ULTRA LOW EMISSIONS A GREAT CHALLENGE FOR LARGE BORE ENGINES

Andrei Ludu
AVL List Austria

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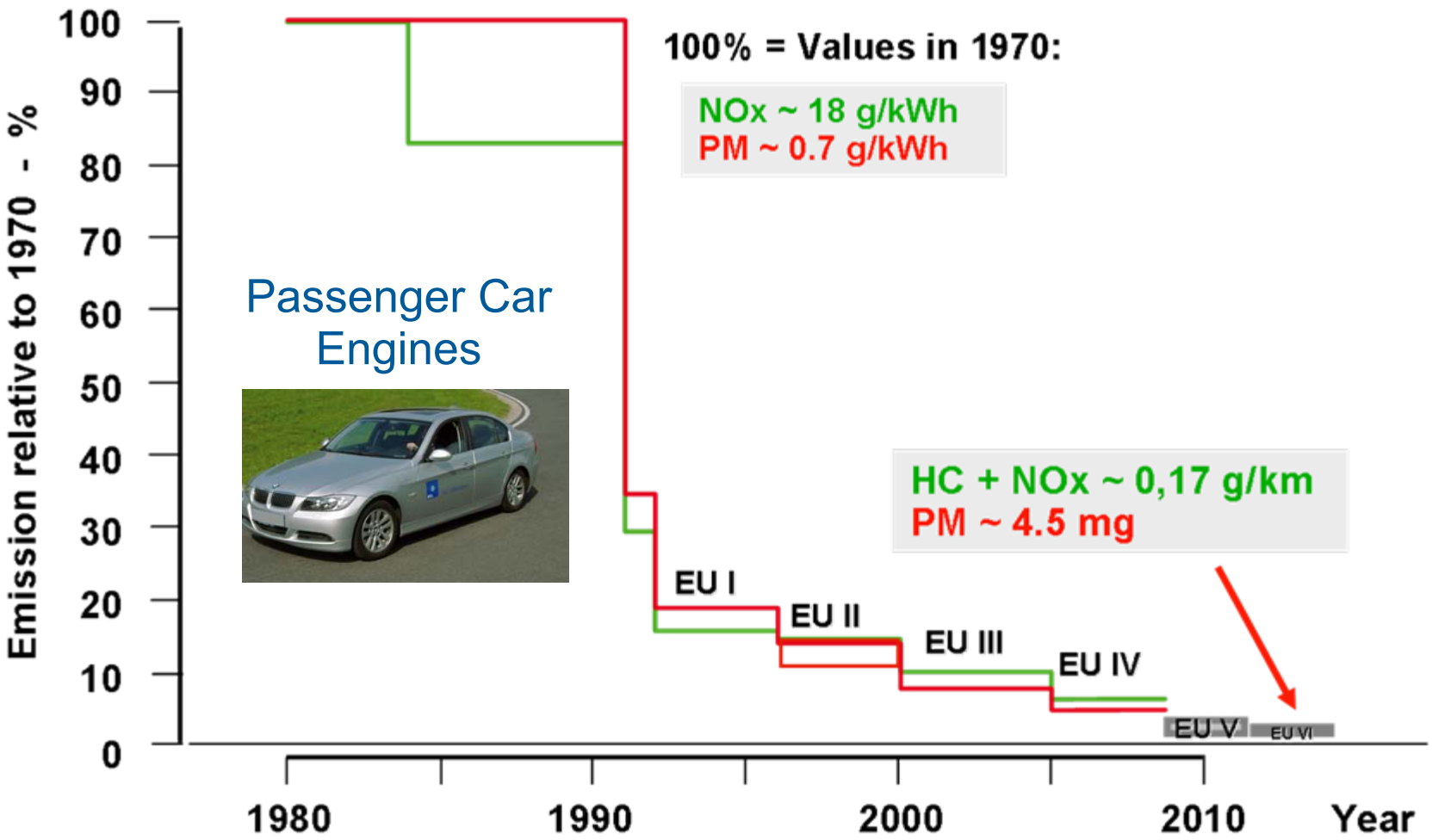
Emission Reduction is a Well-known Subject ….

So, What‘s Special About Large Bore Engine Emission Reduction ?

EMISSION LEGISLATION OVER TIME
PASSENGER CAR – COMMERCIAL VEHICLES – LARGE ENGINES



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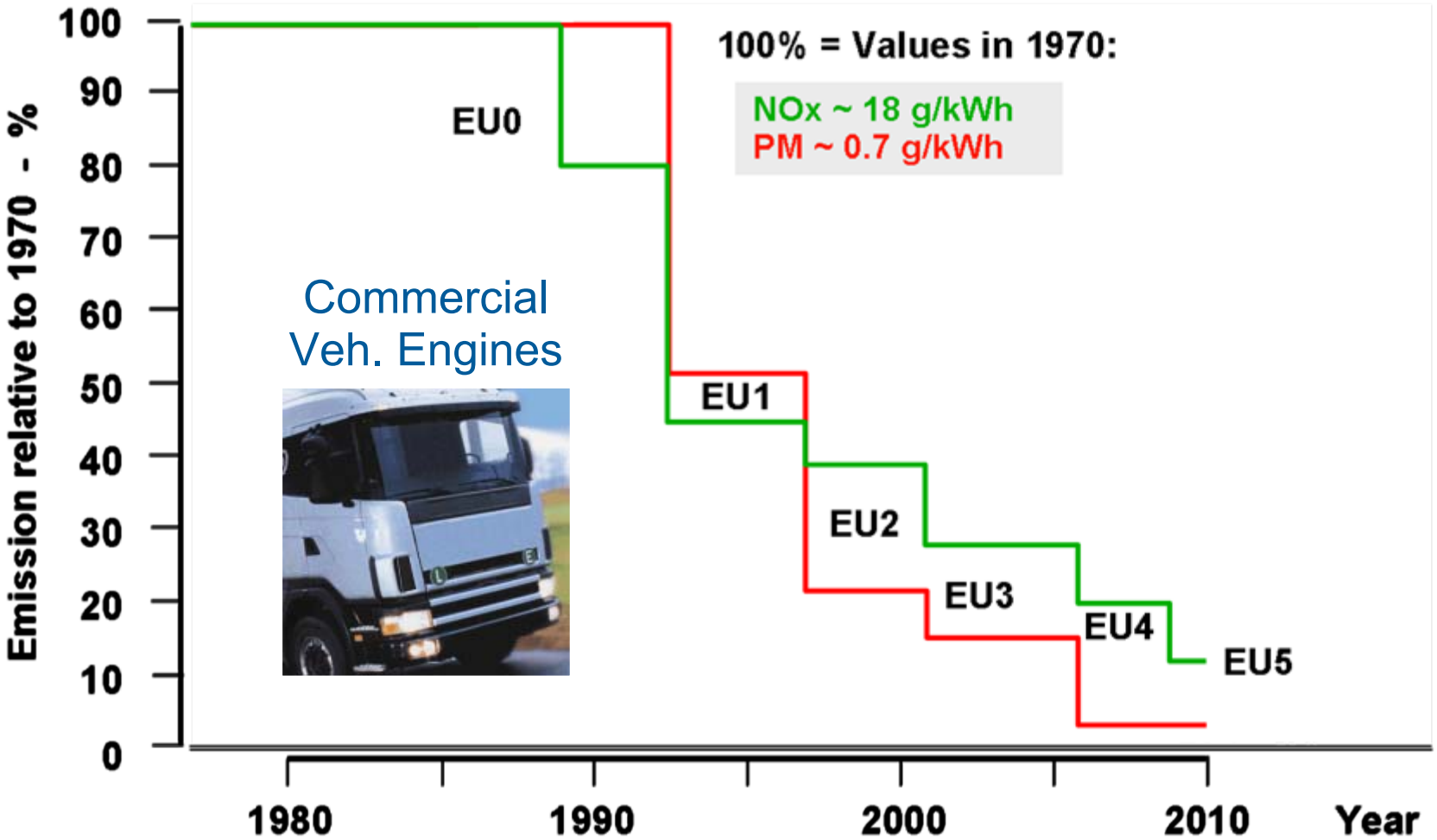

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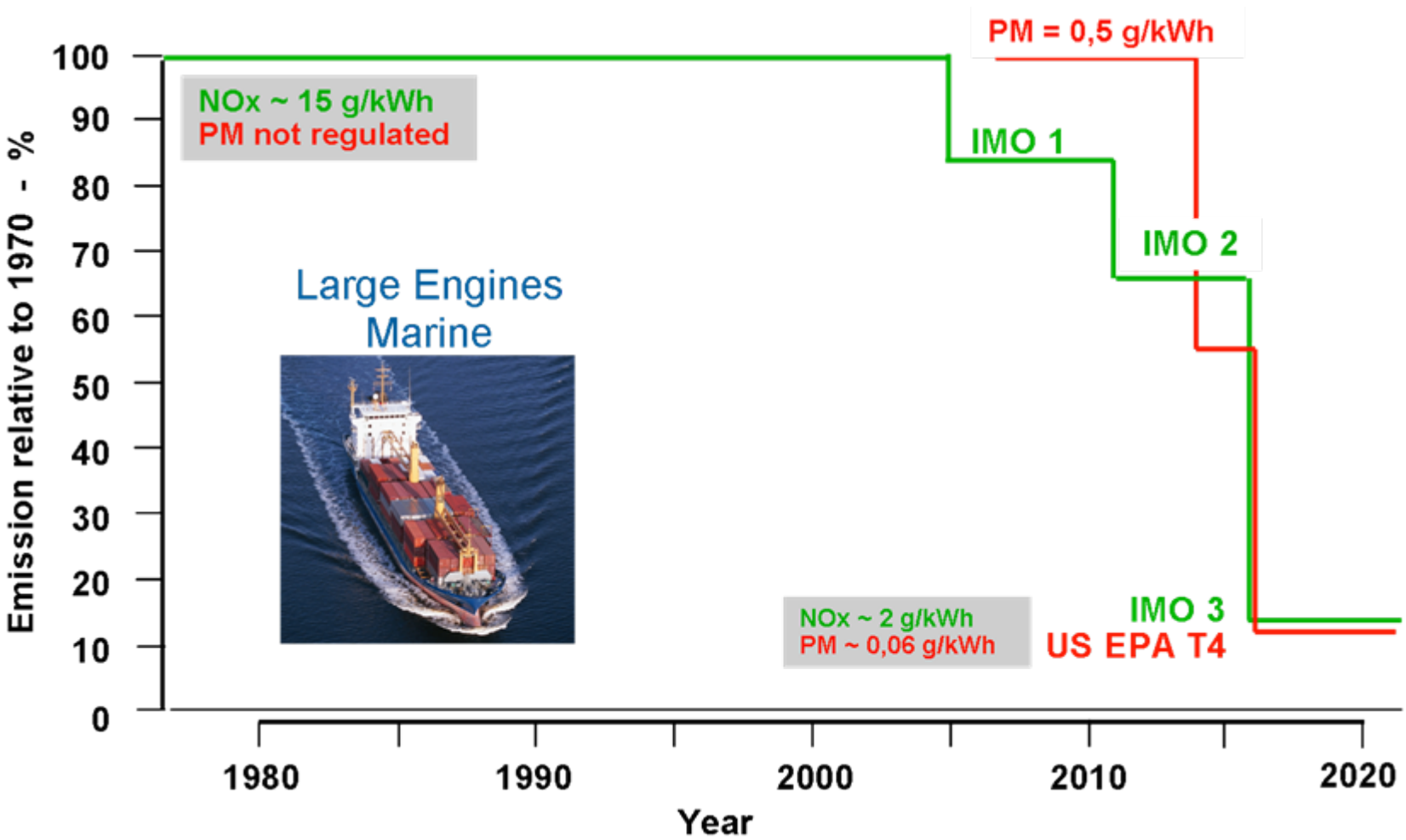

LOW EMISSIONS FOR LARGE BORE ENGINES…..
IS THERE A SPECIAL CHALLENGE ?

