ULTRA LOW EMISSIONS
A GREAT CHALLENGE
FOR LARGE BORE ENGINES
ULTRA LOW EMISSIONS
A GREAT CHALLENGE
FOR LARGE BORE ENGINES

Andrei Ludu
AVL List Austria
Emission Reduction is a Well-known Subject ....

So, What‘s Special About Large Bore Engine Emission Reduction ?
EMISSION LEGISLATION OVER TIME
PASSENGER CAR – COMMERCIAL VEHICLES – LARGE ENGINES

100% = Values in 1970:
- NOx ~ 18 g/kWh
- PM ~ 0.7 g/kWh

Passenger Car Engines

HC + NOx ~ 0.17 g/km
PM ~ 4.5 mg
EMISSION LEGISLATION OVER TIME
PASSENGER CAR – COMMERCIAL VEHICLES – LARGE ENGINES

Commercial Veh. Engines

100% = Values in 1970:
NOx ~ 18 g/kWh
PM ~ 0.7 g/kWh

EU0
EU1
EU2
EU3
EU4
EU5
EMISSION LEGISLATION OVER TIME
PASSENGER CAR – COMMERCIAL VEHICLES – LARGE ENGINES

Large Engines
Marine

Year


Emission relative to 1970 - %

0 10 20 30 40 50 60 70 80 90 100

NOx ~ 15 g/kWh
PM not regulated

PM = 0.5 g/kWh
IMO 1
IMO 2

NOx ~ 2 g/kWh
PM ~ 0.06 g/kWh
IMO 3
US EPA T4
LOW EMISSIONS FOR LARGE BORE ENGINES..... IS THERE A SPECIAL CHALLENGE?

• The Industry Mindset and Development Experience traditionally driven by Reliability and Fuel Consumption – the emission reduction calls for a Focus Shift and New Development Processes

• The Emission Reduction Increment is substantial and the Time is Short: the industry needs fast Technology Awareness, Acceptance and Implementation.

A locomotive idles a lot
A ferry boat runs at very high load
A tug boat needs torque back-up
A ship should have invisible smoke under harbour operation
A genset runs 6000 hours per year at high load
Powergen, Marine, Construction, Oilfield are serviced by the same base high-speed engine
A ship should operate on three fuels: HFO, MDO, LNG
1.8 g/kWh NOx & 0.06 g/kWh PM to be demonstrated by both 5L/Cyl. & 1800 rpm and 35L/Cyl. & 750 rpm engines
LOW EMISSIONS FOR LARGE BORE ENGINES…..
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• The **Emission Reduction Increment** is substantial and the **Time is Short**: the industry needs fast Technology Awareness, Acceptance and Implementation.

• **Diversity!** In Applications, Fuels, Engine Size and Speed, Ratings. The Task is Wide and Complex
PRESENTATION ITINERARY

- BUSINESS DRIVERS
  Market Trends and Key Drivers
  Emissions Legislation

- DEVELOPMENT METHODOLOGY
  High Quality Engine Design Methodology
  Short Time to Market Development Process

- EMISSION COMPLIANCED ROADMAPS
  Diesel Engines
  Alternative Fuels

- OUTLOOK
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- OUTLOOK
MARKET TRENDS OVERVIEW

Shipbuilding:
- Massive Slow Down in Order Intake, Postponements and Cancellations due to Economic Crisis but Recovery Expected Beyond 2010
- New Transportation Patterns
- Replacement of Older Tonnage Has Continued: VLLCs, Bulkers
- Slow Steaming due to Raising Oil Price

Power Generation:
- 2007/2008 Orders Reach Again an All-Times High
- Growing Energy Need, Demographics and Infrastructure Improvements
- High Share of Gas for Unit Power >3.5MW
- Increasing Share of Renewable Energies (Europe Target 20% by 2010)
- Alternative Energies (Wind/Solar/Fuel Cells,..): Longer Term Impact

