AVL

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Future Powertrain Technology Options for Inland Waterway Transport

Public

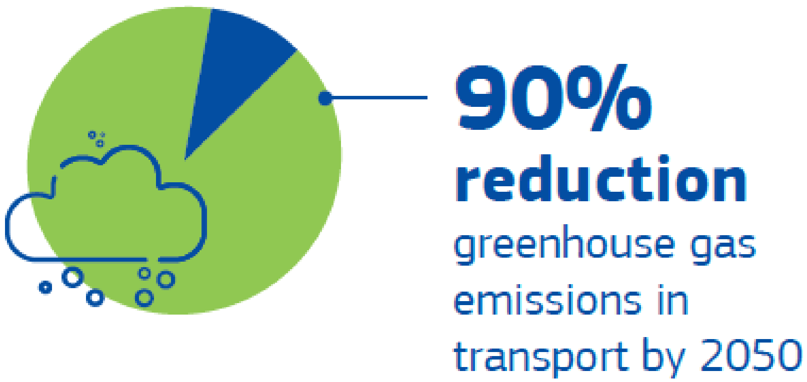
Itinerary

- **Motivation & Drivers**
  - Emission Regulatory & GHG reduction Targets
  - Zero Impact Emissions & IWW transport business models
  - Short term challenges
- **Technology Pathways for IWW Propulsion**
  - Net and zero carbon fuels
  - Energy density of Fuels and installation space on board
  - Engine technology options including Exhaust gas Aftertreatment requirements
  - Alternative propulsion and power generation on board
  - Fuel Cell
- **Summary and conclusions**
  - Fuels & Hydrogen
  - Transition Draft for Propulsion & Power Technology
  - AVL Services

Motivation & Drivers

The European Green Deal

- GHG reduction
  - 2020: - 20% (compared to 1990)
  - 2030: - 50% (55%), previous target 40% (both compared to 2005)
  - 2050: - 90% (compared to 2005), net-zero GHG emissions objective



- Extension of Emission Trading System to traffic and construction

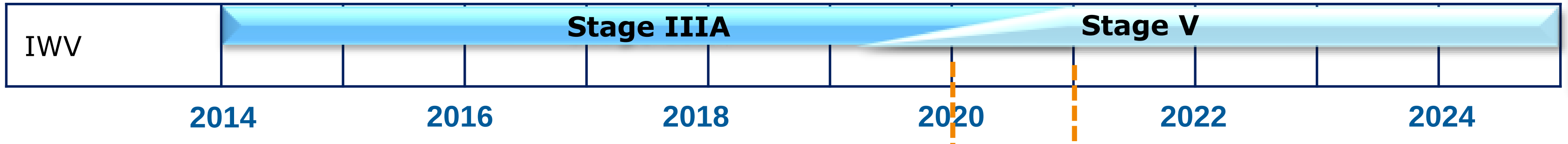
- Increase of the efficiency of the transport system
- Low-emission alternative energy for transport
  - advanced biofuels
  - Electricity
  - Hydrogen
  - renewable synthetic fuels
- Pathway towards zero-emission vehicles
- More stringent air pollutant emissions standards for combustion-engine vehicles, Proposal expected for 2021

Motivation & Drivers

Emission Regulatory and GHG Reduction Targets

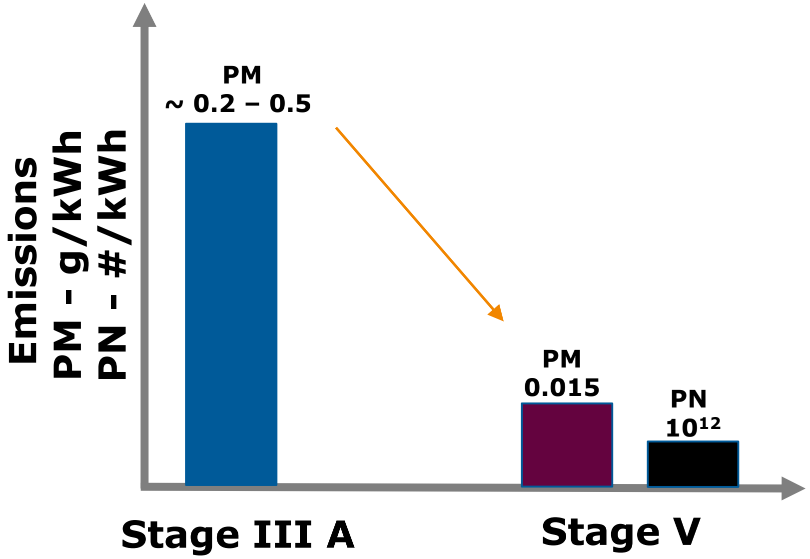
Limited number of engines with higher power

- Inland Waterways

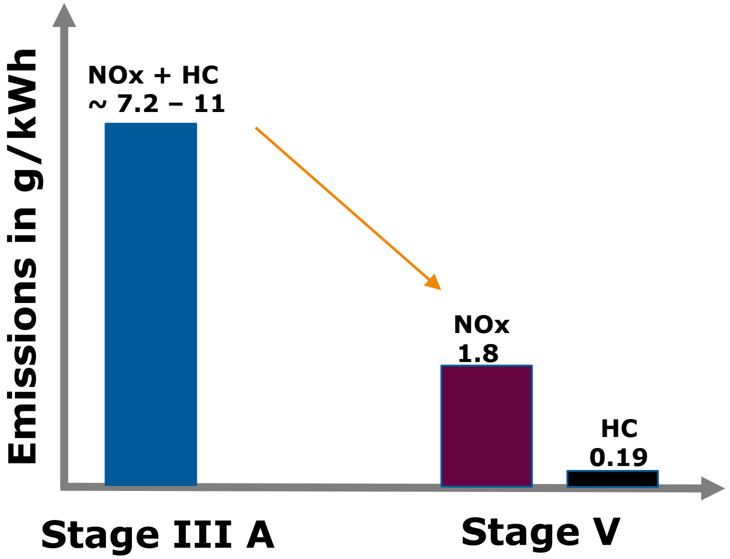


EU Stage V Type approved engines : P≥300 kW →

Placing of transition engines in the market by end of 2021

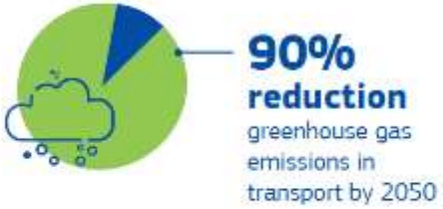


DOC+DPF



+ SCR

Green Deal



2020: - 20% (1990)