- **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 Technlogy Awarness, 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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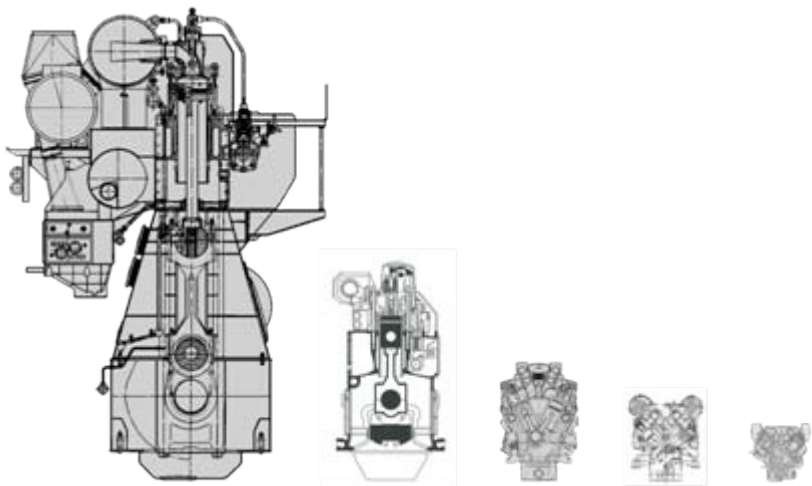
- **<u>Diversity!</u> In Applications, Fuels, Engine Size and Speed, Ratings. The Task is Wide and Complex**



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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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

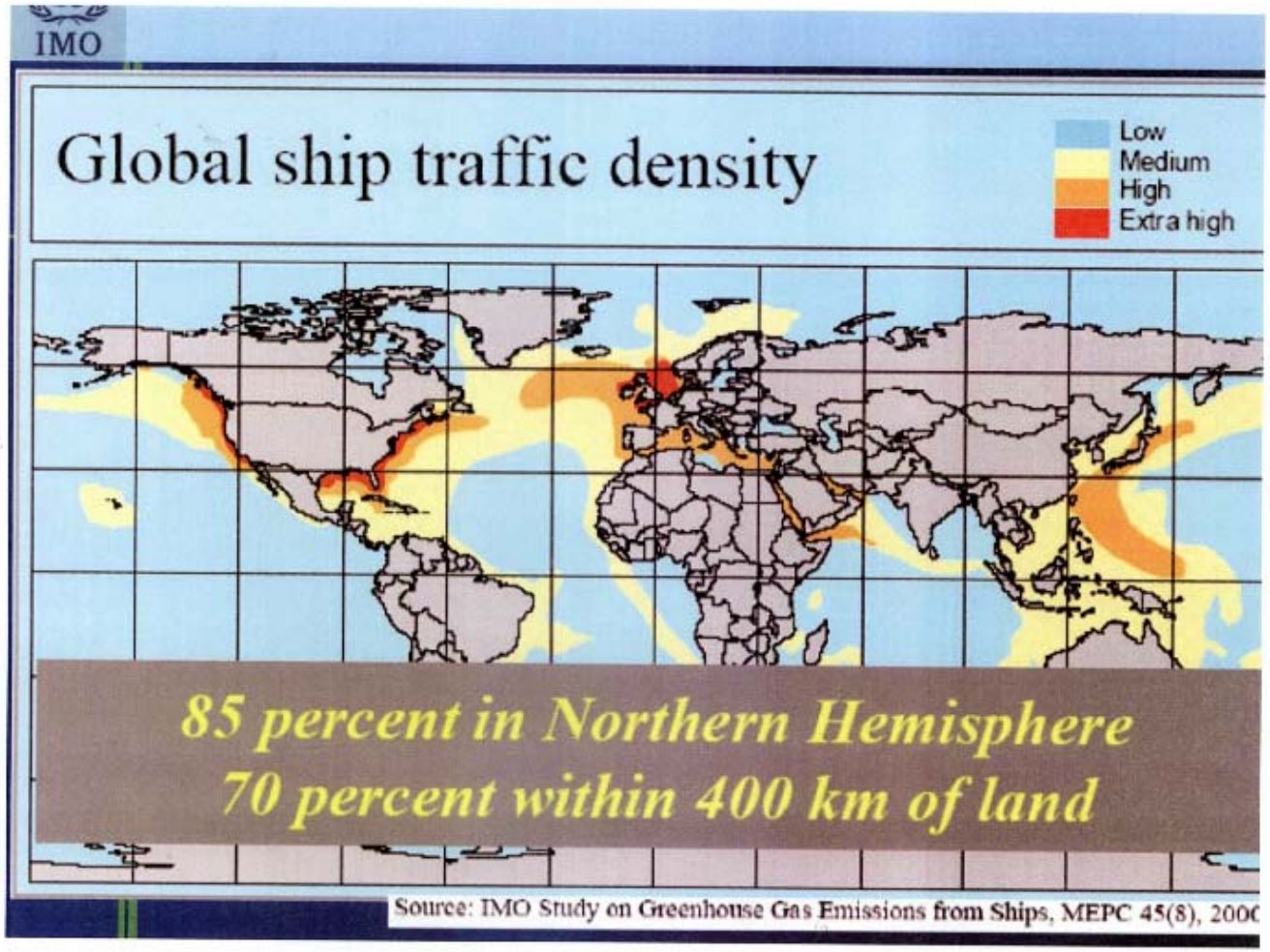
Key Drivers for Engine Technology

- **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**

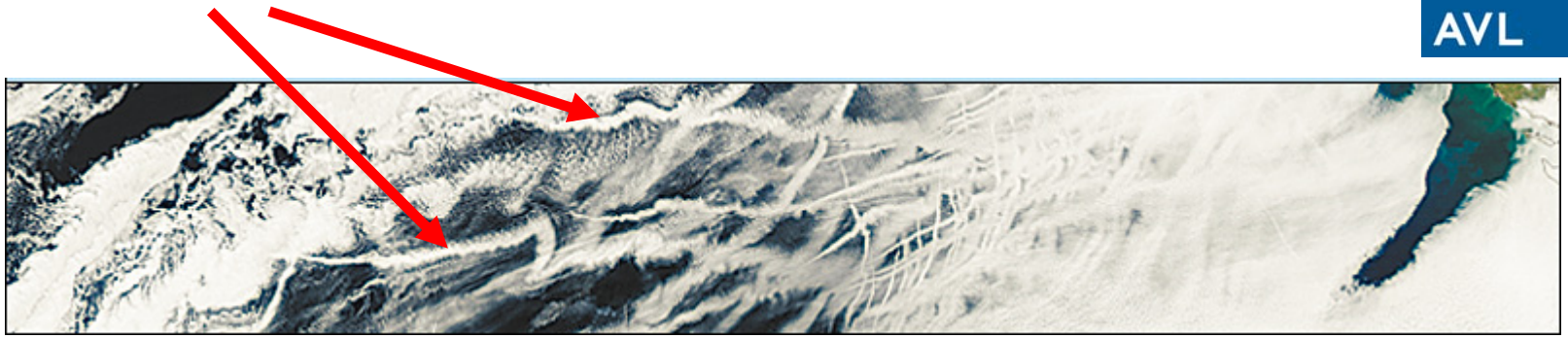
- **Efficiency Matters for All Long Hours Applications**
  - **Thermal Efficiency Up and Above 50% Impacts Combustion, Turbocharging and Mechanical Design**
  - **Combined Power and Heat Generations in Emission- and Fuel Price Sensitive Markets**

- **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**

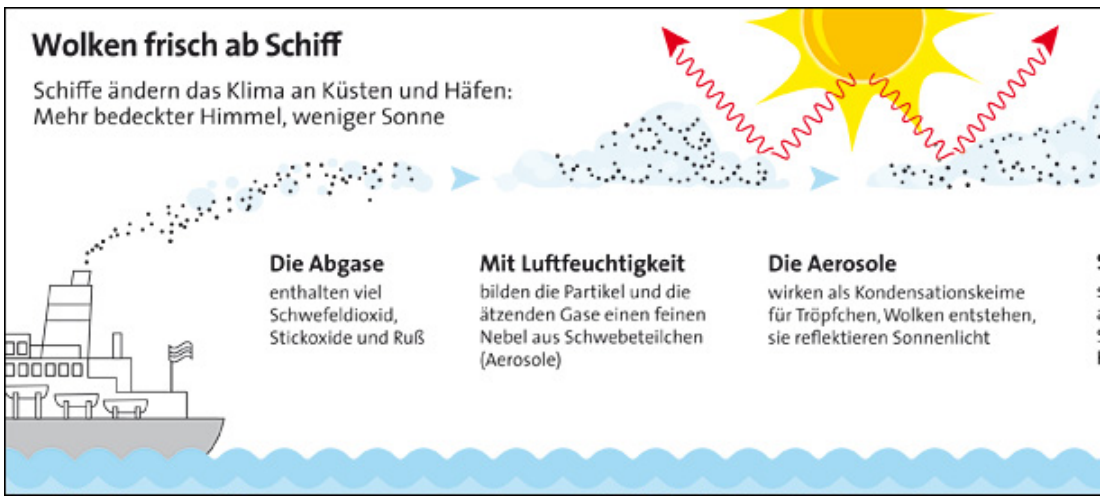
TOMORROW'S FUELS FOR MARINE ENGINES: MARINE TRAFFIC HAS A SIGNIFICANT IMPACT ON LAND



