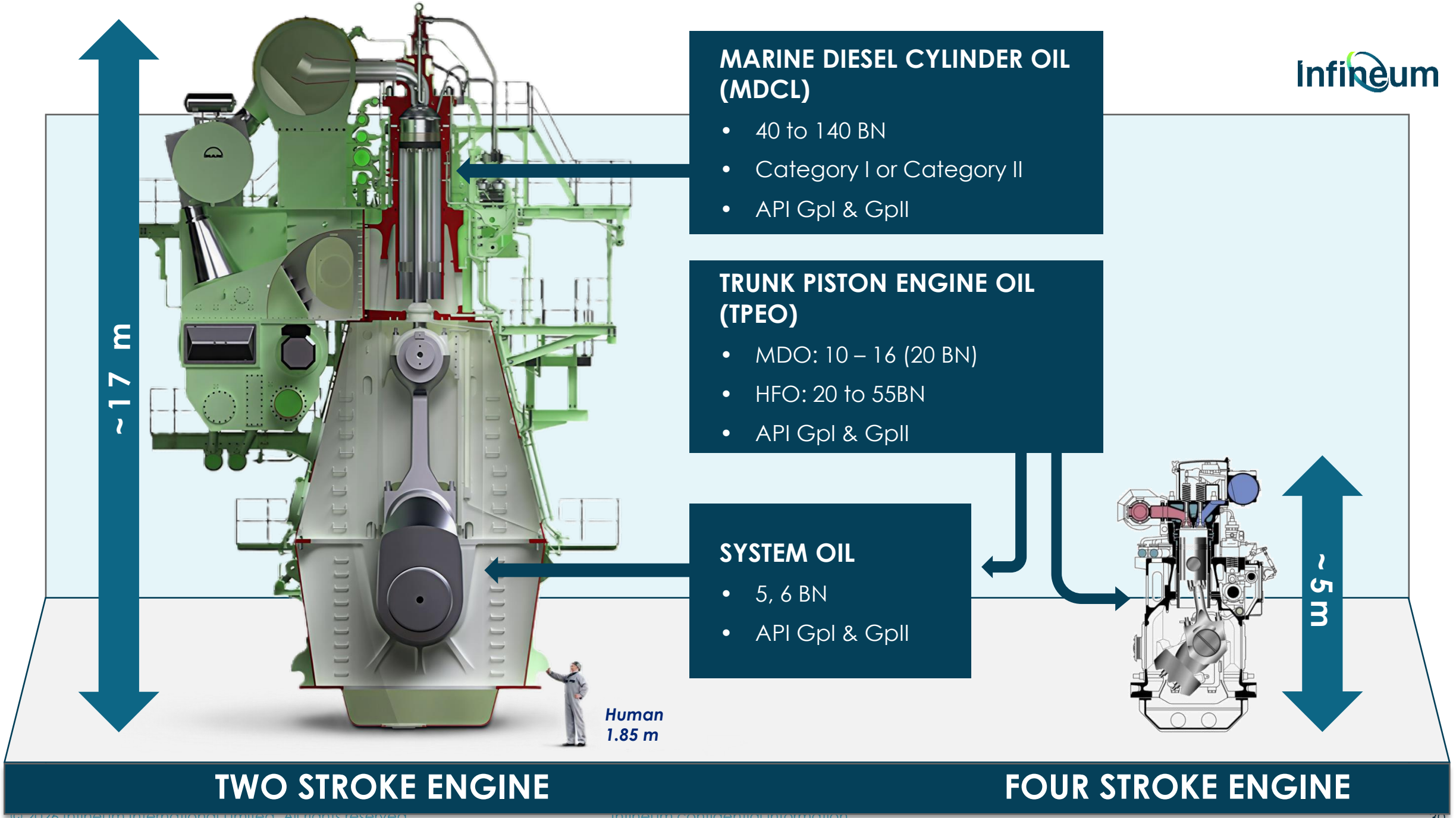
Marine Fuels:

- Distillate ← **Requires different dispersant properties**
- Residual

Marine Engine Lubrication Requirements ← **Asphaltenes!**

Crosshead Engine Design





Typical Marine Diesel Engine Parameters

Engine Type:	Trunk Piston	Crosshead
Manufacturer	Everllence	WinGD
Model	9L58/64	14RTA96C
Cylinders	9	14
Cycle	**4T**	**2T**
Bore, mm (in)	580 (23)	960 (38)
Stroke, mm (in)	640 (25)	2500 (98)
Displacement, L (cu in)	1522 (92,868)	25,334 (1,545,964)
Weight, tonnes	162	2300
Sump, L (gal)	16,000 (4,000)	44,000 (12,000)
Speed, rpm	400	102
Power, kW (Hp)	11,790 (15,811)	84,420 (114,800)

$15,000,000 – $30,000,000

Marine Fuels

Distillate fuel

- Also called Marine Diesel Oil (MDO) or Marine Gas Oil (MGO)
- A little higher viscosity
- A little more sulfur

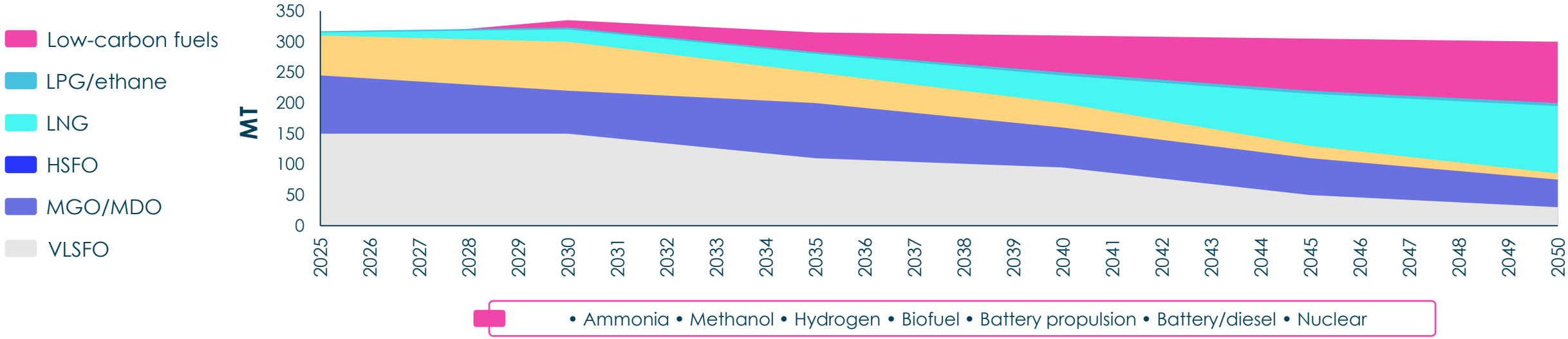
Residual fuel

- Also called Heavy Fuel, Bunker Fuel, No. 6 Diesel, IF 700, etc.
- Hydrocarbon - can be burned for cheap energy
- High sulfur content - 2020 – 0.5% max
- High asphaltene content - gets into TPEO and System Oil via blow-by