Locomotive Market:
- Growth Expected to be 4-5% after Economic Recovery
- Main Areas for Diesel Locomotives: NA and CIS, Asia
Key Drivers for Engine Technology

- **Emission Rules are the Major Driver**
  - NOx and Particulate Matter Need to be Reduced by Up to 80-90% for Most Applications Until 2015-2020 (EPA, EU)
  - This Revolutionizes Combustion Technology and Expands Use of Aftertreatment Whereas Electronic Controls Are a “Must”
  - The Utilization of Fuels w. Low CO2 and SOx Impact Becomes Mandatory:
    - Low Sulphur Heavy Fuel for Marine Enforced Until 2020
    - Diesel Fuel and Bio Fuels for Land Based Application

- **Efficiency Matters for All Long Hours Applications**
  - Thermal Efficiency Up and Above 50% Impacts Combustion, Turbocharging and Mechanical Design

- **Low Life Cycle Cost Driven by Economical Factors**
  - Lowest First Cost for Stand By and Low Hours Operation
  - Long Hours Operation: Ship Engines, Power Gen Call for New Reliability Standards and Advanced Monitoring and Maintenance
TOMORROW’S FUELS FOR MARINE ENGINES:
MARINE TRAFFIC HAS A SIGNIFICANT IMPACT ON LAND

Global ship traffic density

85 percent in Northern Hemisphere
70 percent within 400 km of land

Source: IMO Study on Greenhouse Gas Emissions from Ships, MEPC 45(8), 2000
SHIPTRACKS ON SEA ARE VISIBLE FROM SATELLITE

Exhaust Emissions from Ships ➔ Aerosols ➔ Clouds ➔ Clouds reflect the sunlight

Source: Die Zeit No. 35 / 2006
EMISSION LEGISLATION MARINE
HIGH SPEED n≤1200 rpm

Test Cycle E3

Test Cycle E2

* NOx + HC
IMO STAGE 1, 2 AND 3
NOx EMISSION LEGISLATION

From 2016:
An ocean going ship must comply with Tier II (outside ECA) and with Tier III inside ECA.
IMO RULING OCTOBER 2008
FUEL SULPHUR CONTENT LIMITS

Global:
ECA:
MDO: 0.1 wt.% S
EMISSION LIMITS, THE END GAME

<table>
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<tr>
<th>Year</th>
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<th>NOx [g/kWh]</th>
<th>PM [g/kWh]</th>
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ASME ICED Conference Lucerne_Sep. 2009
PRESENTATION ITINERARY

- BUSINESS DRIVERS
  - Market Trends and Key Drivers
  - Emissions Legislation

- DEVELOPMENT METHODOLOGY
  - High Quality Engine Design Methodology
  - Short Time to Market Development Process

- EMISSION COMPLIANCED ROADMAPS
  - Diesel Engines
  - Alternative Fuels

- OUTLOOK
TRANSFORMING THE LARGE ENGINE DEVELOPMENT PROCESS

What Really Counts:

• Customer Value to Market
• Cost to Market
• Time to Market

Specifics of Large Engines
1. High Cost of Hardware and Testing
2. Short Time Available for development (<2 Years)
3. Highest Reliability Standards
4. Multi-Parameter Optimization

The AVL Approach
1. Frontloading Design & Simulation
2. The Single Cylinder Test Engine
3. Advanced Measurement and Data Processing Tools
4. Structured R&D Process
MOTIVATION FOR THE AVL ADVANCED DEVELOPMENT METHOD

- High Quality Products in Performance and Reliability
- Reduced Time to Market
- Low Production Costs
FRONTLOADING IN DESIGN

AVL Engine Development process

First engine run

Concept Study

Digital Prototype

Pre-Production Development

Product Maturity

Production Development

Production Validation

Traditional Approach

Frontloading
Design Methodology:

Importance of Technical Specification Manuals

- Requirements
- Function Requirements
- Production Requirements
- Engine Packaging
- Customer Service Requirements
- Checkability of Supplied Parts/Systems
- Assembly Requirements