SHIPTRACKS ON SEA ARE VISIBLE FROM SATTELITE

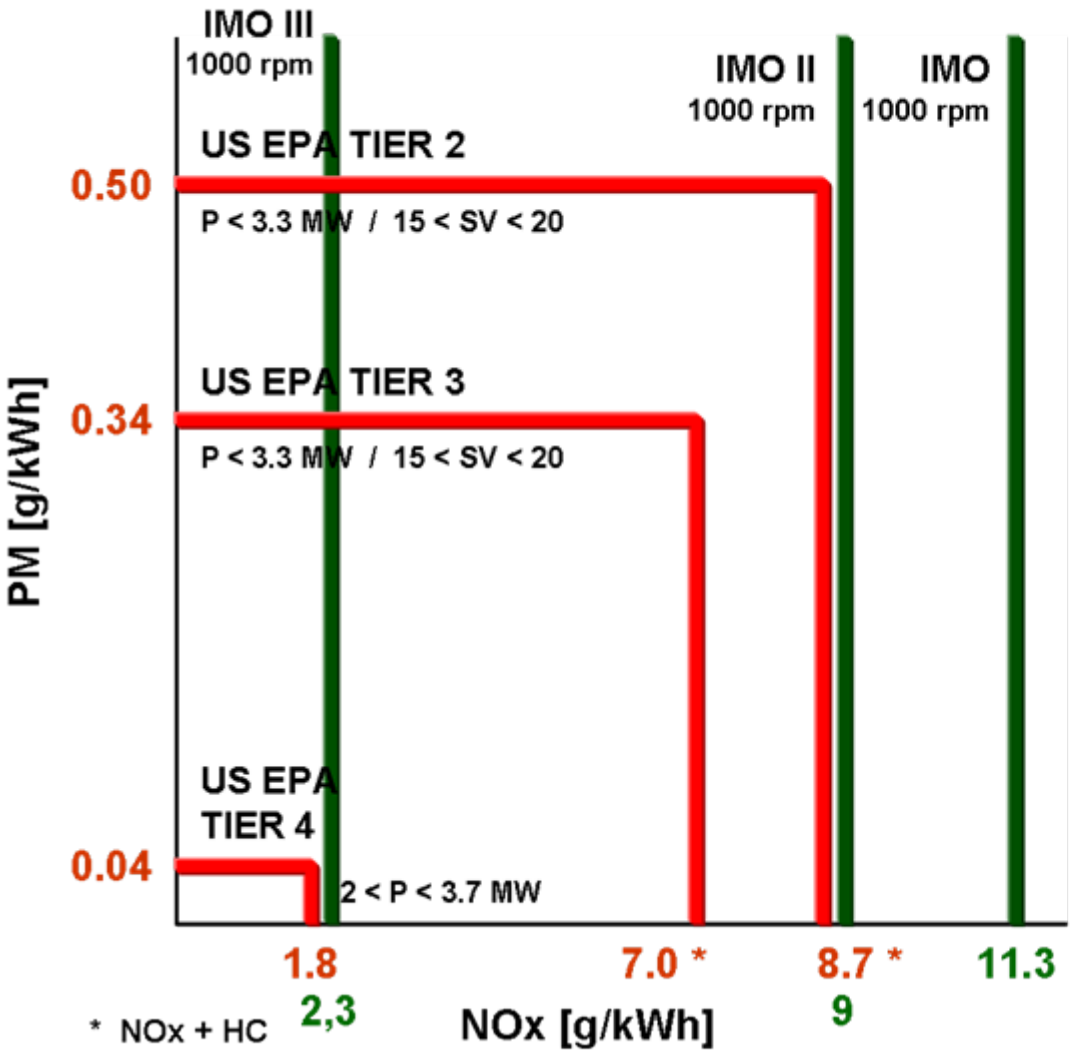


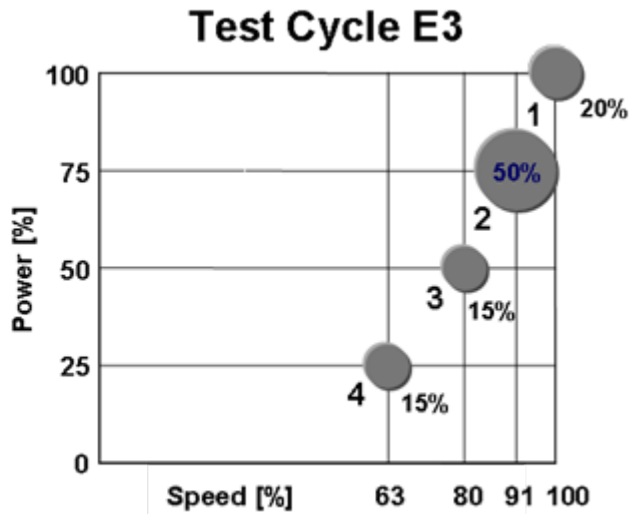
Exhaust Emissions from Ships → **Aerosols** → **Clouds** → **Clouds reflect the sunlight**

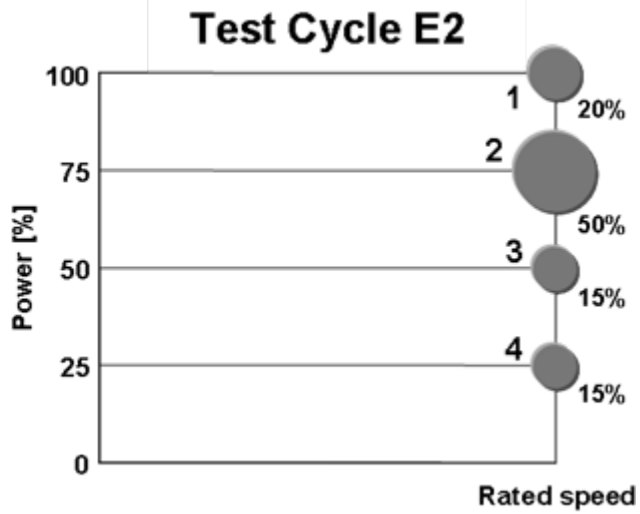


Source: Die Zeit No. 35 / 2006

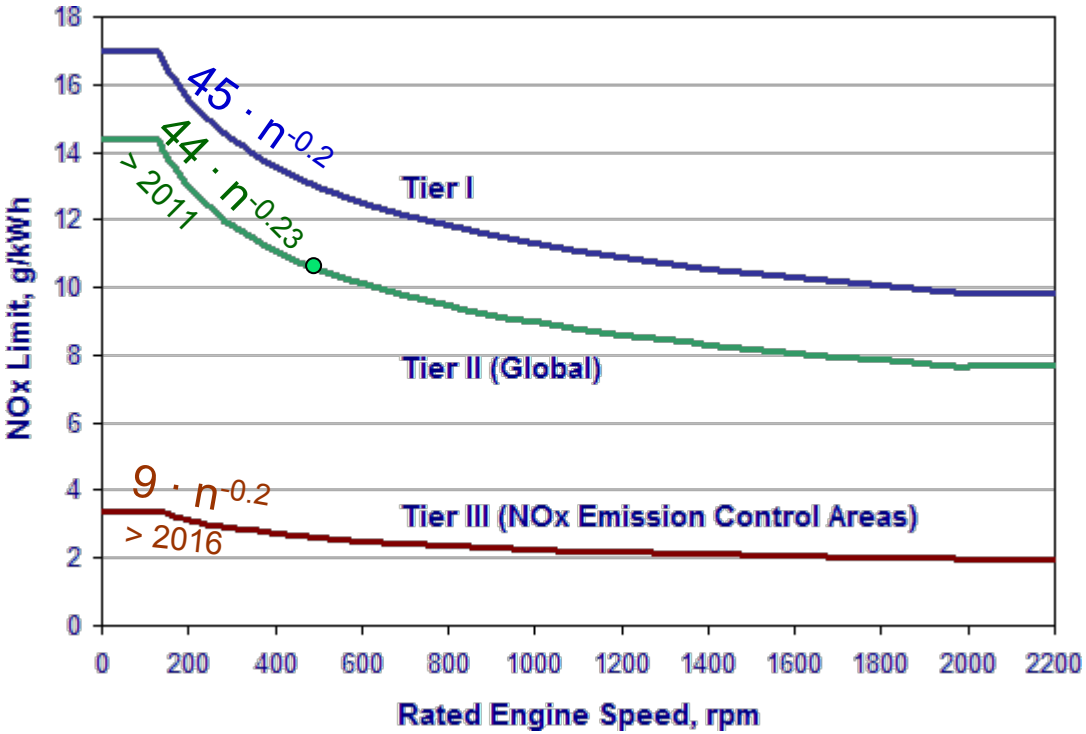
EMISSION LEGISLATION MARINE
HIGH SPEED n≤1200 rpm