2030: - 55% (2005)

2050: - 90% (2005)

Motivation & Drivers

Zero Impact Emissions & IWW transport business models

- Efficient infrastructure and system of ports, vessels and waterways
  - Optimum integration of inland waterway transport into the multimodal logistics chain
  - **Developed infrastructure for future fuels ensuring shore-to-ship bunkering based on fixed fuel stations**
  - Resilient and well-maintained waterway infrastructure is crucial
  - Qualified personal (staff)
  - Digital services to collect required (intelligent), not big data (for the sake of collection)
  - These data could help to make the operational excellence and the way vessels are operated visible
  - These data could help to grant GHG or CO_2 credits or tax reductions supporting investments into new technology
  - Modernized inland waterway vessels w technology upgrades

- Large scale production and clear regulatory for new fuels (LNG, Hydrogen, MeOH, Ammonia)
  - Transport & distribution
  - Installation and type approvals
  - Fueling, on board usage and taxes
  - Safety standards from production, transport and storage
  - Further investment risks regarding future emission regulatory:
    - Internal combustion engine : Upcoming Methane slip regulation
    - Vessel: Volatile organic components VOC, total organic components TOG or reactive organic gases ROG, …

Motivation & Drivers

Short term challenges

Overview on Stage V Type approved engines

- IWP
  - Beta Marine Ltd | Beta105T | 28/06/2019 by GDWS, DE
  - FPT Fiat Power Train Industrial S.p.A. | F4HF45PB10A , - PA10A by 28/06/2019 and F4HF45PB11A by 18/11/2019 by GDWS, DE
- IWA
  - Hatz Motorenfabrik GmbH | H50TIC-IWA-cs | 29/04/2019 by KBA, DE
  - JCB Power Systems Limited | JCB 448 TGWA-60, -68, -72 | 01/04/2019 by Swedish transport agency
- Marinized NRE ≤ 560kW
  - Deutz AG | TCD4.1L4 | 30/10/2018 by KBA, DE
  - Hatz Motorenfabrik GmbH | 3/4H50TICD-cs | 12/06/2018 by KBA, DE
- Marinized Stage VI HD Engines ≤ 560kW
  - DAF / PACCAR MX11 | 17/01/2020 and 06/07/2020 by RDW, NL
  - DAF / PACCAR MX13 | 06/07/2020 by RDW, NL

https://listes.cesni.eu/2060-en.html | Status from 27th of Sept., 2020

Key take away:
Limited number of engines with higher power

Motivation & Drivers

Short term challenges

Transition from EU Stage IIIA or CCNR II to Stage V

- New vessel w transition engines (EU Stage IIIA, CCNR II) placed to the market by end of 2021 at latest
- Alternative use of marinized Engines P < 560kW
  - NRE Stage V Engines
    - P ≤ 30KW/Cylinder | ~ 1,0l/Cylinder | R4: P ≤ 120kW (Deutz TCD 4.1 L4)
  - EU Stage VI Truck Engines
    - P ≤ 55kW/Cylinder | 1,8 l/Cylinder | IL6: P ≤ 330kW (DAF / PACCAR MX11)
    - P ≤ 65kW/Cylinder | 2,2 l/Cylinder | IL6: P ≤ 390kW (DAF / PACCAR MX13)

Key take away:
Limited number of engines
No engines with higher power

- Category 4 IWP- and IWA- engines resp. w a Power P > 560 kW w Stage V Type approval are not yet available
- The build of new vessels w mechanical propulsion engines w gearbox P > 390kW seems to be an issue
  - HD Truck engines — Potential max. Power 520kW < P_{V8} ≤ 610kW | ≤ 75kW/Cylinder | 2.2 to 2l.7l/Cylinder
  - High Speed Large Engines: — Power 70kW/Cylinder < P ≤ 215kW/Cylinder | 3 to 5.5l/Cylinder | 1200 < n ≤ 2300rpm
  - Medium Speed Large Engines: — Power 150kW/Cylinder < P ≤ 215kW/Cylinder, | 8 to ~20l/Cylinder | 720 < n ≤ 1000rpm

V8 not existing, will not be developed (most probably)

EU Stage V Approval IWA,IWP not evident Status from 27th of Sept., 2020, https://listes.cesni.eu/2060-en.html

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- **Technology Pathways for IWW Propulsion**
  - Net and zero carbon fuels
  - Energy density of Fuels and installation space on board
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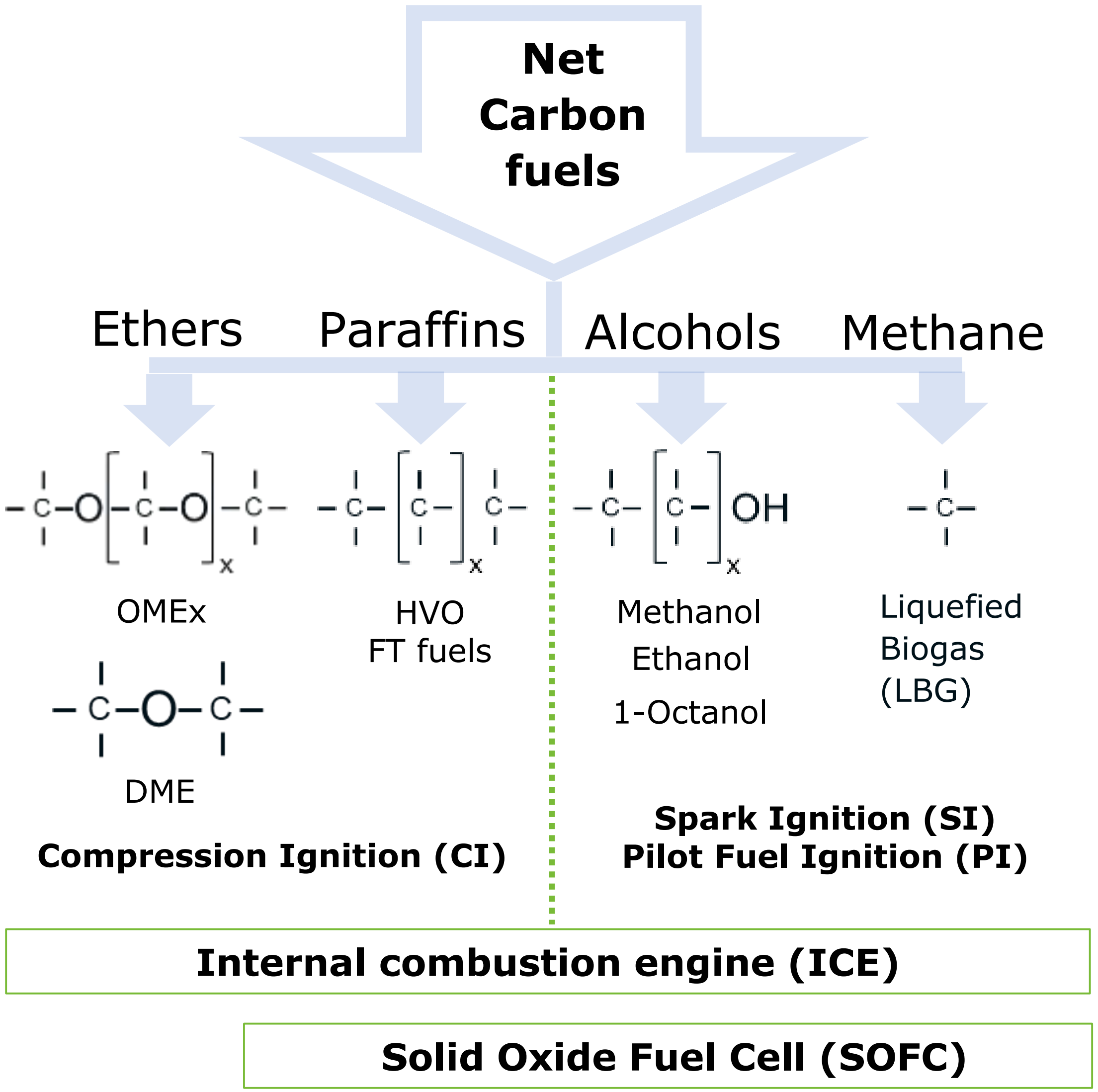
Technologies Pathways for IWW Propulsion