Parameter:

- Costs
- Investment Costs
- Assembly Costs
- Costs for Supplied Parts/Systems
- Single Part Costs
SINGLE CYLINDER ENGINE (SCE) – THE BRIDGE BETWEEN TECHNOLOGY CREATION AND APPLICATION

Technology Module Creation

Technology Evaluation and Selection on SCE

Technology Application and Validation on MCE

Fundamental Research

Development of Basic Performance & Emissions

Validate MCE Performance & Emissions & Mechanics
THE AVL SCE TECHNOLOGY EVALUATION & SELECTION SYSTEM

**Management**
(PUMA Open Test Bed Automation, CAMEO Self Learning Algorithms, ...)

**Combustion Development**

**Simulation**
(Air System, SCE Transfer to MCE, ...)

**AVL Large SCE with Dyno**
Highly Flexible Modular Platform

**Development Tools**
(VISIOLUTION, ...)

Time to Market: 9 mo earlier
Dev. Costs: 1 mio €/y reduced
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- OUTLOOK
1. 

Incremental Improvement of Engine Performance: Power Density, Efficiency, Manufacturing Cost, Reliability in HFO, DO, Gas

- Mechanical Design & Structures
- Thermodynamics & Combustion
- Tribology/Wear Management
- Modular/Low Cost Design
- Adv. Maintenance Systems
1. Incremental Improvement of Engine Performance: Power Density, Efficiency, Manufacturing Cost, Reliability in HFO, DO, Gas


- Fuel Inject Syst.: Common Rail
- Advanced Air Systems
- Variable Valve Timing
- Low NOx and PM Combustion
- Combustion of “Clean Fuels“
Different Emission Reduction Means – Rated Output

\[ \Delta = 10 \text{ g/kWh} \]

Miller Cycle

Pilot Injection

Increased Compression Ratio

Source: AVL Research, SCE Test Results
THE RELEVANCE OF VERY HIGH INJECTION PRESSURE

High injection pressure mandatory for low soot

Source: AVL Research, SCE Test Results
UNDERSTANDING COMBUSTION VISUALISATION

Cylinder Head

Endoscope Unit

Illumination Unit

CCD-Camera

Source: AVL Research, SCE Test Results
THE RELEVANCE AND CHALLENGE OF EGR

EGR enables NOx limit compliance

Soot challenge with EGR
High EAR ratio mandatory

Source: AVL Research, SCE Test Results
MILLER CYCLE AND EGR

BSFC benefit with Miller Cycle and EGR

Miller Cycle and EGR require high TC compressor pressure ratio

Source: AVL Research, SCE Test Results
AIR SYSTEMS REVOLUTION:
2-STAGE TC, VVT, MILLER VALVE TIMING, CONTROLS

- Miller Timing, EGR and Power Density need increased Boost Pressures:
  - Single Stage $\pi = 5.5$
  - Two Stage $\pi > 5.5$
- VVT for aggressive Miller process
- Wide Torque and BMEP Range
  - Variable Turbocharger Geometry
  - Sequential Turbocharging
- BSFC and Waste Heat Recovery Drive Turbo Efficiency

![Graph showing Boost Ratio vs. BMEP Bar with 1 Stage and 2 Stage comparisons.](image)
INTELLIGENT ENGINE CONDITION MONITORING INTEGRATED IN A VESSEL PERFORMANCE SYSTEM

KONGSBERG - Vessel Performance System
Logical system architecture

Display/Communication
Analysis
Network
Measurement devices

Measurement devices

Admin network
Ship/shore comm.
Bridge network
VDR/NAV
Care network
K-Com network

Descision Support System
MIP analysis
K-Link

High Speed Information/Data bus

Interface
Display
I/O
Sensors
Autochief Engine control
Torque monitoring
Fuel monitoring
MIP Cylinder perform.
Turbo Charger perform.

