Power for Ships on Inland Waterways

24. Int. Danube Conference, Samorin

3rd of December, 2019 | Maria SEGURA, Hinrich MOHR
Overview

Drivers

Background, Drivers, Regulations and Trends

▪ AVL Background
▪ Tightening of Emission Regulations

Engine Technology

Engine Technology & Trends

▪ 4 Stroke Engine Developments

Propulsion System

Future Propulsion Systems

▪ Alternative Fuels
▪ Hybridization
▪ Fuel Cell
Background of AVL

- AVL is the world's largest independent company for development, simulation and testing technology of powertrains.
- AVL's portfolio covers combustion engines, transmission, electric drive systems, batteries and fuel cell systems for all applications.
- AVL supports engine OEMs and operators in engine and system optimization with in-house SW tools and expert knowledge over the last 70 years.
AVL General Figures

**RESEARCH 10%**
of turnover in-house R&D

**INNOVATION 1500**
generated patents

**STAFF**
10,500 employees
65% engineers & scientists

**GLOBAL FOOTPRINT**
44 engineering locations
• >220 testbeds
• Global customer support network

**GROWTH**

<table>
<thead>
<tr>
<th>Year</th>
<th>Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>0.15 billion €</td>
</tr>
<tr>
<td>2017</td>
<td>1.55 billion €</td>
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<tr>
<td>2018</td>
<td>1.75 billion €</td>
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<tr>
<td>2019</td>
<td>2.05 billion €</td>
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</tbody>
</table>

**EXPERIENCE**
70 years!

**SALES**

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**ONE PARTNER**
AVL Engine Development Experience

![Graph showing the relationship between displacement/cylinder and power/cylinder.](image)
Classification of emissions

Future legal requirements are based on two main aspects:

<table>
<thead>
<tr>
<th>Global Warming</th>
<th>Pollution</th>
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</thead>
<tbody>
<tr>
<td>GHG/CO₂</td>
<td>NOx &amp; PM/PN Emissions</td>
</tr>
<tr>
<td>Global Problem</td>
<td>Local Problem</td>
</tr>
<tr>
<td>Energy Sources and Technology</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PT - Technology</td>
</tr>
</tbody>
</table>

Focus on reduction of global CO₂ and local NOx & PM/PN emissions
Required reduction of CO₂ Emissions
Worldwide Transportation

A dramatic CO₂ reduction will be needed. Especially in areas, where it is possible by technology, like transport

CO₂ scenarios for worldwide transportation - tank to wheel (ttw) emissions.

\( \rightarrow \text{Need of DPF arises for engines of power class (P \geq 300), for PN control} \)

<table>
<thead>
<tr>
<th>Engine subcategory</th>
<th>Power range</th>
<th>Engine ignition type</th>
<th>( \text{CO} ) g/kWh</th>
<th>( \text{HC}^{1} ) g/kWh</th>
<th>( \text{NO}_x ) g/kWh</th>
<th>PM mass g/kWh</th>
<th>PN #/kWh</th>
<th>Mandatory date of application of this regulation for</th>
<th>Test-cycle</th>
<th>EDP</th>
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</thead>
<tbody>
<tr>
<td>IWP.v.1</td>
<td>19 \leq P &lt; 75</td>
<td></td>
<td>5.00 (HC + NO(_x) \leq 4.70)</td>
<td>0.30</td>
<td>-</td>
<td>6.00</td>
<td>1 January 2018</td>
<td>1 January 2019</td>
<td>E3</td>
<td>10000</td>
</tr>
<tr>
<td>IWP.v.2</td>
<td>75 \leq P &lt; 130</td>
<td></td>
<td>5.00 (HC + NO(_x) \leq 5.40)</td>
<td>0.14</td>
<td>-</td>
<td>6.00</td>
<td>1 January 2018</td>
<td>1 January 2019</td>
<td>E2</td>
<td>10000</td>
</tr>
<tr>
<td>IWP.v.3</td>
<td>130 \leq P &lt; 300</td>
<td></td>
<td>3.50</td>
<td>1.00</td>
<td>2.10</td>
<td>0.16</td>
<td>-</td>
<td>1 January 2019</td>
<td>1 January 2020</td>
<td></td>
</tr>
<tr>
<td>IWP.v.4</td>
<td>P \geq 300</td>
<td></td>
<td>3.50</td>
<td>0.19</td>
<td>1.80</td>
<td>0.015</td>
<td>( 1 \times 10^{-2} )</td>
<td>6.00</td>
<td>1 January 2019</td>
<td>1 January 2020</td>
</tr>
<tr>
<td>IWP.c.1</td>
<td>19 \leq P &lt; 75</td>
<td></td>
<td>5.00 (HC + NO(_x) \leq 4.70)</td>
<td>0.30</td>
<td>-</td>
<td>6.00</td>
<td>1 January 2018</td>
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<td>1 January 2019</td>
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Source: AVL Emission Report

\textbf{\textit{\`{C}ategory IWP\textquotec}}

Engines exclusively for use in inland waterway vessels, for their direct or indirect propulsion, or intended for their direct or indirect propulsion, having a reference power that is greater than or equal to 19kW