Net Carbon Fuels

- synthetic fuel produced from renewable or sustainable feedstock
- CO_2 neutral production or production process with carbon capturing
- Produced via renewable electric energy
  - Ethers
    - Oxymethylethers OMEx
    - Dimethylether DME
  - Paraffins
    - Hydrogenated vegetable oil HVO
    - Fischer Tropsch fuels FT
  - Alcohols
    - Methanol
    - Ethanol
    - 1-Octanol
  - Liquefied biogas (LBG)

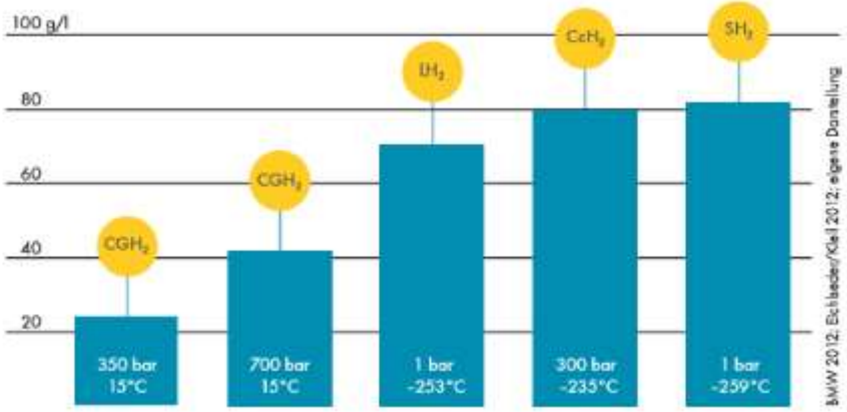


Technologies Pathways for IWW Propulsion

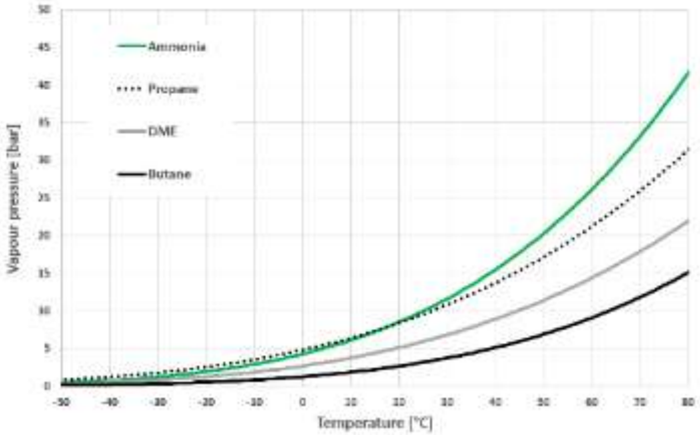
Zero Carbon Fuels

- No carbon per chemical composition
- Hydrogen produced via renewable electricity (wind turbines, solar panels, hydroelectric power)

- Hydrogen
  - CGH_2 — Compressed gaseous hydrogen
Single or multi-pressure tank 350 and 700bar
  - LH_2 — Super-insulated low-pressure cryogenic tank -253°C
  - CCH_2 — Cryo-compressed hydrogen
Super-insulated cryogenic pressure tank 300bar, -235°C
  - SH_2 — Slush Hydrogen, 1bar, - 259°C