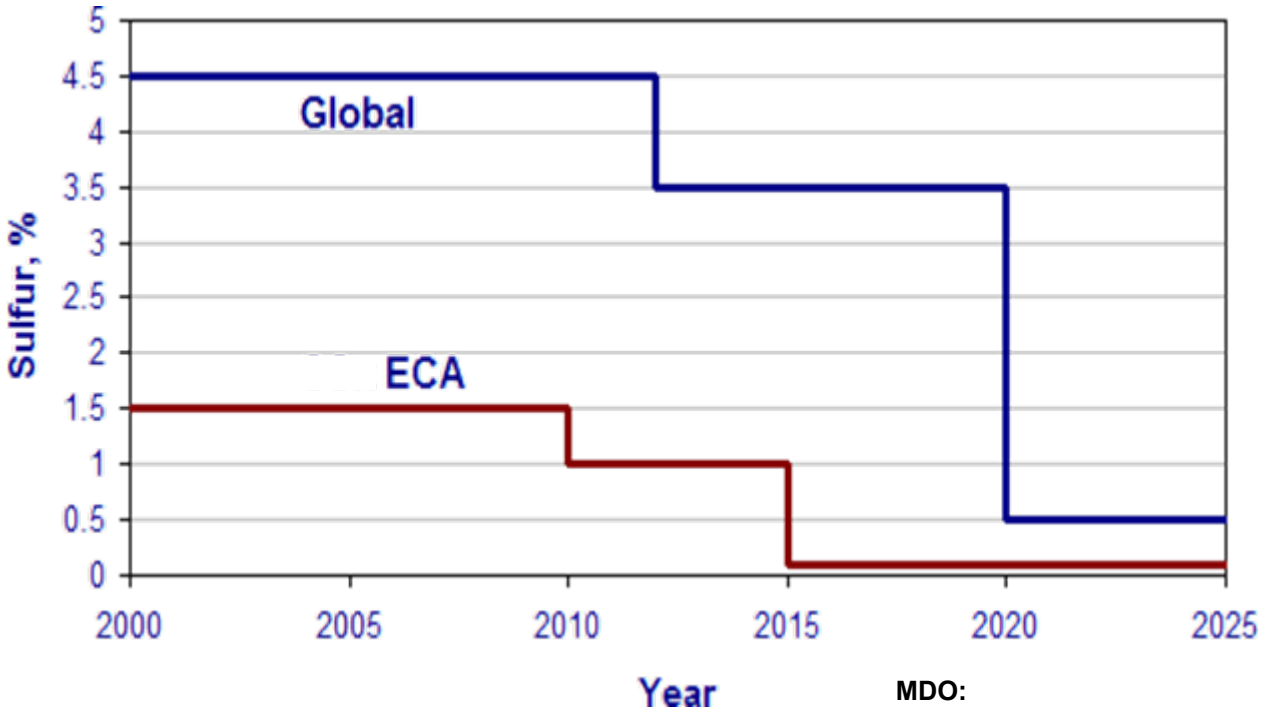
IMO STAGE 1, 2 AND 3
NOx EMISSION LEGISLATION



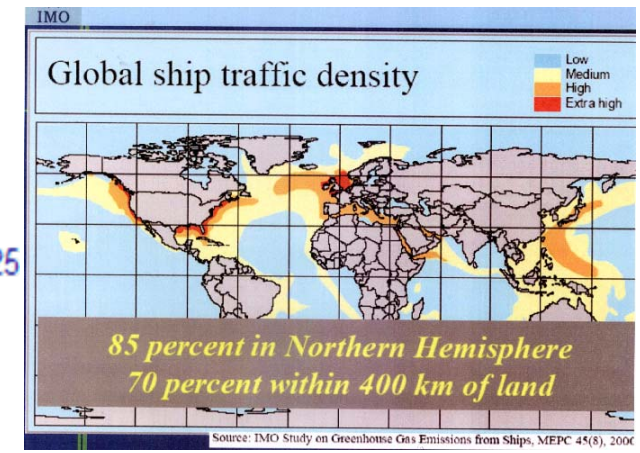
From 2016:

An ocean going ship must comply with Tier II (outside ECA) and with Tier III inside ECA

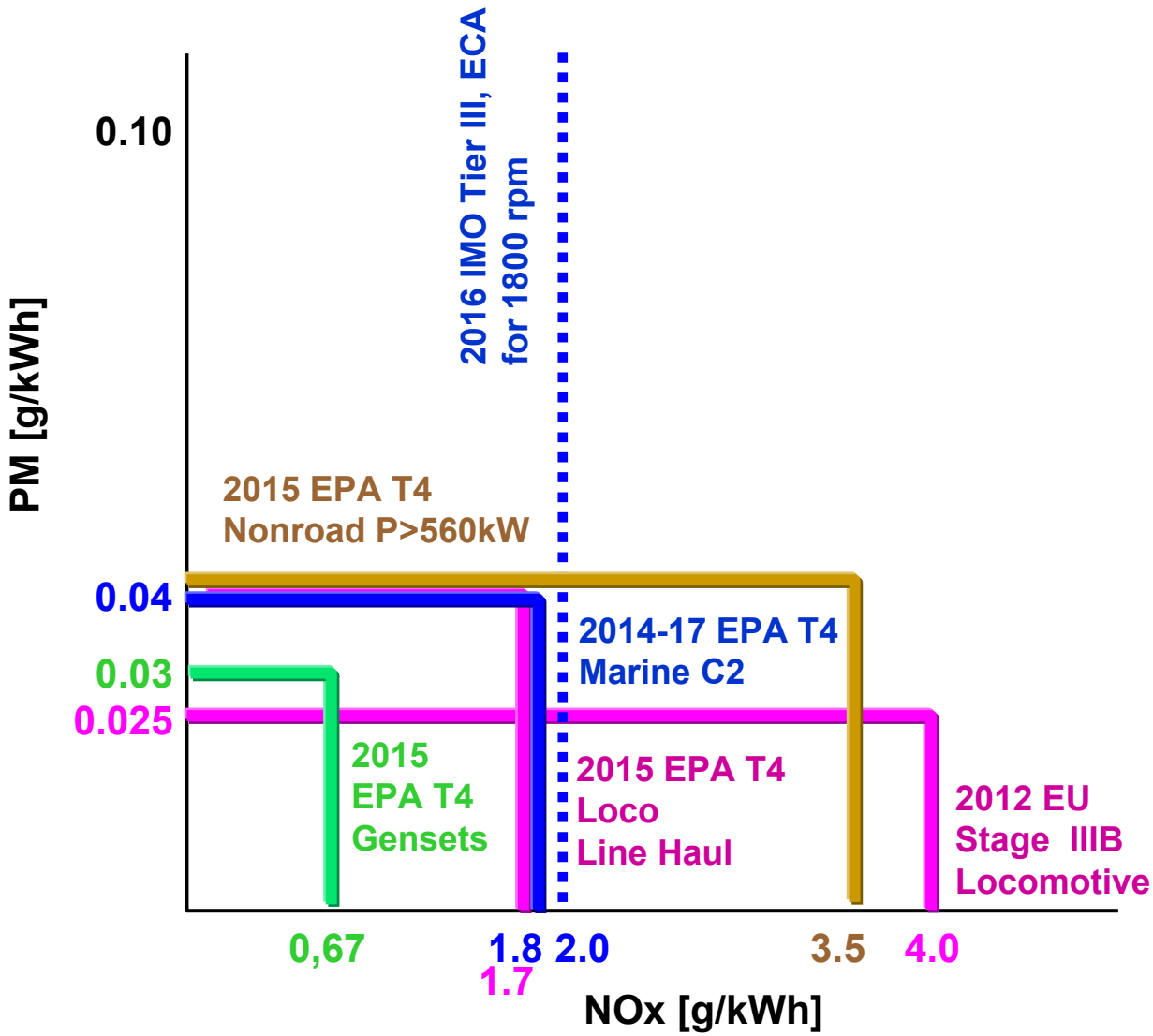
IMO RULING OCTOBER 2008
FUEL SULPHUR CONTENT LIMITS



MDO:
0.1 wt.% S



EMISSION LIMITS, THE END GAME



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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**