Interface
Display
I/O
Sensors
Interface
Display
I/O
Sensors
Interface
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Sensors
Interface
Display
I/O
Sensors

Display/Communication

Analysis

Network

Measurement devices
LONG LIFE MONITORING SENSOR

*Integrated FPM-cable*

*GaPO₄ piezo-elements*

*Leak proof concept (verified)*
LONG LIFE MONITORING SENSOR
GRAPHICAL USER INTERFACE OF THE AVL EPOS™ - ENGINE MONITORING SYSTEM
1. *Incremental Improvement* of Engine Performance: Power Density, Efficiency, Manufacturing Cost, Reliability in HFO, DO, Gas

2. Quantum Steps in NOx, PM Emission Reduction Through Advanced Technologies *Inside The Engine* and „Clean Fuels“ w. Lower CO2 Impact

3. Exhaust Gas *Aftertreatment* Becomes Essential for Near Zero NOx & PM

- Oxydation Catalysts
- DPF
- SCR
- 3-Way Cat/Stoich. W. EGR
- NOx Adsorbers
- Thermal Management is Key
IMO3 DEMONSTRATOR SHIP
SCR APPLICATION FOR SEA-GOING VESSELS

SCR-System Overview

Main Components:
- Catalyst
- Reactor housing
- Dust/soot blowing unit *)
- Urea injection system
- NO\textsubscript{x} control unit
- Data sampling system

*) fuel quality dependent
Species distribution

Region of higher turbulence with better evaporation, higher residence time for evaporation and higher NH3 gas fractions

NH3 peak due to hydrolysis of HNCO

Region of smaller NH3 gas fractions causes NO/NO2 break-troughs
PRESENTATION ITINERARY

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  Alternative Fuels

- OUTLOOK
MAIN DRIVERS OF THE FUEL SELECTION

- Economic and Demographic Growth
- Fuel Supply Dynamics
- Energy Strategies
- Emissions & Climate Change

Fuels of Tomorrow
VARIETY OF FUELS FOR MARINE, ELECTRIC POWER AND LOCOMOTIVE ENGINES

Fossil Fuels
- HFO
- Distillate
- Natural Gas
  - LNG
  - LPG

Biofuels
- Biomass to Gas (BtG)
- Biomass to Liquid (BtL)
- Bio Hydrogen
- Bio-DME*)

Derivate Fuels
- Hydrogen from Nat. Gas or Electrolysis
- Coal to Liquid (CtL)
- Other Synfuels

*) DME can be generated also from Fossil Fuels
TECHNICAL ADVANCE OF GAS ENGINES
DRIVEN BY KEY TECHNOLOGIES

• From TA Luft to Near Zero Emissions NOx<10ppm
• Thermal Efficiency 46-50% Depending on Bore Size
• Power Density Equals Diesel BMEP>25bar

Electronic Controls
- Cyl. Press. Sensors
  - NOx Sensors
  - A/F Ratio
  - Ignition
  - Cooling

Air Systems
- Miller/Atkinson
- VTG for A/F Ratio Ctrl.
  - High Boost Ratio
  - Waste Gate/Bypass

Ignition Systems
- Spark Ignition
- High Energy Spark Plugs
- Micro Pilot Injection
- Laser Ignition
- Self Ignition

Combustion Control
- Swirl & Tumble
- Bowl geometry
- Open Chamber
- Pre-Chamber
- Air/Fuel Ratio
- Homogeneous Ignition

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WORLD WIDE “GAS ECONOMY” DRIVES GAS ENGINE TECHNOLOGIES

Large Bore Dual Fuel Engines for Gas Tankers

Natural Gas Playing a Major Role in the Energy Supply (~25% of the W/W Primary Energy Consumption)
CO₂ Emissions Reduced by ~20%, SOₓ ≥ 0%
Potential for “Near Zero” NOₓ and PM Emissions

Aftertreatment Technology for “Near Zero” NOₓ / PM / HC / CO / VOC Emissions for Power Gens:

- Oxicat
- SCR
- 3 Ways Cat Technology for Stoichiometric Combustion

Source Wartsila

Source MAN
WHAT ABOUT FUTURE FUELS?