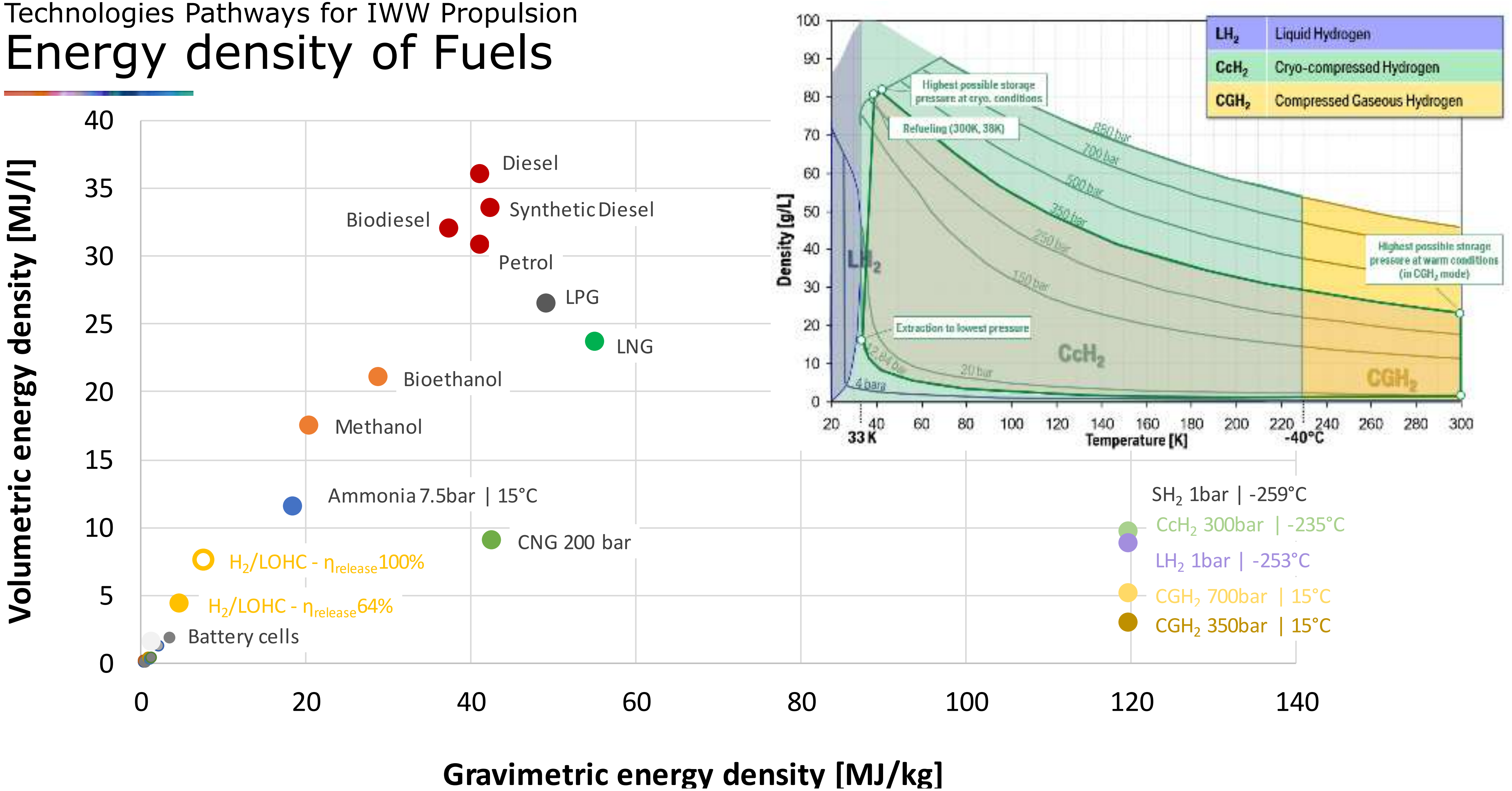


- Ammonia NH_3
  - low-pressure cooled tank -33.4°C (at 1 bar pressure)
  - or tank similar to LPG systems



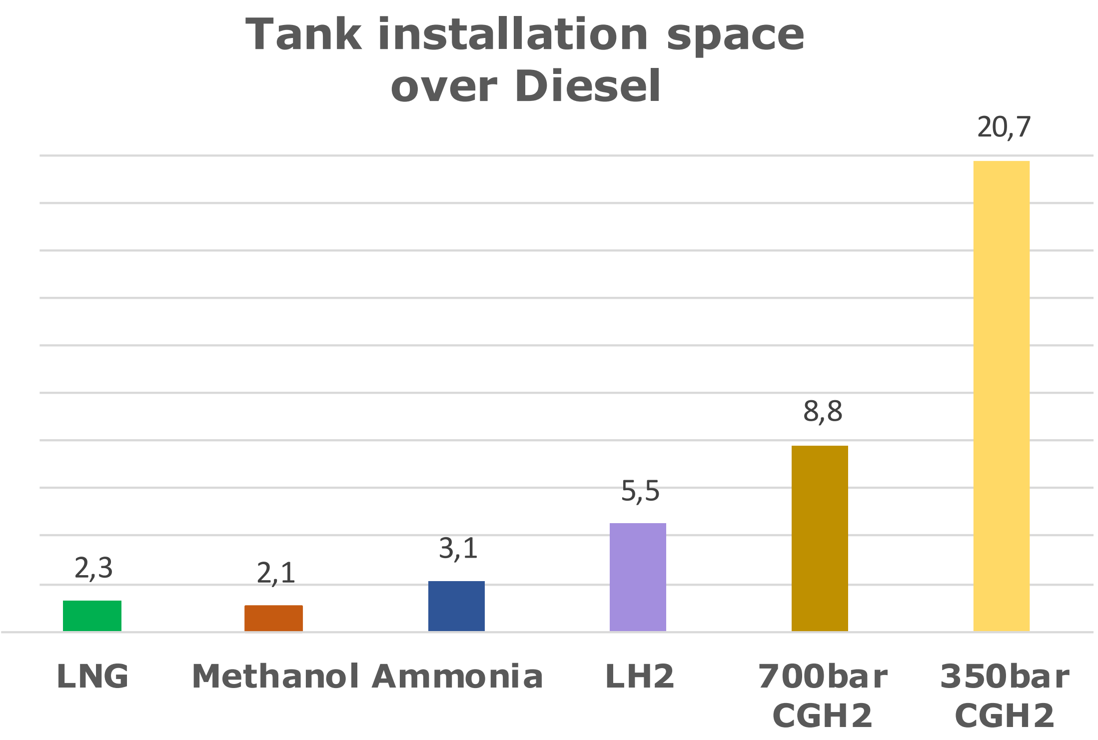
Technologies Pathways for IWW Propulsion

Energy density of Fuels



Fuel Tank installation space on board

Fuel	Volumetric Energy Density Fuel MJ/l	Volumetric Energy Density Fuel + Tank MJ/l
Diesel	36,0	33,3
LNG	23,6	14,7
Methanol	17,5	16,2
Ammonia	11,5	10,8
Liquid H_2	8,7	6,1
Compressed H_2 (700 bar)	5,0	3,8
Compressed H_2 (350 bar)	2,9	1,6



Fuel tank integration and shore to ship bunkering frequency could be challenging

Engine Technology Options

- **Short term**
  - Diesel engines must have a DOC+DPF with SCR
  - Mono fuel enriched lean burn gas engines could be certified for EU Stage V w/o after treatment system
  - Dual fuel engines may have a DPF filter and for diesel mode backup a SCR system
  - MeOH and synthetic fuels can contribute to PM reduction
  - Some synthetic fuels such as OME_x show disadvantage in CO_2
- **Medium term – "Grey fuels"**
  - H_2 enriched NG engines as back up for upcoming Methane slip regulations
  - Mono fuel stochiometric NG engines w 3 way catalyst, cooled EGR for further Methane slip reduction
  - H_2 enriched NH_3 engines for further CO_2 reduction, if NH_3 is the established carrier for hydrogen on board
  - Pure H_2 engines to be developed towards higher power density
- **Long term – "Green fuels"**