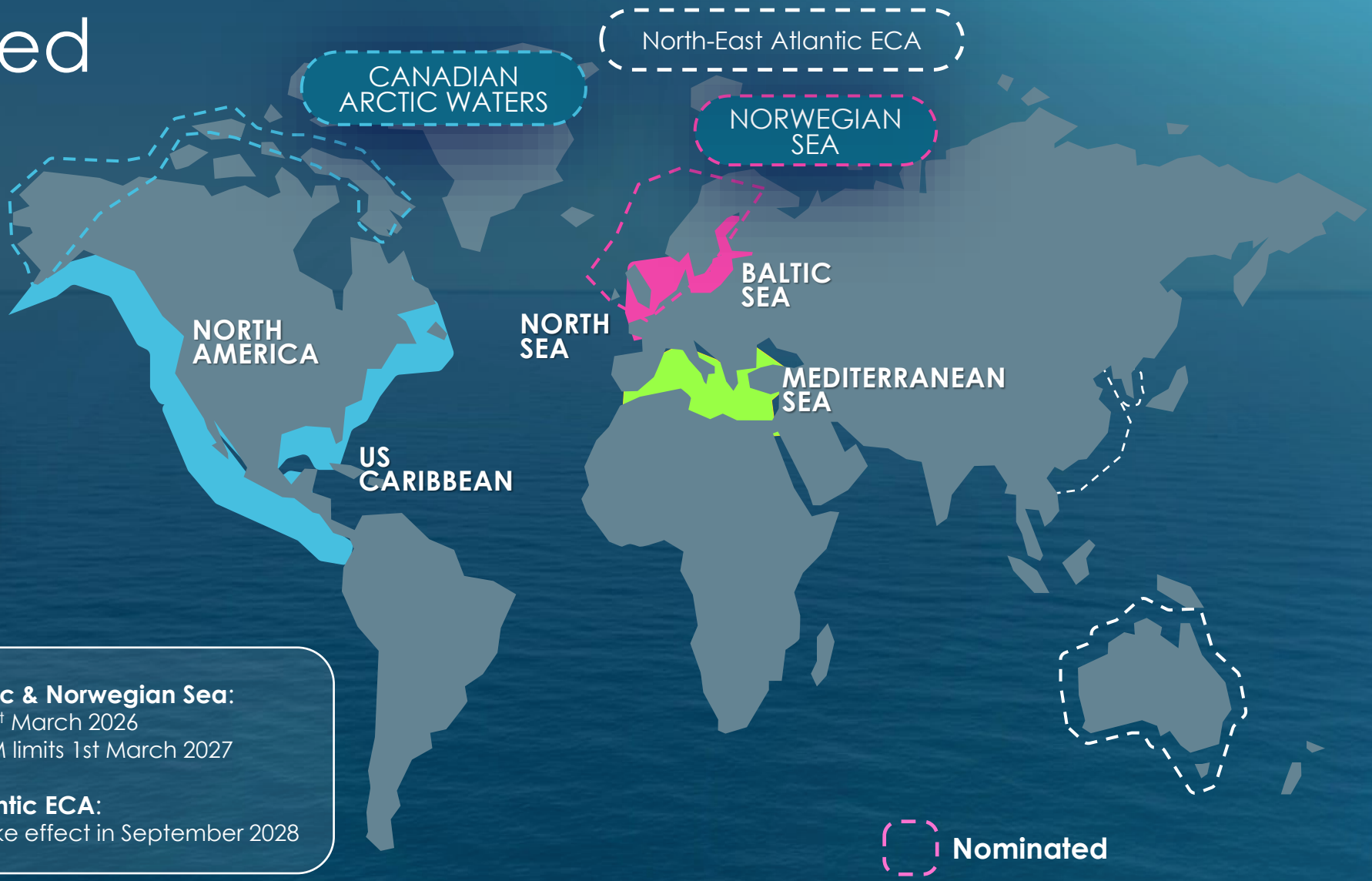
Alternative and low-carbon fuels

Ammonia | Methanol | Hydrogen | Biofuel | Battery propulsion | Battery/diesel | Nuclear

Each brings a different combustion environment, and a different lubrication challenge.