\textbf{\textit{\`{C}ategory IWA\textquotec}}

Auxiliary engines exclusively for use in inland waterways vessels, having a net power greater than 19 kW
Apart from the reduction in allowable PM emissions, Stage V introduces PN limits for mid to large engines (P ≥ 300 kW)
- Introduction of PN limit makes the application of DPF mandatory
- Emissions regulations are defined for both propulsion and auxiliary engines
Technologies for Future Large Engines

**Multi-purpose engine integrated into system**

**Fuel Flexibility**
Diesel, DF and Gas
Methanol (CH$_3$OH), Ammonia (NH$_3$)
Hydrogen (H$_2$) LP
Hydrogen (H$_2$) HP-DI

**High peak firing Pressure**

**Aggressive Miller**
(VIVT required)

**High Efficiency Charging**
Family concept same TC size & type for all
Single stage from 2 to 4 turbos (cylinder number) extended with sequential TC, where needed

**2-Stage TC**

**Multi Fuel Combustion Direct Injection**

**EGR**
actually niche only

**Exhaust Aftertreatment**
DOC+DPF+SCR+ASC

**Variable Valve Actuation**
(De-coupled intake valve closing)

**Friction optimized**

**New materials**
Strength and heat transfer

**Smart components to support condition Monitoring**
Smart bearings
Closed loop injector
Cylinder pressure controlled ECU

**Increased BMEP**
Power-to-X Routes and Efficiencies

Power source | Power electronics | electrolysis | Gas treatment | Synthesis Process +treatment

Power-to-X Processes:
- Drying, PSA, TSA, Membrane

Products and Efficiencies:

<table>
<thead>
<tr>
<th>Product</th>
<th>$\eta_{\text{conv.}}$</th>
<th>$\eta_{\text{future}}$ (near future)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>67%*</td>
<td>80%**</td>
</tr>
<tr>
<td>Methane</td>
<td>49%*</td>
<td>80%**</td>
</tr>
<tr>
<td>FT Diesel</td>
<td>45%*</td>
<td>51%*</td>
</tr>
<tr>
<td>Methanol</td>
<td>45%*</td>
<td>72%*</td>
</tr>
<tr>
<td>DME</td>
<td>53%*</td>
<td>65%*</td>
</tr>
</tbody>
</table>

Sources:
* Based on Literature:
  - Tremel, 2017
  - Becker, 2012
** based on AVL project results

PSA ... Pressure swing adsorption
TSA ... Temperature swing adsorption
DME ... Dimethyl ether
Influencing factors to select the future energy carrier

- **Ecology**
  - Greenhouse gas emissions – CO₂ equivalent
  - Particulate emissions – mass and number
  - Pollutant emissions – NOₓ, SOₓ, CO, HC,…

- **Economy**
  - Efficiency – Well to Wake / Wheel – Cradle to Grave ?
  - Availability – Infrastructure for production, transport and storage
  - Energy Density – Operation time and range
  - Safety – Production, transport, storage and consumption
  - Flexibility – Usable for multiple applications, Re-use ICE PTs

- **Politically**
  - Public acceptance – No fear and good image
  - Incentives – For building up production and infrastructure, lower taxes
  - Legislation – Definition of boundary conditions
Liquefied Natural Gas – alternative fuel for transportation expanding into Danube region

Workshop on Modernization of Danube Vessels Fleet
Vienna, 18 April 2018

LNG in the Danube Region
- LNG Masterplan for Rhine-Main-Danube
- LNG for Upper Austria
- Projects in Slovakia
- Projects in Hungary
- Projects in preparation in Romania (Constanta & Galati)

Source: Pro Danube Management GmbH, Manfred Seitz
Ship Hybrid Retrofit Scope of Work – System Simulation

- Simulation of Initial System (Reference Case)
- Optimization of Power Management
- Battery Concept
- Simulation & Optimization of Hybrid System
- Profitability Assessment
Electrification & Hybridization
Drivers and Benefit

Efficiency benefit and ROI fully depends on application, hybrid system architecture and implementation of controls strategy.

- **Zero Emission Operation**
  - Battery Electric Operation
  - Fulfilling Local Regulations

- **Efficiency Improvement**
  - Sweet Spotting
  - Part-load operation & boosting
  - Spinning reserve minimization

- **Machinery Protection**
  - Peak shaving
  - Avoiding load jerks

- **Reducing Transients**
  - Manoeuvering
  - Dynamic Positioning

- **Redundancy**
  - Improvements to reliability and availability

- **Silence & Comfort**
  - Reduced no. of engines running
  - Hotel load pure on battery power