Technologies Pathways for IWW Propulsion

Diesel Engine Technology w DOC, DPF and SCR

- Marinized EU Stage VI HD engines
  - limited in power → 2 or more engines on board

- EPA Tier 4 compliant Marine engines
  - Upgrade from SCR to DOC,DPF + SCR would be needed for type approval as EU Stage V IWP, IWA engine
  - EPA Tier 4 PM 0.040 g/kWh → 0.015g/kWh
  - EPA Tier 4 = EU Stage V NOx 1.8g/kWh

- Marinized EU Stage V Rail Engines (very small sector)

- Development of IMO II/III Medium speed diesel engines towards Stage V approval by Engine OEMs not evident

- Use of Drop in fuels (HVO, FT Fuels) in future

Technologies Pathways for IWW Propulsion

Gas Engine Technology

- Natural Gas engines
  - Lean burn High Speed and Medium Speed Engines, established technology for power generation
    - Open chamber spark ignited (OCSI)
    - Pre-Chamber spark ignited (PCSI) with gas admission to pre-chamber
    - Applicable for electric propulsion and (high) power generation on board
  - Gas Engines for mobile applications, upcoming technology
    - Marinized power generation engines
    - Developed towards improved transient response, applicable for direct mechanical drives
    - Cylinder individual gas admission valves, double wall gas rail
    - w/o Aftertreatment if THC ≤ 6.19g/kWh (current EU Stage V Methane slip limitation)
  - Stoichiometric gas engines with 3 way catalyst (and cooled EGR), reduced engine power
  - HPDI engines w SCR (niche technology for Truck Engines)
  - Hydrogen enriched NG engines for Methane slip reduction (option to be further developed)
- Pure hydrogen engines, currently w limited power (developments ongoing, 2-stage TC)
- Hydrogen enriched Ammonia PCSI Gas engines (essential developments needed)

Technologies Pathways for IWW Propulsion

Alternative propulsion and power generation on board

- Electric propulsion – integrated system w power generation on board
  - ICE driven generators
    - at least two independent energy sources must be installed on board
  - Combination of ICE driven generators and fuel cell
  - Fuel cell only expected on long term
  - Batteries limited to the needed extend (Low energy density)
  - Provision of energy to achieve the vessel’s minimum required maneuverability for at least 30 minutes

Fuel Cell Types

	Strengths	Weaknesses
PEMFC (Polymer Electrolyte Membrane Fuel Cell) 	• Low volume and weight • Lowest cost per kW • Wide operating temperature (-35 to +95C) • High Dynamics (0,5 s)	• Needs high purity hydrogen • Dependence on membrane hydration which limits the maximum operating temperature
SOFC (Solid Oxide Fuel Cell) 	• Works with different fuels • High tolerance to impurities • High grade heat and efficiency for CHP	• Low volumetric and gravimetric power density • Not suitable for dynamic applications • Not local zero emission (if not using hydrogen)

- PEM Fuel cells can be used as main propulsion AND base/auxiliary load
- SOFC are ideal for base load AND in case there is no hydrogen available

Fuel Cell Integration

- Fuel cells to be combined with an electrical propulsion system
  - Proton Exchange Membrane Fuel Cell (PEMFC)
  - Solid Oxide Fuel Cell (SOFC)
- Ratio of fuel cell to battery power to be optimized for the specific vessel type, route and schedule
- Vessel power system must have the capability to deliver maximum rated power, but vessels are rarely operated at max power.
- The power system should be optimized for efficiency at the real load / usage profiles and if applicable to the typical or average operating point (evaluated vessel duty cycles).
- For propulsion, redundant energy systems are required.
- Modularized Fuel cells are combined in parallel to provide the power and redundancy needed by the application.
- Safe delivery of electrical and thermal energy from Fuel Cell, Level of safety equivalent to that of conventional combustion engines
- Arrangement and access for service and maintenance
- Fire and explosion proof, Control, monitoring and safety systems
- Multiple 200kW blocks, electrically-configured in parallel, could provide efficient, dispatchable vessel power up to 2.0MW.

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Fuels - Hydrogen

Potential

- Renewable hydrogen produced through electrolysis based on wind or solar power, almost zero GHG emissions.
- Cleanest fuel currently available in terms of SOx, Particulate matter and slip issues (unburned fuel)
- Cleanest fuel in terms of NOx in case of ultra lean burn operation
- Hydrogen could be used in internal combustion engine (ICE) **and** fuel cells (FC)