Approved & Nominated ECAs



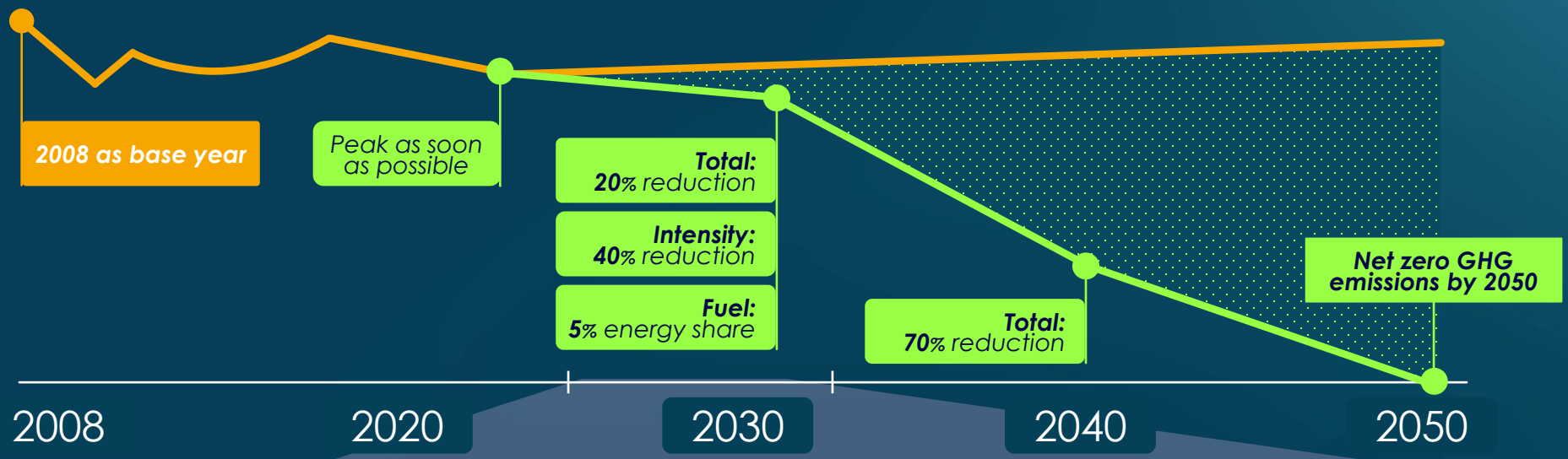
Canadian Arctic & Norwegian Sea:
- NOx limits: 1st March 2026
- Sulphur & PM limits 1st March 2027