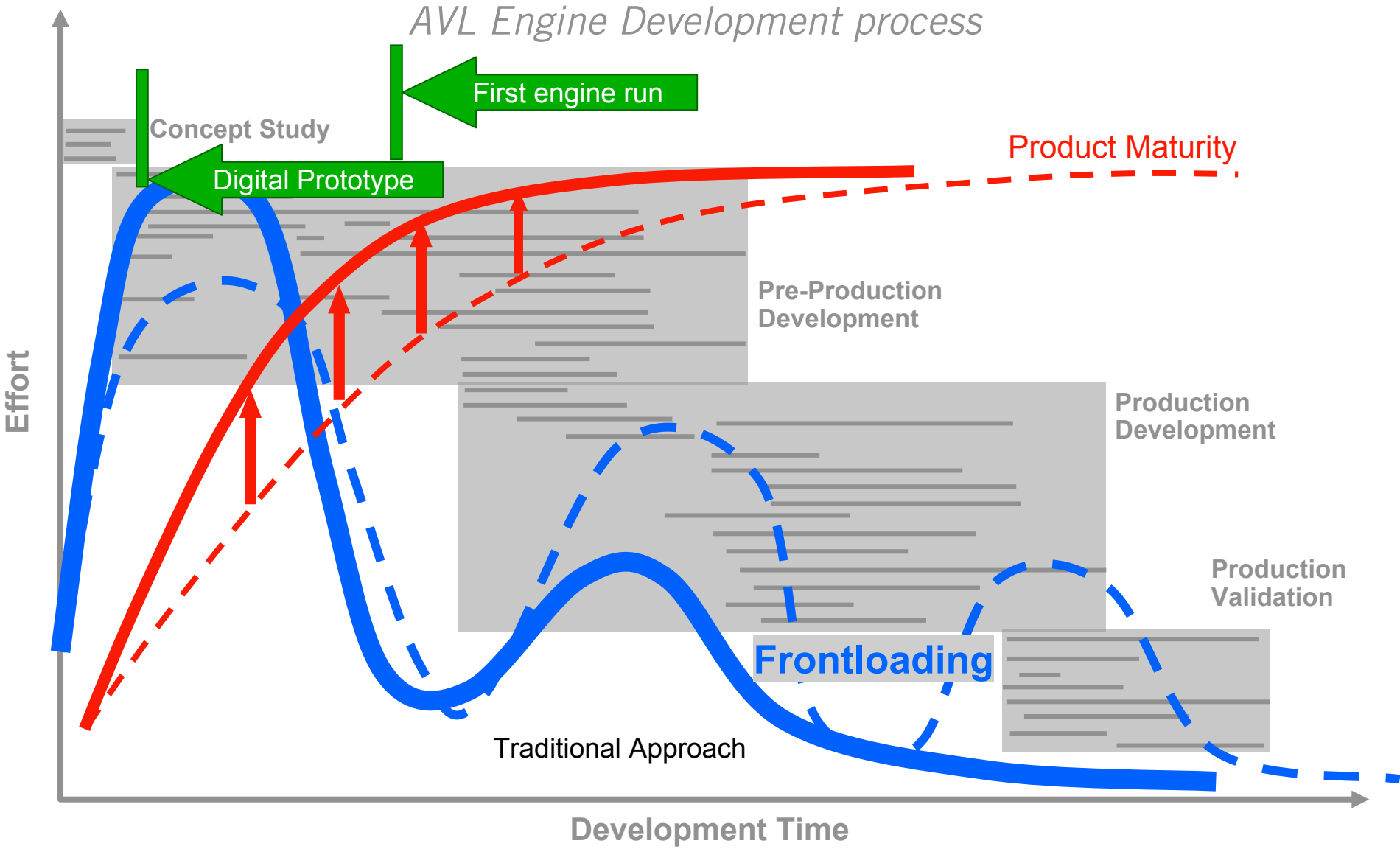
The AVL Approach

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



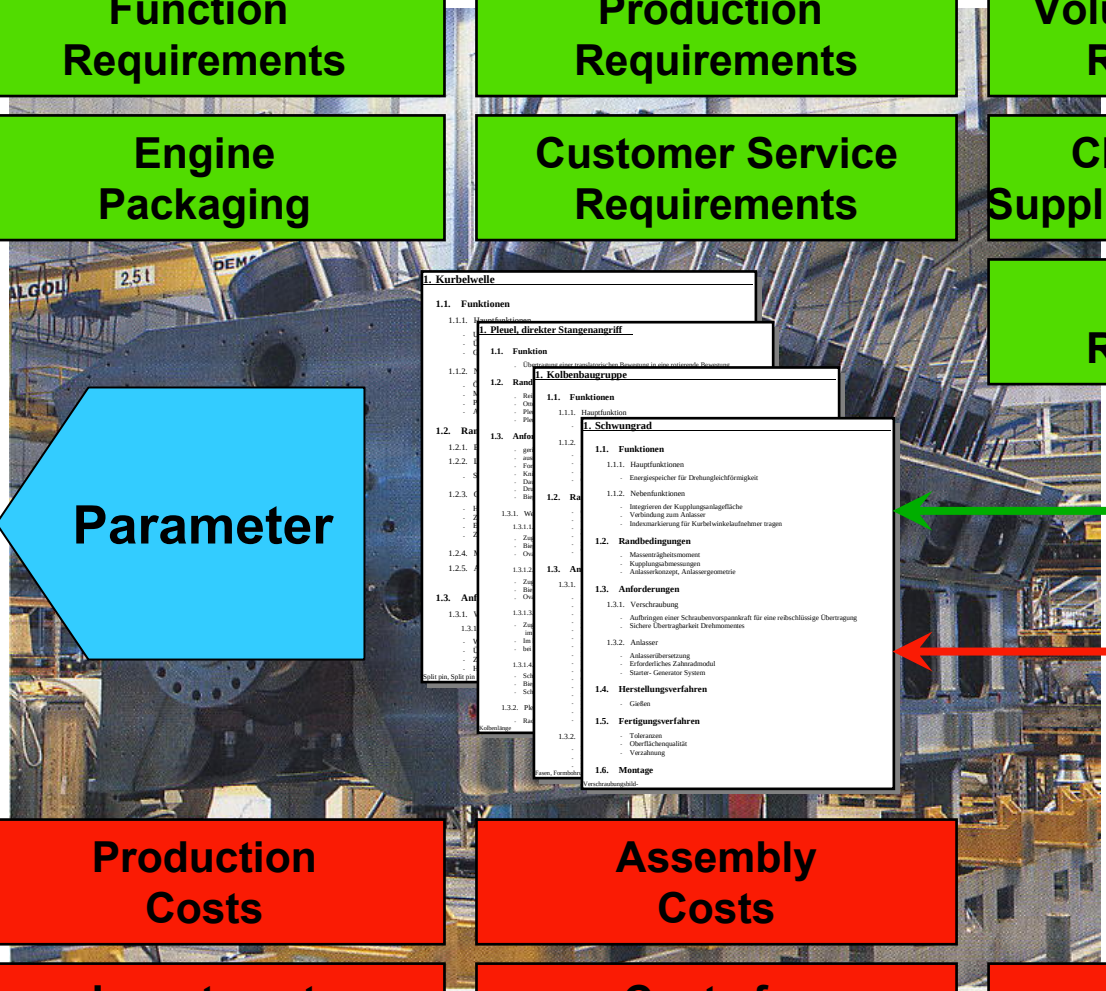
DESIGN METHODOLOGY
IMPORTANCE OF TECHNICAL SPECIFICATION MANUALS

Requirements

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

Design Methodology

Parameter



Costs

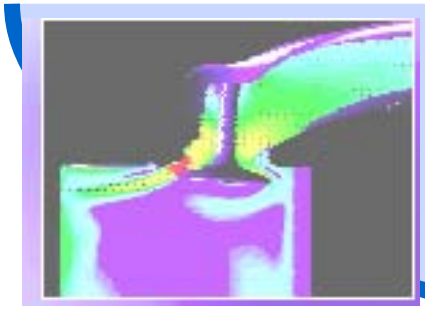
- Production Costs
- Assembly Costs
- Investment Costs
- Costs for Supplied Parts/Systems
- Single Part Costs

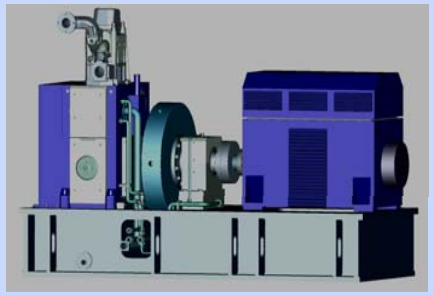
SINGLE CYLINDER ENGINE (SCE) – THE BRIDGE BETWEEN TECHNOLOGY CREATION AND APPLICATION

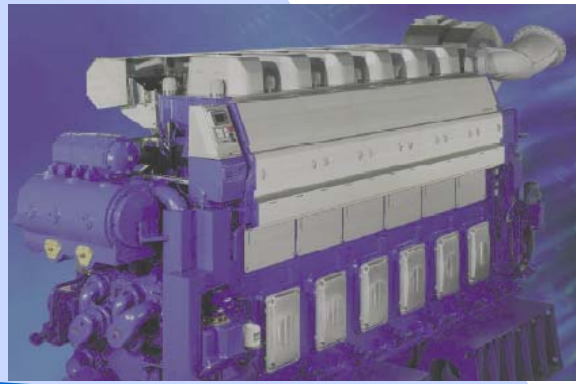
Technology Module Creation

Technology Evaluation and Selection on SCE

Technology Application and Validation on MCE





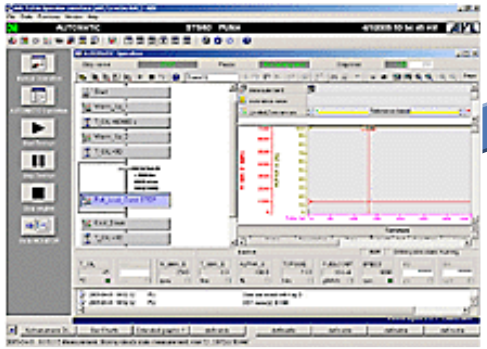


Fundamental Research

Development of Basic Performance & Emissions

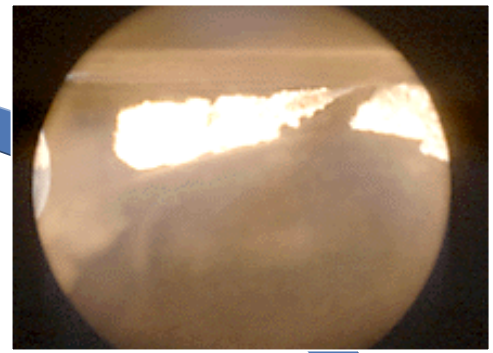
Validate MCE Performance & Emissions & Mechanics

THE AVL SCE TECHNOLOGY EVALUATION & SELECTION SYSTEM



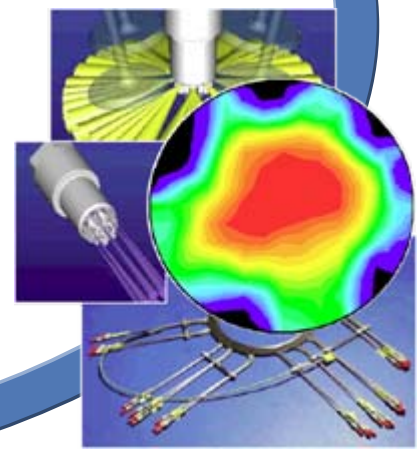
Management
(PUMA Open Test Bed Automation, CAMEO Self Learning Algorithms, …)

AVL Large SCE with Dyno
Highly Flexible Modular Platform



Combustion Development

Simulation
(Air System,SCE Transfer to MCE, …)



Development Tools
(VISIOLUTION, …)

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

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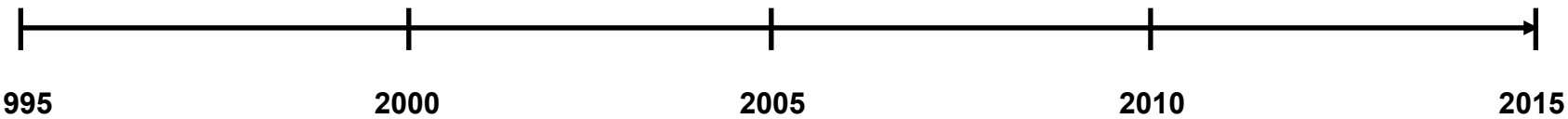
LARGE ENGINES TECHNOLOGY: MODULE 1

- **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

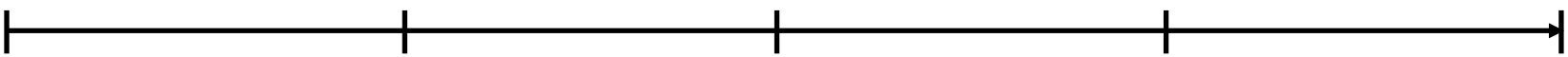


LARGE ENGINES TECHNOLOGY: MODULE 2

- **Fuel Inject Syst.: Common Rail**
- **Advanced Air Systems**
- **Variable Valve Timing**
- **Low NOx and PM Combustion**
- **Combustion of “Clean Fuels“**