Challenges

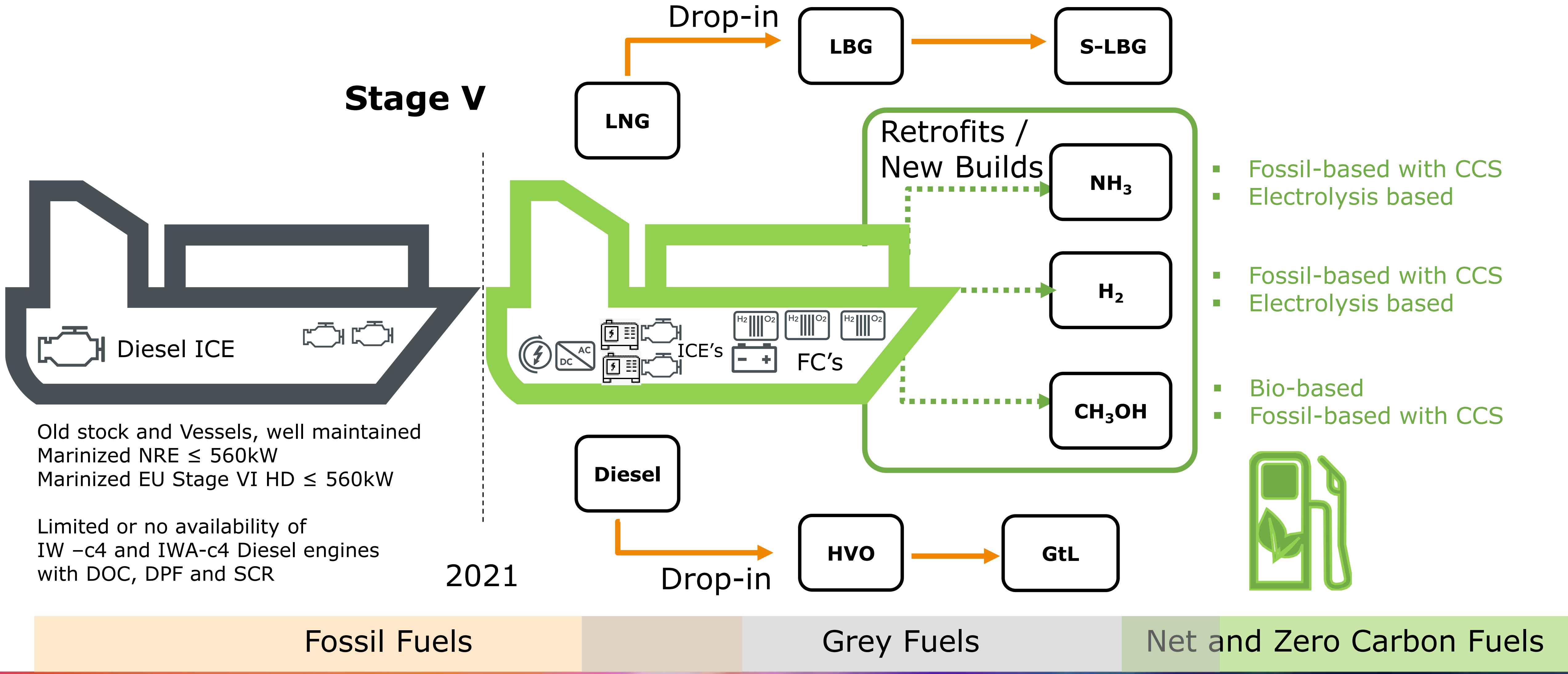
- Hydrogen production is very energy intensive, expensive and not available at scale
- The “grey fuel” pathway (H_2 production via methane steam reforming or via brown coal - water gas shift reaction / NH_3 production via Bosch Haber process) does not contribute to the mitigation of GHG emissions
- The energy density of hydrogen and storage volume onboard are important obstacles.
- Safety standards to be developed and improved.
- Infrastructure defines Power & Propulsion technology.
- Some Applications e.g. large merchant vessels not practical.

Fuels

- New fuels of a high diversity, a few based on renewable energy, will come up soon replacing the traditional fuels.
- Currently no single fuel can be defined as THE future fuel.
- Fuel cells might establish towards an alternative to the internal combustion engine.
- Upsizing for large cargo vessel propulsion by modules
- Electrical energy storages will find their way on board for various applications
- Virtual system integration at the early phase of product definition is essential.
- Real-time system simulation is a valuable tool to investigate and optimize the operation of vessels, especially with complex system architectures, different energy storages and prime movers.

Summary and Conclusions

Transition Draft for Propulsion & Power Technology



Transition Draft for Propulsion & Power Technology

- Most of the inland waterway fleet continues to use diesel engines (observation).
- New and greener propulsion systems are a persistent and increasingly important subject in the sector in perspective of the GHG reduction as reflected by a variety of funded pilot projects.

- Alternatives for diesel are Liquified Natural Gas (LNG), Gas to Liquid (GTL) and hydrogen.
- The success of these systems in the future will be highly dependent on their reliability, their availability, their durability and probably very importantly, their price.

- Liquefied Natural Gas (LNG), hydrogen fuel cells and battery-powered propulsion systems are currently being developed, tested and implemented as alternatives.
- The success of these systems in the future will highly depend on their reliability, availability, durability and cost.
- Under this perspective the Combustion engine adapted for the new alternative fuels is still a favorable solutions
- A single substitute for the diesel engine would not be available soon, though a combination of systems on future vessels is possible.

Transition Draft for Propulsion & Power Technology

- Tailored approaches for the specific High Power System Business sectors and Applications needed (Power Generation, Marine incl. IWW, Non road mobile machinery, Rail)
- Transfer of solutions for HD-on road, EPG, NRMM and Rail to IWW where applicable
- Large scale infrastructure unclear, Regulatory for H_2 and NH_3 under development
- Fuel diversification scenario expected
- Engine Solutions needed for:
  - LNG: Further improvements towards increased power density and efficiency
  - H_2 & NH_3: Retrofits and new builds – Further developments Gas admission, Combustion & Turbocharging
  - MeOH: Dual Fuel for Marine engines
  - Syn./E & Biofuels: Conventional engine technology, Reliability topics
- Focus on further development of Fuel cells (and batteries)

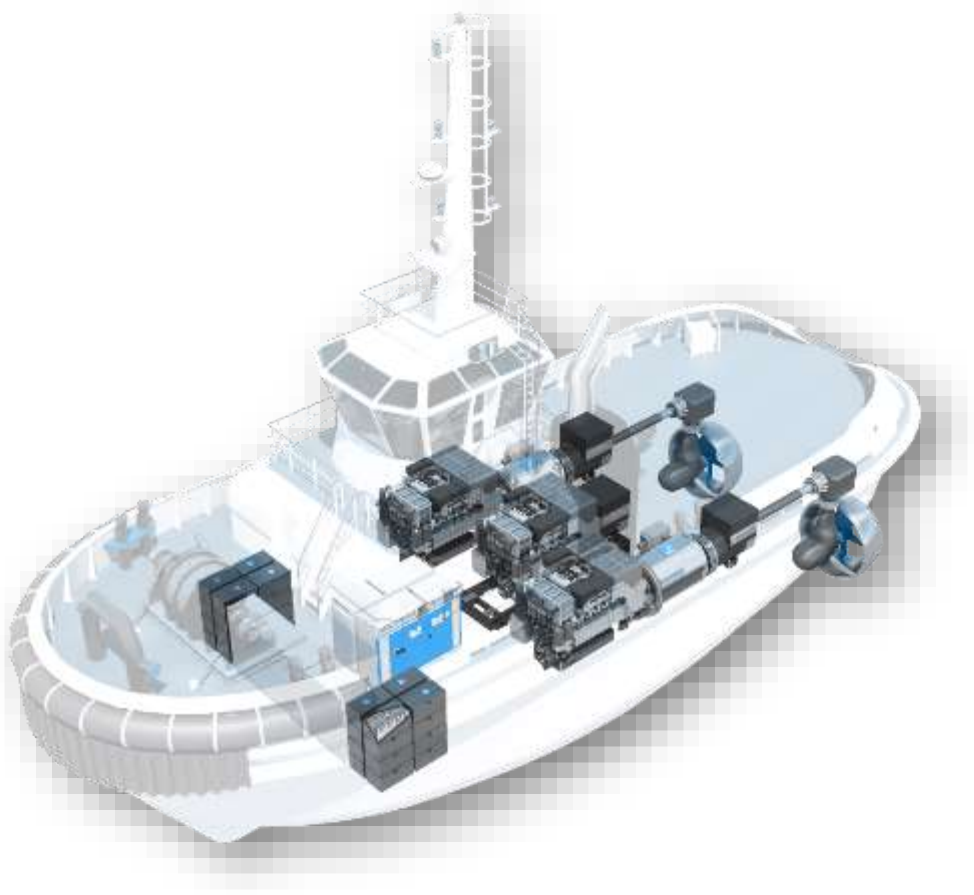
Transition Draft for Propulsion & Power Technology