- **Acoustic Signature**
  - Alter acoustic signature
  - Silent mode operation

- **Power Boost**
  - Adding additional power for short time

Source: CORVUS Energy

**Battery Ferries**
Source: EST-Floattech

**Hybrid Tugs**
Source: Sintef

**Hybrid OSVs**
Source: Abeking und Rasmussen

**Hybrid Pilots**
Source: Boskalis

**Hybrid Dredgers**
Source: Rolls-Royce

**Hybrid Fregattes**
Source: Heesen Yachts

**Hybrid Yachts**
Source: Heesen Yachts
Fuel Cell for Marine Propulsion
Still too big?

Volumetric Power Density of Diesel Engine is similar to PEM Fuel Cell

3.2 MW Diesel Engine

3 MW PEM Fuel Cell

2 m
### >20 Fuel Cell Projects in Shipping

<table>
<thead>
<tr>
<th>Project</th>
<th>Concept</th>
<th>Year</th>
<th>Fuel Cell</th>
<th>Capacity</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/V Gjesen</td>
<td>Small passenger ship in the harbour of Bergen</td>
<td>2010</td>
<td>HTPEM</td>
<td>12 kW</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Class</td>
<td></td>
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<tr>
<td>MF-Vågen</td>
<td>Hybrid propulsion using a fuel cell and a diesel engine</td>
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<td></td>
<td>Submarines</td>
<td></td>
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<tr>
<td>US SSFC</td>
<td>The program addresses technology gaps to enable fuel cell power systems that will meet the electrical power needs of naval platforms and systems</td>
<td>U.S. Department of Defense, Office of Naval Research</td>
<td>2000 - 2011</td>
<td>PEM</td>
<td>MFCF</td>
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<tr>
<td>SP-BRZEZE</td>
<td>Feasibility study of a high-speed hydrofoam fuel cell passenger ferry and hydrogen refueling station in San Francisco bay area</td>
<td>SanDiego National Lab., Rad and White Fox</td>
<td>2015 - present</td>
<td>PEM</td>
<td>Hydrogen</td>
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<tr>
<td>E4ships - Topolmen</td>
<td>Support of IFG Cede development to include a FC chapter and set the regulatory framework for the use of maritime FC systems</td>
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<tr>
<td>RiverCell</td>
<td>250 kW modularized HT-PEM fuel cell system developed and tested as part of a hybrid power solution for river cruise vessels</td>
<td>Meyer Werft, DNVGL, Neptun Werft, Viking Cruises</td>
<td>Phase 1: 2015-2017</td>
<td>HTPEM</td>
<td>250 kW</td>
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<td></td>
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<td></td>
<td>Phase 2: 2017-2022</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>RiverCell - Elleta</td>
<td>Feasibility study for a fuel cell as part of a hybrid power solution for a tollway in Amsterdam</td>
<td>Tü Berlin, BehAHLA, DNvGL, etc.</td>
<td>2015-2016</td>
<td>HTPEM</td>
<td>-</td>
</tr>
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<tr>
<td>ZenShip - Absefiver</td>
<td>100 kW PEMFC system developed and tested onboard of a small passenger ship in the area of Aalborg in Denmark</td>
<td>Proton Motor, GL Abtei Touristik GmbH, Linde Group, etc.</td>
<td>2006-2013</td>
<td>PEM</td>
<td>96 kW</td>
</tr>
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<td></td>
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<tr>
<td>FCSHIP</td>
<td>Assess the potential for maritime use of FC and develops a Roadmap for future R&amp;D on FC application on ships</td>
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<tr>
<td>Now N-HShip</td>
<td>Research project on the use of hydrogen in marine applications</td>
<td>INE (Icelandic New Energy), GL, DNvGL, etc.</td>
<td>2004-2006</td>
<td>HTPEM</td>
<td>-</td>
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<tr>
<td>Nanko H2</td>
<td>Small passenger ship in the canals of Amsterdam</td>
<td>RiederJovers etc.</td>
<td>2012-2014</td>
<td>PEM</td>
<td>60 kW</td>
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</tr>
<tr>
<td>Hornblower Hybrid</td>
<td>Hybrid ferry with diesel generator, batteries, PV, wind and fuel cell</td>
<td>Hornblower</td>
<td>2012-2014</td>
<td>PEM</td>
<td>32 kW</td>
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</tr>
<tr>
<td>Hydrogen-Ship</td>
<td>Small passenger ship which operates in Bristol</td>
<td>Bristol Boat Trips etc.</td>
<td>2012-2014</td>
<td>PEM</td>
<td>12 kW</td>
</tr>
</tbody>
</table>

**Table A.1: Fuel cell projects in shipping**

**Source:** EMSA Study on the use of Fuel Cells in Shipping

Confidential
Summary

- New regulations will drive new technologies for prime movers, energy storage and hybridized propulsion system architectures
- Diesel engines will require a DPF to fulfill EU Stage V emission regulations. EGR or SCR for NOx reduction
- Fossil LNG as intermediate fuel. Future: Bio-LNG and synthetic LNG from renewable sources. Investments necessary
- Electrical energy storages will find their way on board for various applications, in most cases taking the fluctuating load from the installed prime movers
- Hybrid systems will allow an optimum and flexible provision of energy on board with low environmental impact for a wide variety of marine applications
- Fuel cells might establish towards an alternative to the internal combustion engine, although there are big challenges regarding hydrogen availability (large scale), storage of hydrogen as fuel, bunkering and transportation
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With the right Fuel and Technologies, The Internal Combustion Engine is far from dead!
www.avl.com