- **Fossil Fuels** Liquid and Gas Continue to Dominate But Stricter Emission Limits Drive the Development

- **Biofuels and Derivate Fuels** A Complementary Resource to Reduce Supply Vulnerability and Environmental Impact

- **The Right Investments** in Efficiency, New Technologies and New Infrastructures Are Vital
OUTLINE OF THIS PRESENTATION

- BUSINESS DRIVERS
  Classical Challenges >>> Low Fuel Consumption
  >>> High Reliability
  Emissions Reductions
  Low Production Costs

- DEVELOPMENT METHODOLOGY
  High Quality Engine Design Methodology
  Short Time to Market Development Process

- ROADMAPS AND TECHNICAL SOLUTIONS
  Diesel Engines
  Alternative Fuels

- OUTLOOK
EMISSION COMPLIANCE WILL REQUIRE NEW ENGINE DESIGNS

Two-stage turbocharging for high power density and EGR

New engine designs for high power density and EGR
## Technologies to Meet Legislation Limits

### Applications & Legislation

<table>
<thead>
<tr>
<th>Technologies</th>
<th>IMO 3</th>
<th>US EPA Tier 4</th>
<th>Non-road Tier 4 C&amp;I Powerg.</th>
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<tr>
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2. Quantum Steps in NOx, PM Emission Reduction Through Advanced Technologies Inside The Engine and „Clean Fuels“ w. Lower CO2 Impact

3. Exhaust Gas Aftertreatment Becomes Essential for Near Zero NOx & PPM

4. Deeper System Integration: Excellent Performance w. Lowest Emissions

- Deep Integration of All Engine Related Systems
- Cogeneration, Combined Gas & Steam WHR Systems
- Energy Storage & Hybrids

LARGE ENGINES TECHNOLOGY EVOLUTION SCENARIO
SHIP PROPULSION ENERGY SYSTEM

- Efficiency Gain > 10%
- Reduced Total Emissions (NOx, CO2, SOx, Particulates) by >10%
- Reduced Maintenance Cost for Auxiliary Sets
- Reduced Cooling Loss
- Improved Power Management Capability
- Reduced Lubeoil Cost

Source Wartsila Diesel
Turbogenerator Concept by Peter Brotherhood Ltd
CONCLUSION

- Economical Growth and Changing Customer Requirements: Opportunity for Large Engine Industry

- Emission Rules: Most Important Technology Driver but also Substantial Challenge in a Short Time and a Divers Product

- Alternative Fuels: More Importance, as an Additional Source


- New Engine Design: To Combine High Power Density and Emission Compliance

- Evolution: From Component Design to Advanced System Integration

- Getting Better Products to Market in a Shorter Time and at Lower Cost: New R&D Process
Thank You for Your Attention!

Andrei Ludu
Andrei Ludu
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Head of Product Management
Large Engines

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Conference Activity

ASME
- Key-Note Speaker at the ASME ICED Conference 2009 in Lucerne
- Session Chairman at ASME ICED Conference 2006 in Aachen
- Published papers at the ASME ICED Conferences 2001 in Argonne and 2003 in Salzburg
- Attended several ASME ICED Conferences

CIMAC
- Session Chairman at the CIMAC Conference 2010 in Bergen
- Panelist at the CIMAC Conference 2007 in Vienna
- Session Chairman at the CIMAC Conference 2007 in Vienna
- Published papers at CIMAC and attended several CIMAC Conferences

Curriculum Vitae

Born 1962 in Bucharest, Romania

2004 – present: Deputy Product Line Manager and Head of Product Management, Large Engines, AVL List GmbH


1986 – 1990: Combustion and Thermodynamics Expert at the Development and Research Institute for Thermal Machines in Bucharest, Romania

Education
Technical University of Bucharest, Mechanical Engineering, Internal Combustion Engines