- System complexity will increase
- Complexity will enable flexibility
- Electrification is a driver of optimizing system integration
- Comprehensive system simulation is key for a system integration of complex components
- Integrative and consistent application of models throughout the entire development process is an additional added value
- AVL can contribute to this process, by development knowhow, experience and the tools

AVL Services

- Technical and strategic consulting
- Development of engines and power train systems
- Customer-specific definition of fuel cell system, e-drive architectures, vehicle packaging and built
- Detailed system and vehicle benchmarking as the basis for recommendation on system layout, cost, etc.
- Prediction of vehicle performance via model-based development to save development time and cost
- Customer-oriented PEMFC system and vehicle controls, including operating strategies and software development
- Excellent supplier network for fuel cell stack, hydrogen tank and fuel cell sub-components (compressor, humidifier, etc.)
- Detection and differentiation of fuel cell stack's failure modes during fuel cell operation - thanks to AVL's new diagnostic-based control device (AVL THDA™)
- Integration of diagnostic-based fuel cell control into the vehicle's control unit and power electronics without added hardware costs
- Profound know-how in application of PEMFC for passenger cars, light-duty to heavy-duty trucks, buses, forklifts, trains and marine applications

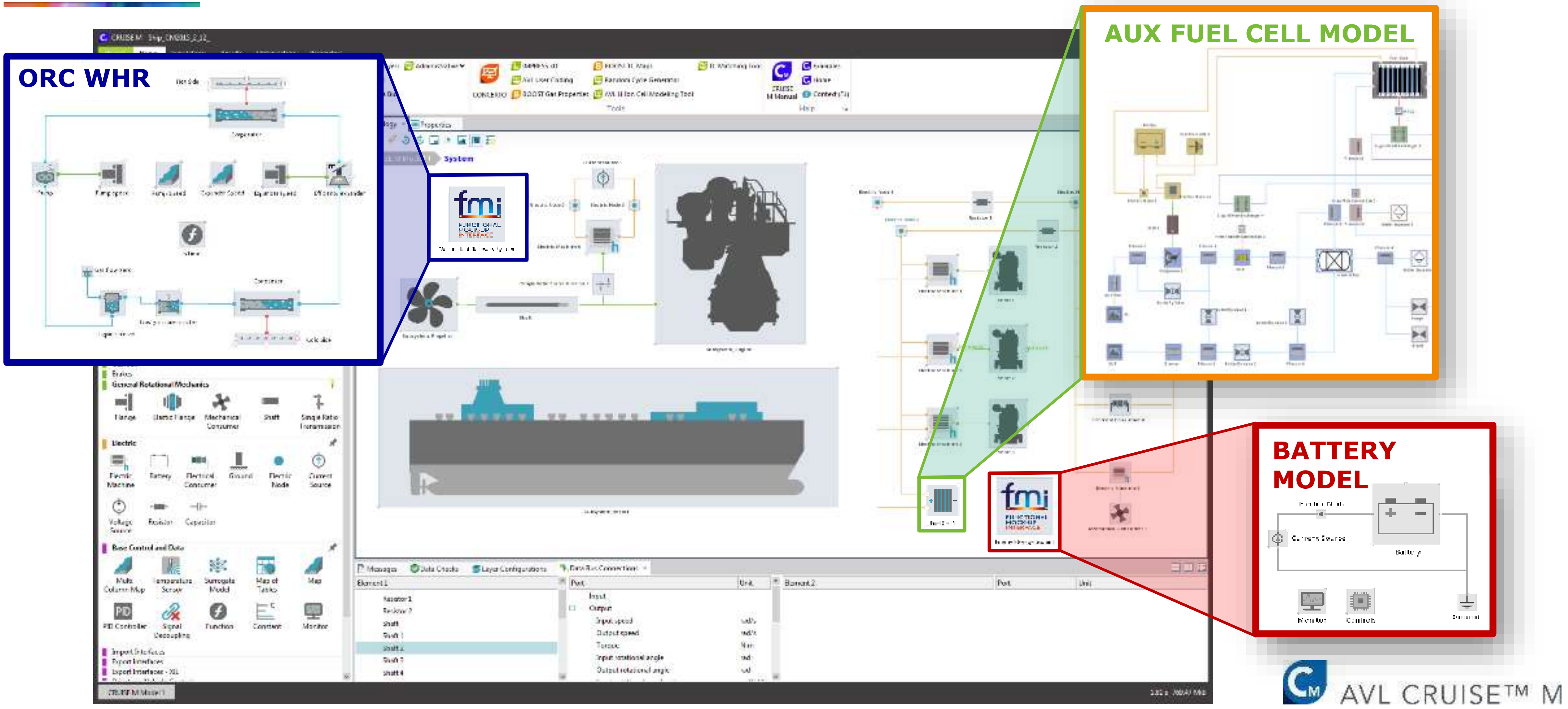
AVL Services – Simulation of Complex Systems



Key Benefits of System Simulation

- System simulation and model-based approaches are the key for any complex system optimization and ensure optimum system behavior
- Digital twins and system simulation help to avoid development and testing loops (time and cost reduction)
- Virtual approaches can be seen as a measure of quality assurance (risk minimization, early failure detection)
- AVL has an all-in-one solution with suitable tools (e.g. AVL CRUISETM M, AVL Model.CONNECTTM), experienced simulation teams and development teams for high power systems (e.g. marine, inland waterway shipping)

AVL Services – Simulation of Propulsion & Energy System



AVL Services – Simulation of Propulsion & Energy System

Numerous Fields of Application

- Feasibility studies / proof of concept studies
- Definition and optimization of system topology
- System analysis and optimization of systems by integral modeling approach
- Simulation of dynamic system behavior of propulsion and energy systems
- Specification of hybrid components: e.g. main and aux. engines, alternators, E-motors, inverters, energy storage systems, fuel cells, automation and controls etc.
- Optimization of operating strategy for given operating profile/duty cycle
- Support of change management and retrofit processes by means of virtual approaches
- Model-based pre-calibration and optimization of software functions prior to a final hardware verification (model-in-the-loop, hardware-in-the-loop, virtual testbed) by means of real-time models

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Thank you very much for your attention and interest!