North-East Atlantic ECA:
- SOx limits take effect in September 2028

Note: areas are indicative only, for full Lat/Long information visit imo.com

IMO Strategy on GHG Reductions

Units: GHG emissions -



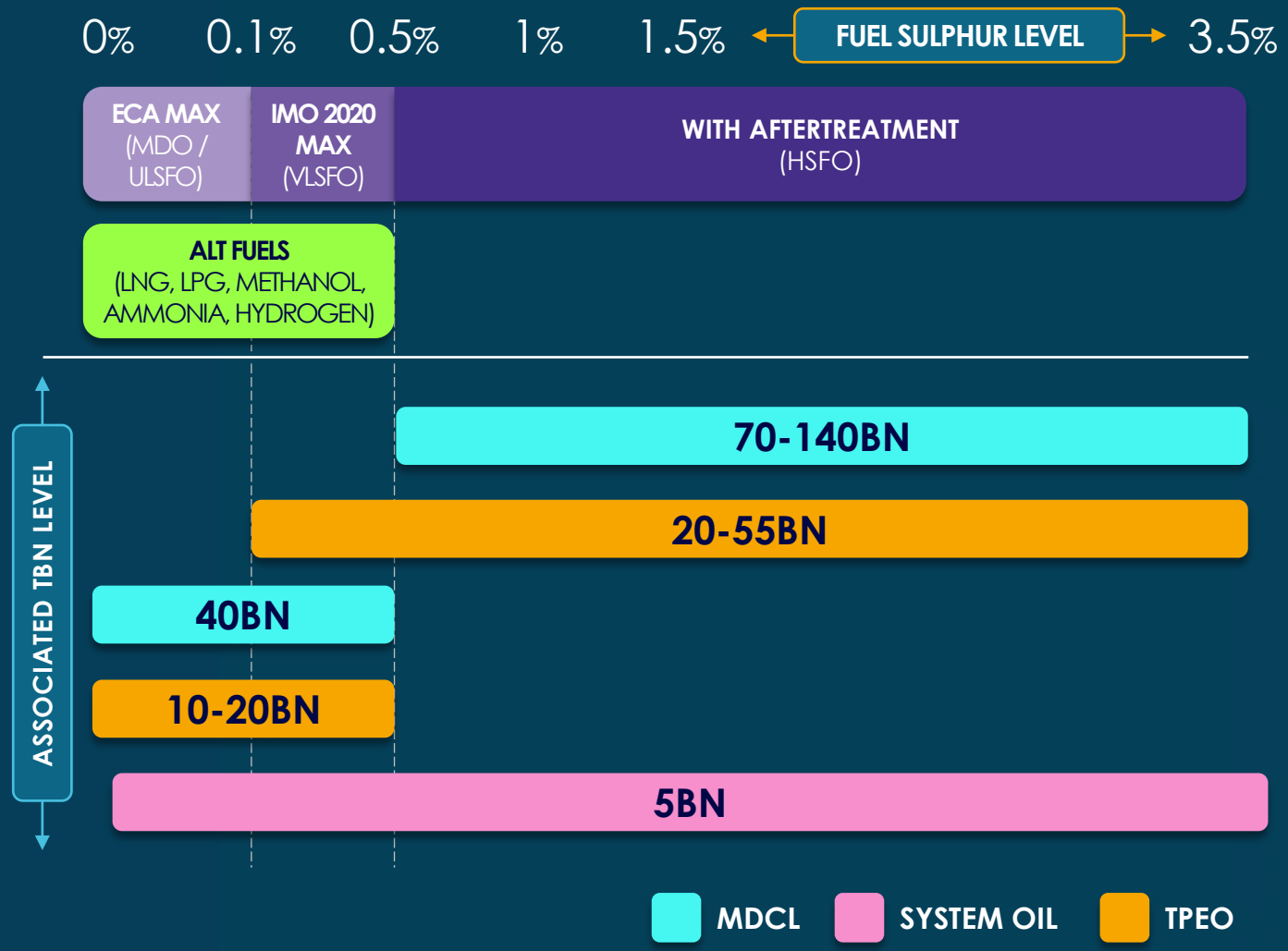
Emission pathway in line with IMO's GHG Strategy

Business-as-usual emissions

Emission gap

OEM hardware readiness -

Marine Engine Oils – Typical Segmentation



- >500,000 hours testing
- 2 and 4 stroke engines
- All conventional fuels
- And evaluating those coming in the future
- In GpI and GpII base stocks
- Approvals with all of the major OEMs

What's New and Exciting?

Base Oil Flexibility

Broader aspect of Gp I capacity reduction

Regulatory Pressures Restricting Formulation Options

- Develop to meet lower BN requirements
- Opportunity to extend to higher BN range

Base Stock Replacements & Alternative Thickeners

Group I capacity reduction impacting bright stock availability

Fuel Economy and Lower Operating Costs

Lubricant formulation to survive higher oil stress and oil starvation

Alternative Fuels

Support lower carbon intensity and IMO targets net-zero ambition

Marine Field Trial Video

Large Engine Lubricants

Have special requirements, based on:

- Fuel
- Engine design
- Type of service

Gas Engine Oils require:

- Limited sulfated ash and phosphorus
- High oxidation and nitration stability
- Deposit control

Railroad and Inland Marine Oils require:

- Zinc-free
- OEM approval letters

Marine oils require:

- Corrosive wear and deposit control
- Asphaltene-handling
- Water-handling

Large Engine Lubricants are approved through **field performance**

Thank you

Formulating tomorrow together

Permissions