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

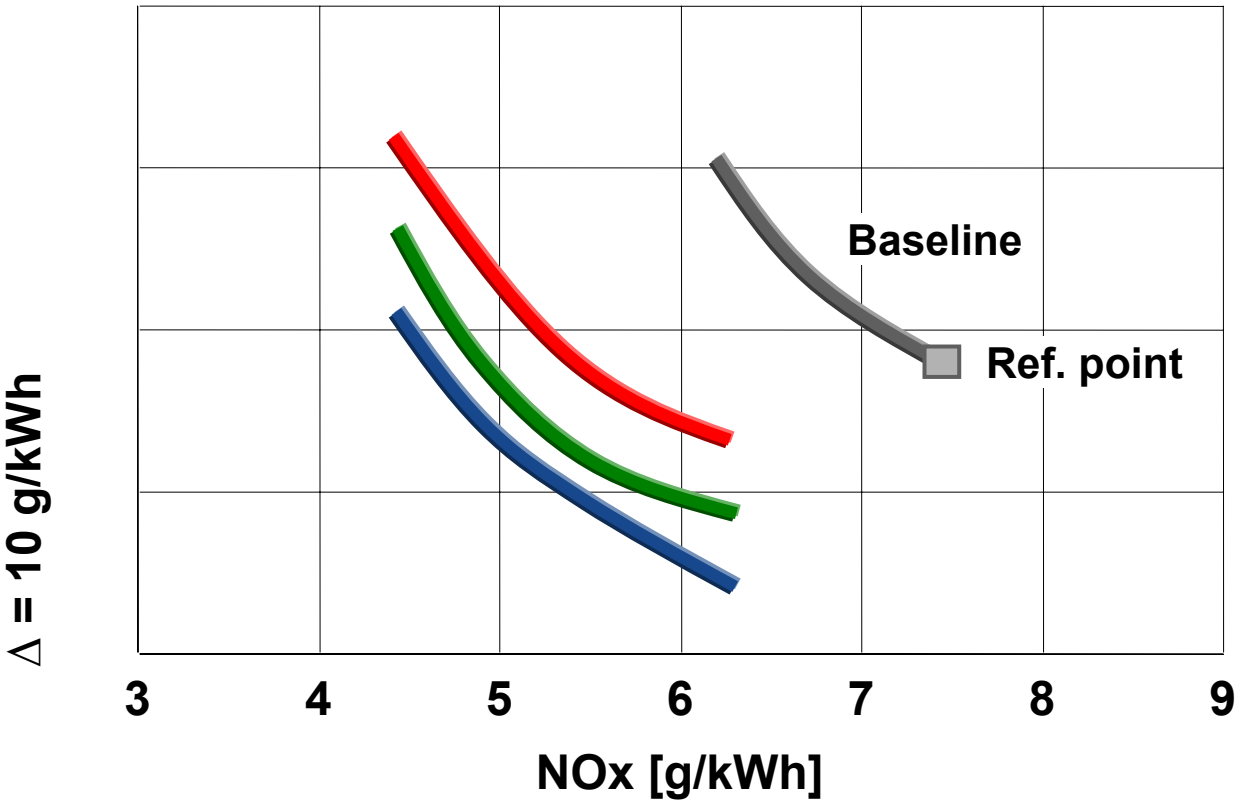
1. Incremental Improvement of Engine Performance: Power Density, Efficiency, Manufacturing Cost, Reliability in HFO, DO, Gas



1995 **2000** **2005** **2010** **2015**

RATED OUTPUT: THE EMISSION CYCLE MAKER FOR LOCOMOTIVE APPLICATIONS

Different Emission Reduction Means – Rated Ouput



Miller Cycle

+

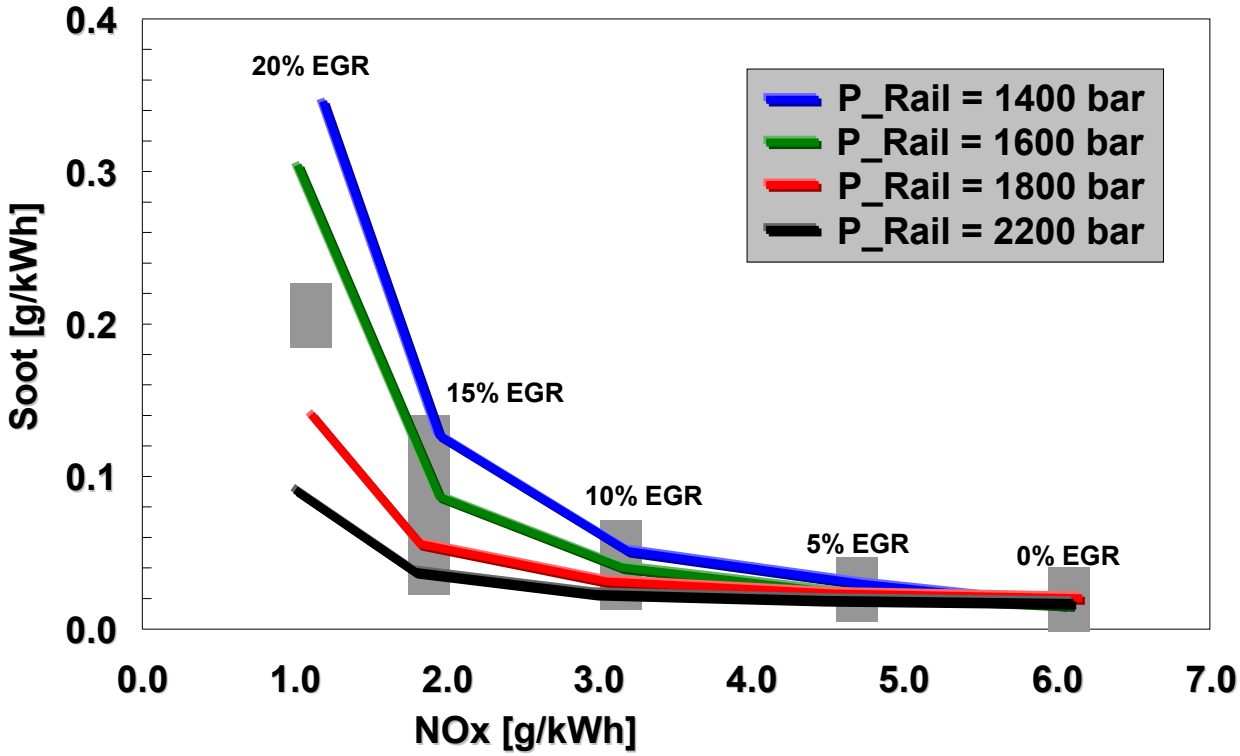
Pilot Injection

+

Increased Compression Ratio

Source:
AVL Research,
SCE Test Results

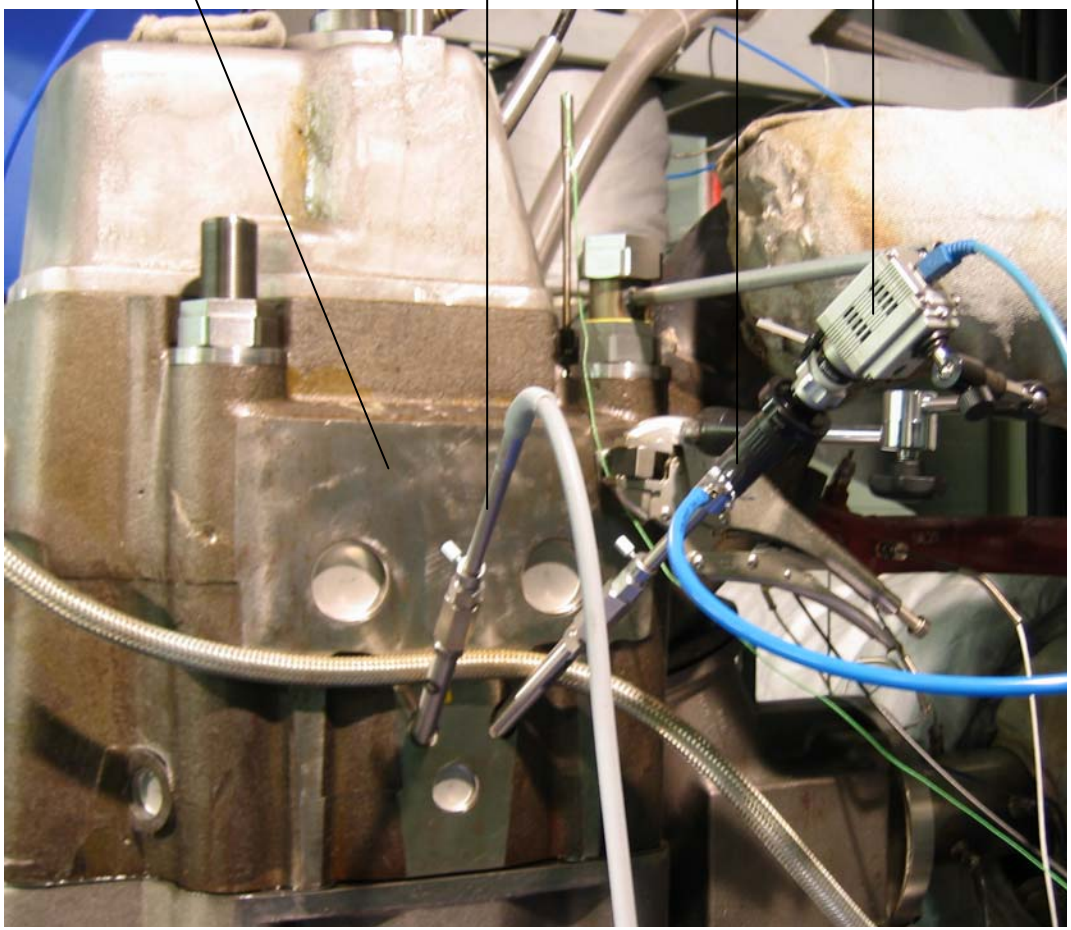
THE RELEVANCE OF VERY HIGH INJECTION PRESSURE