Appendix

Appendix

Short term challenges

Transition from EU Stage IIIA or CCNR II to Stage V

Power	Engines	EU IIIA and CCNR II		Stage V		
		2017	2018	2019	2020	2021
< 300KW	Stage V Type approval					
	Stage V Placing on market					
	Production of transition engine Stage IIIA, CCNR II or NRE					
	Placing of transition engine Stage IIIA and CCNR II to the market					
	Placing of Vessel with Stage V Engine on Market					
	Production date of Vessel with Transition engine					
	Placing of Vessel with Transition engine on the market					
≥300kW	Stage V Type approval					
	Stage V Placing on market					
	Production of transition engine Stage IIIA, CCNR II or NRE					
	Placing of transition engine Stage IIIA and CCNR II to the market					
	Placing of Vessel with Stage V Engine on Market					
	Production date of Vessel with Transition engine					
	Placing of Vessel with Transition engine on the market					

Interpretation from Source: https://www.cesni.eu/wp-content/uploads/2018/11/FAQ_Engines_en.pd

Key take away (question):
How will IWW vessels produced beyond mid of 2021 be powered ?

Appendix

Transition Draft

- LNG — Liquified natural gas
- LPG — Liquified petroleum gas
- MeOH — Methanol
- HVO — Hydro treated vegetable oil

- NG-H_2 — Hydrogen from natural gas (Methane steam reforming)
- NG-NH_3 — Ammonia from natural gas (Bosch Haber)
- NG-MeOH — Methanol from natural gas

- LBG — Liquified biogas
- Elec-H_2 — Hydrogen from electrolysis based on renewable electricity
- Elec-NH_3 — Ammonia from electrolysis based on renewable electricity

Appendix
Transition from EU Stage IIIA to Stage V

- **Overview on OEM's delivering CCNR II compliant Transition Engines**
  - AB Volvo Penta
  - Anglo Belgian Corporation
  - Baudouin
  - Caterpillar (by Perkins Engines Company Limited
  - Caterpillar Inc.
  - Caterpillar Motoren GmbH & Co KG (MAK)
  - Cummins Engines Co. Inc
  - Deutz AG
  - Doosan
  - FPT Fiat Power Train Industrial S.p.A (incl.ex Iveco S.p.A.)
  - General Electric
  - Genpower
  - Guangxi Yuchai Machinery Company Limited
  - Guascor SA
  - Hyundai Seasall Co., Ltd.
  - IVECO S.p.A.
  - KMD
  - Liebherr Machines Bulle SA
  - MAN Nutzfahrzeuge AG
  - Meyer & van der Kamp GmbH & Co. KG
  - Mitsubishi
  - Motorenfabrik Hatz GmbH & Co. KG
  - MTH
  - MTU Friedrichshafen GmbH
  - Perkins Engines Company Ltd.
  - Scania CV AB
  - Sisu / AGCO Power Inc.
  - Wärtsilä Finland Oy, Wärtsilä France s.a.s, Wärtsilä Nederland B.V.
  - Weichai Power Co Ltd
  - Yanmar Co. Ltd.
  - Zeppelin Power Systems GmbH & Co.KG

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Appendix

Transition from EU Stage IIIA to Stage V

- **Overview on OEM’s delivering EU Stage IIIA compliant Transition Engines**
  - AB Volvo Penta, TA ranging from 27/04/2007 to 05/06/2013
  - Le Moteurs Baudouin, TA ranging from 31/05/2010 to 30/10/201
  - Caterpillar Inc., TA ranging from 30/11/2006 to 04/10/2018
  - Deutz AG, TA ranging from 26/05/2009 to 31/01/2012
  - FPT Fiat Power Train Industrial S.p.A. and former IVECO S.p.A., TA ranging from y to 21/11/2017
  - General Electric
  - IVECO S.p.A.
  - John Deere Power Systems
  - MAN Nutzfahrzeuge AG and MAN Truck & Bus
  - MTU Friedrichshafen GmbH
  - Perkins Engines Co. Ltd.
  - S. I. des Moteurs Baudouin (Weichai Power Co.,Ltd)
  - Scania CV AB
  - Sisu Diesel Inc.
  - STEYR MOTORS GmbH
  - Weichai Power Co Ltd

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Appendix

Applicable Standards & Regulatory Authorities

- Regulation (EU) 2016/1628 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery
- European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN)
- Rhine Vessel Inspection Regulations (RVIR) or Directive (EU) 2016/1629
- European Committee for drawing up Standards in the field of Inland Navigation (CESNI)
- Others

Appendix
Abbreviations

Abbreviation	Meaning
▪ CCS	Carbon capture and storage
▪ CH4	Methane
▪ CI	Compression Ignition
▪ CO2	Carbon dioxide
▪ Elec-H2	Hydrogen from electrolysis based on renewable electricity
▪ Elec-NH3	Ammonia from electrolysis based on renewable electricity
▪ FC	Fuel cell
▪ GHG	Greenhouse gas
▪ GWP100	Global warming potential over 100-year time horizon
▪ H2	Hydrogen
▪ HB	Haber–Bosch
▪ HVO	Hydrotreated vegetable oil
▪ ICE	Internal combustion engine
▪ LBG	Liquefied biogas
▪ LNG	Liquefied natural gas
▪ MeOH	Methanol
▪ MGO	Marine gas oil
▪ NG	Natural gas
▪ NG-H2	Hydrogen from natural gas
▪ NG-MeOH	Methanol from natural gas
▪ NG-NH3	Ammonia from natural gas
▪ NH3	Ammonia
▪ N2O	Nitrous oxide
▪ NOX	Nitrogen oxides
▪ OCSI	Open chamber spark ignited (gas engine)
▪ PCSI	Pre chamber spark ignited (gas engine)
▪ PEM FC	Proton-exchange membrane fuel cell
▪ PM	Particulate matter
▪ SCR	Selective Catalytic Reduction
▪ SI	Spark ignition
▪ SO2	Sulphur dioxide
▪ SOFC	Solid oxide fuel cells
▪ USD	US dollar