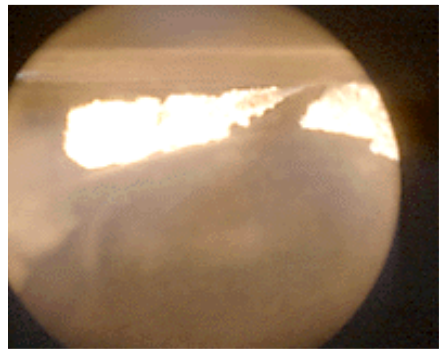


High injection pressure mandatory for low soot

Source:
AVL Research,
SCE Test Results

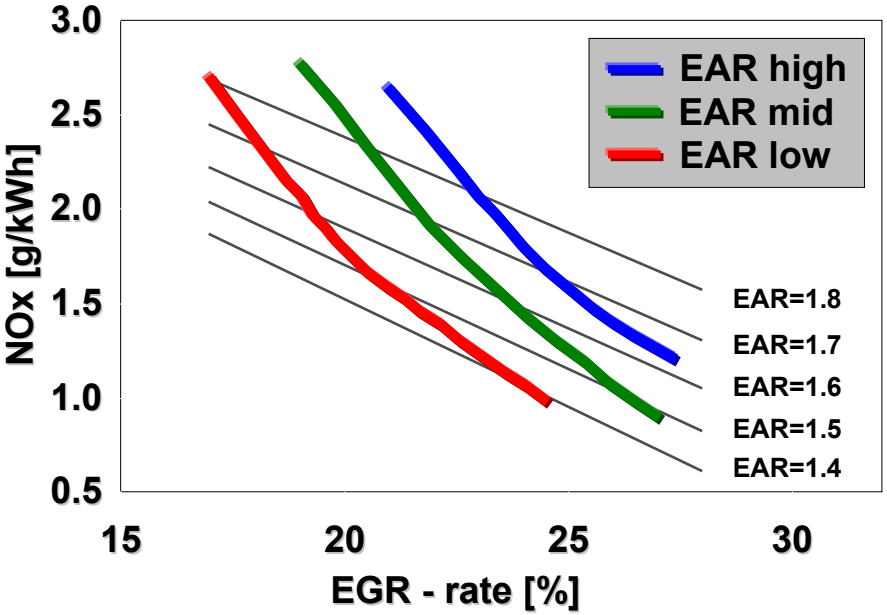
UNDERSTANDING COMBUSTION VISUALISATION

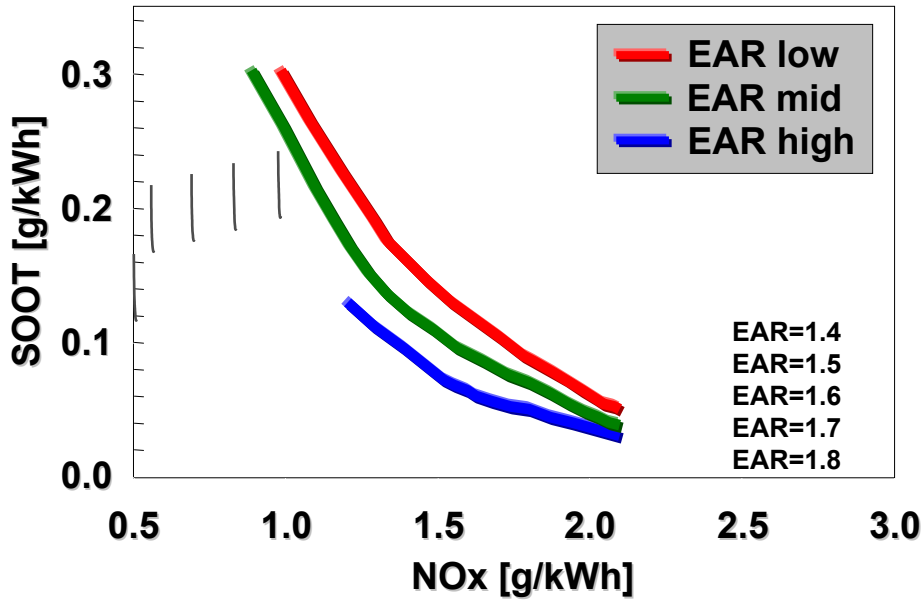




Source:
AVL Research,
SCE Test Results

THE RELEVANCE AND CHALLENGE OF EGR



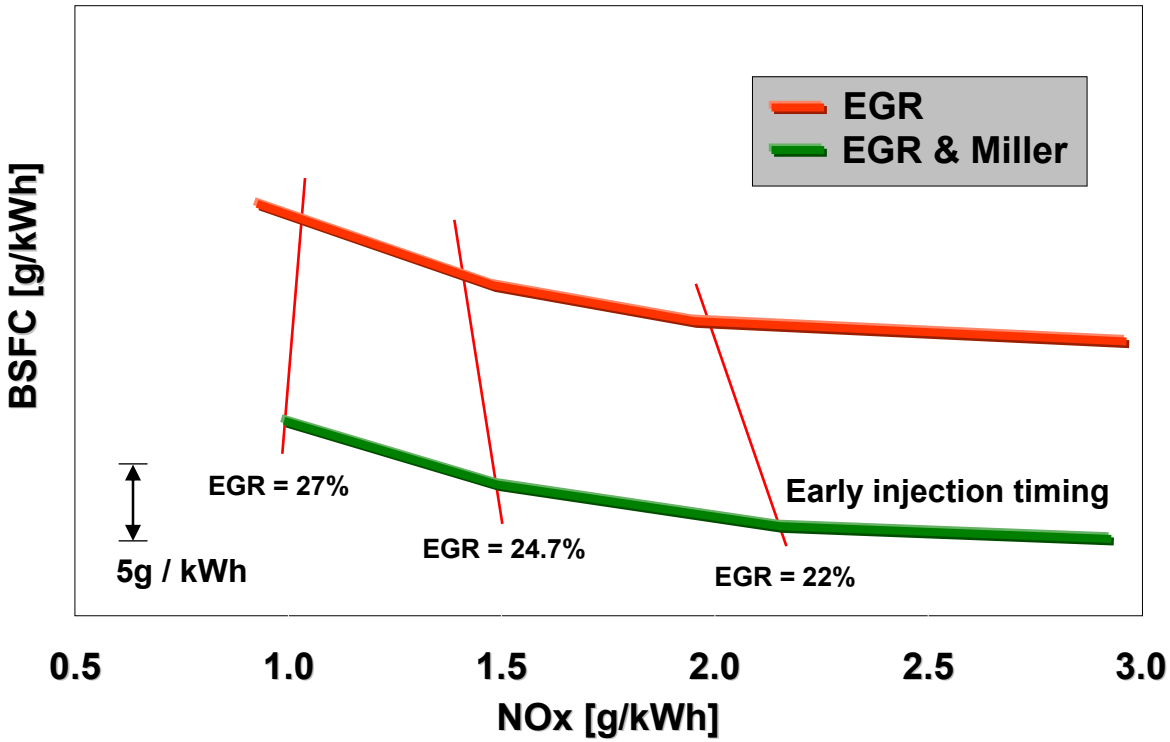


EGR enables NOx limit compliance

Soot challenge with EGR High EAR ratio mandatory

Source:
AVL Research,
SCE Test Results

MILLER CYCLE AND EGR



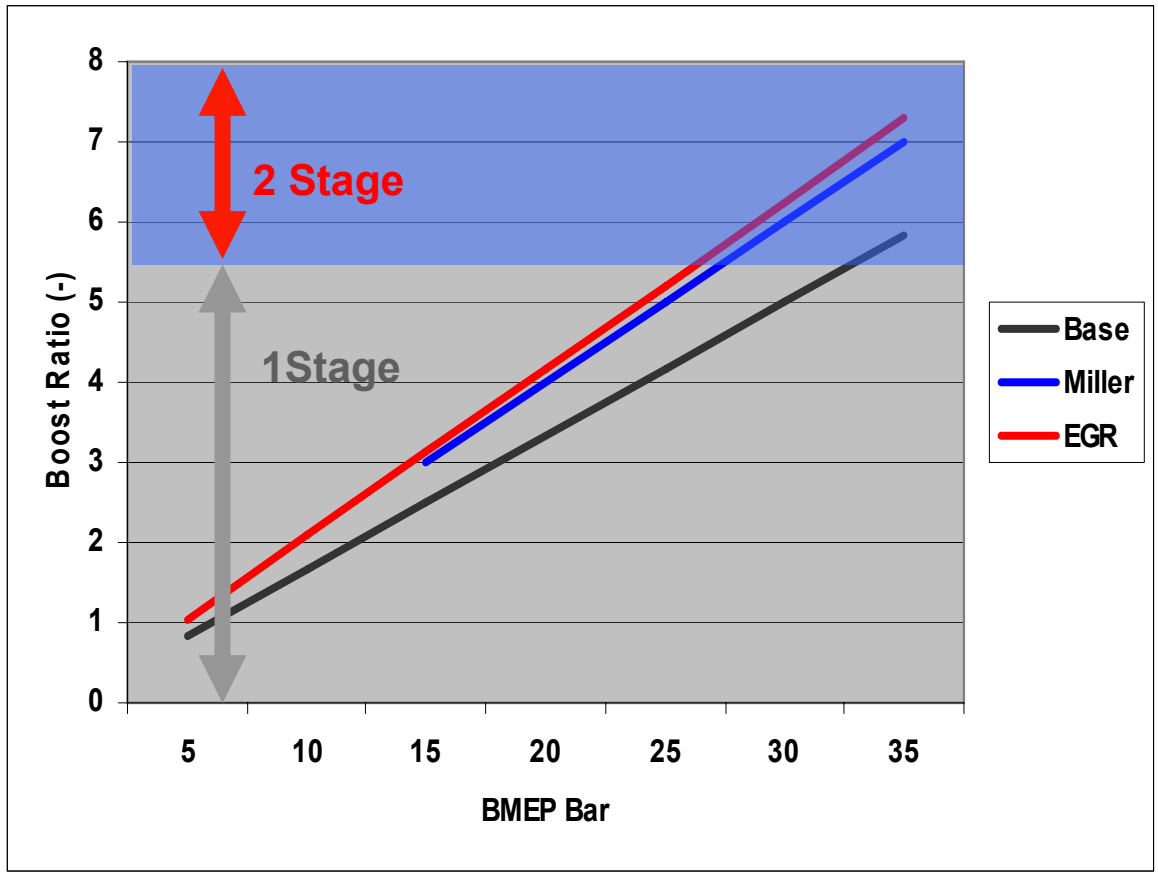
BSFC benefit with Miller Cycle and EGR

Miller Cycle and EGR require high TC compressor pressure ratio

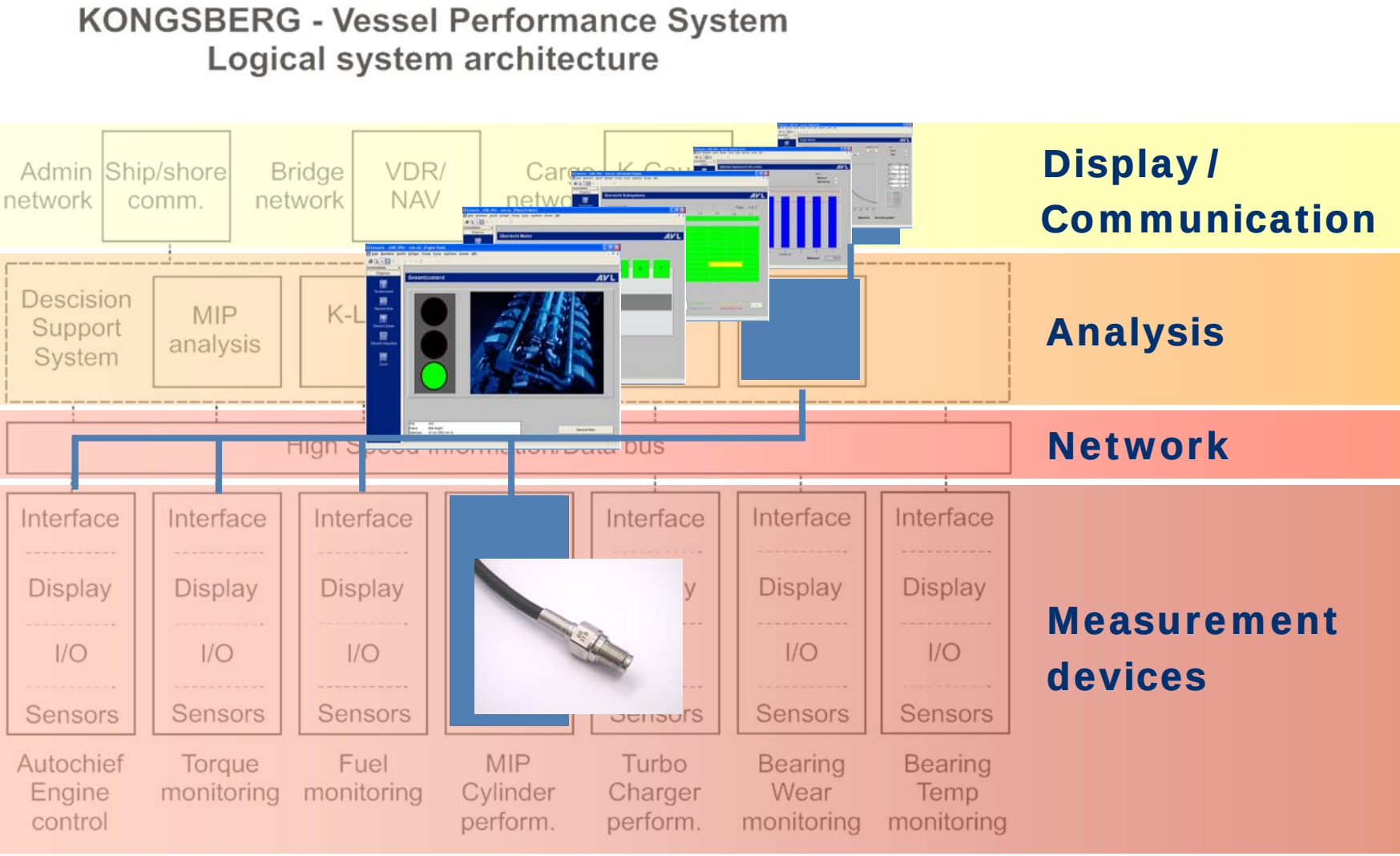
Source:
AVL Research,
SCE Test Results

AIR SYSTEMS REVOLUTION:
2-STAGE TC, VVT, MILLER VALVE TIMING, CONTROLS

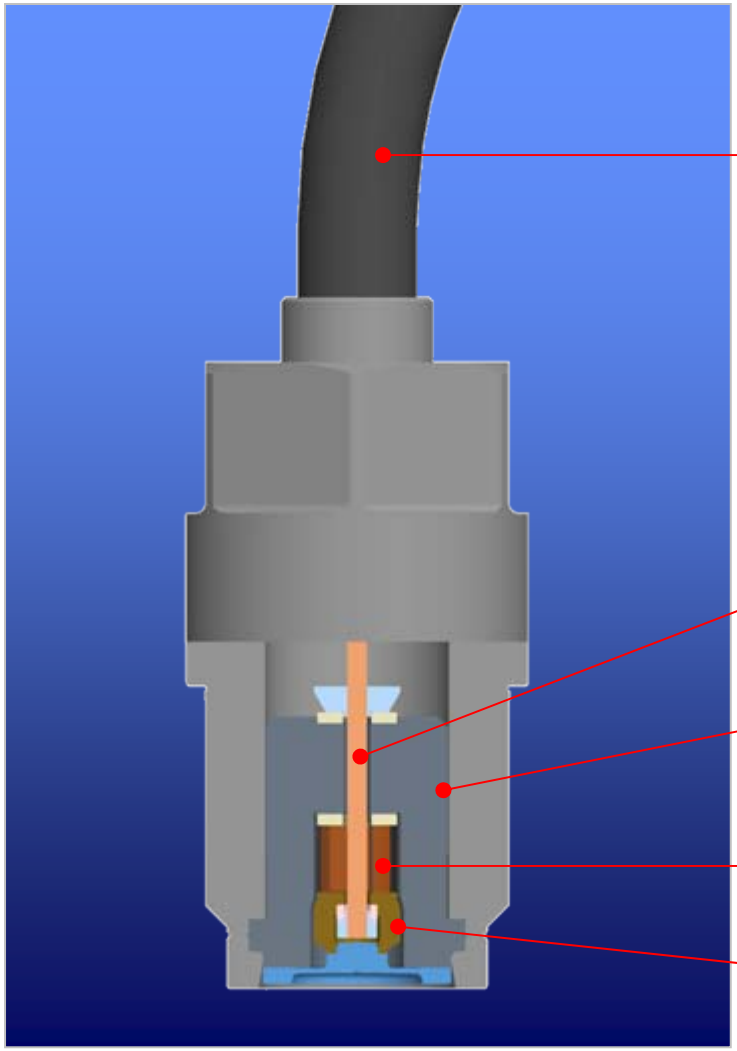
- **Miller Timing, EGR and Power Density need increased Boost Pressures:**
  - **Single Stage π = 5.5**
  - **Two Stage π > 5.5**
- **VVT for aggressive Miller process**
- **Wide Torque and BMEP Range**
  - **Variable Turbocharger Geometry**
  - **Sequential Turbocharging**
- **BSFC and Waste Heat Recovery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



INTELLIGENT ENGINE CONDITION MONITORING INTEGRATED IN A VESSEL PERFORMANCE SYSTEM



LONG LIFE MONITORING SENSOR



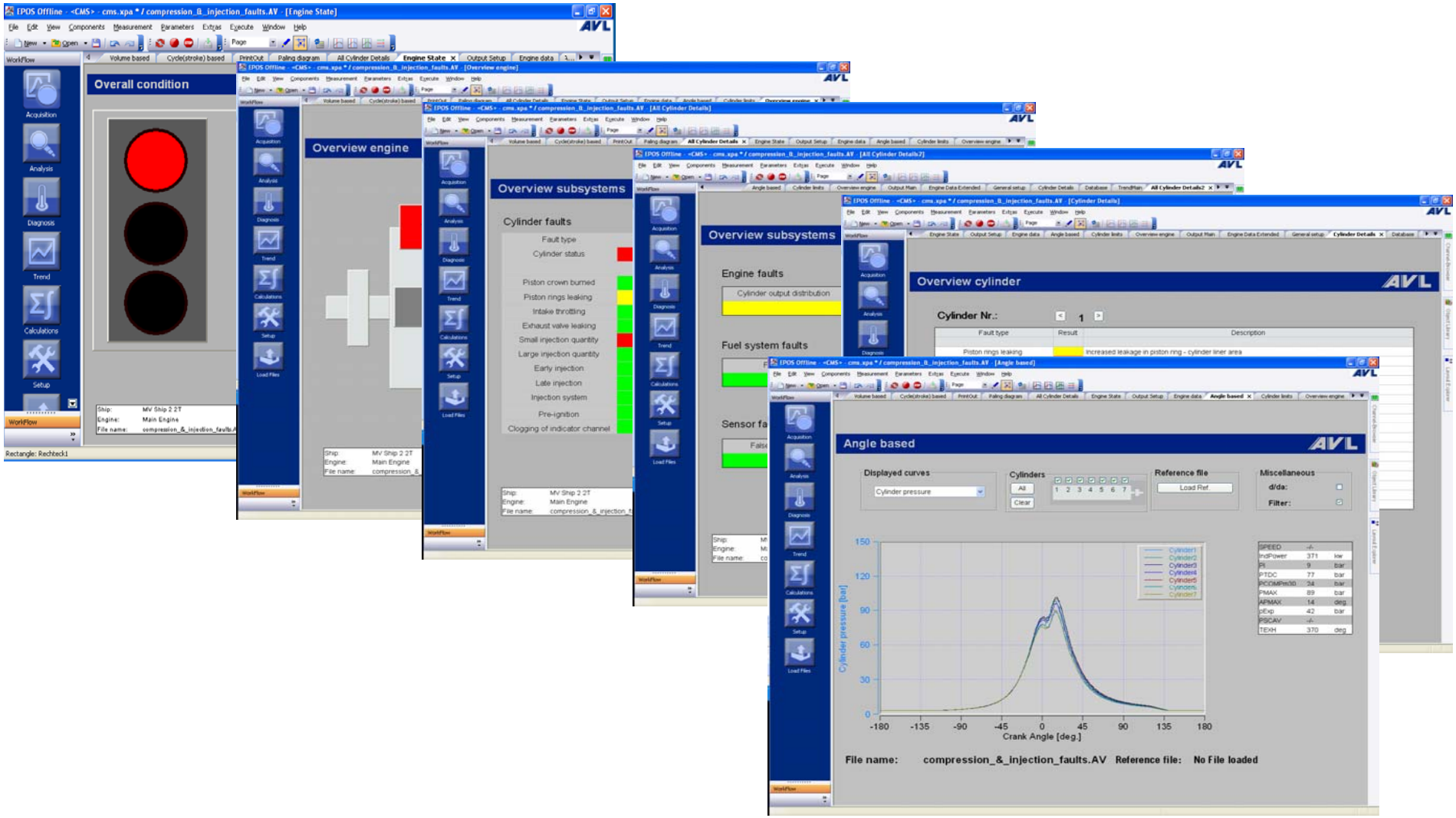
Integrated FPM-cable

$GaPO_4$ piezo-elements

Leak proof concept (verified)

LONG LIFE MONITORING SENSOR

GRAPHICAL USER INTERFACE OF THE AVL EPOS™ - ENGINE MONITORING SYSTEM



LE TECHNOLOGY: KEY AREAS MODULE 3

- **Oxydation Catalysts**
- **DPF**
- **SCR**
- **3-Way Cat/Stoich. W. EGR**
- **NOx Adsorbers**
- **Thermal Management is Key**

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

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

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

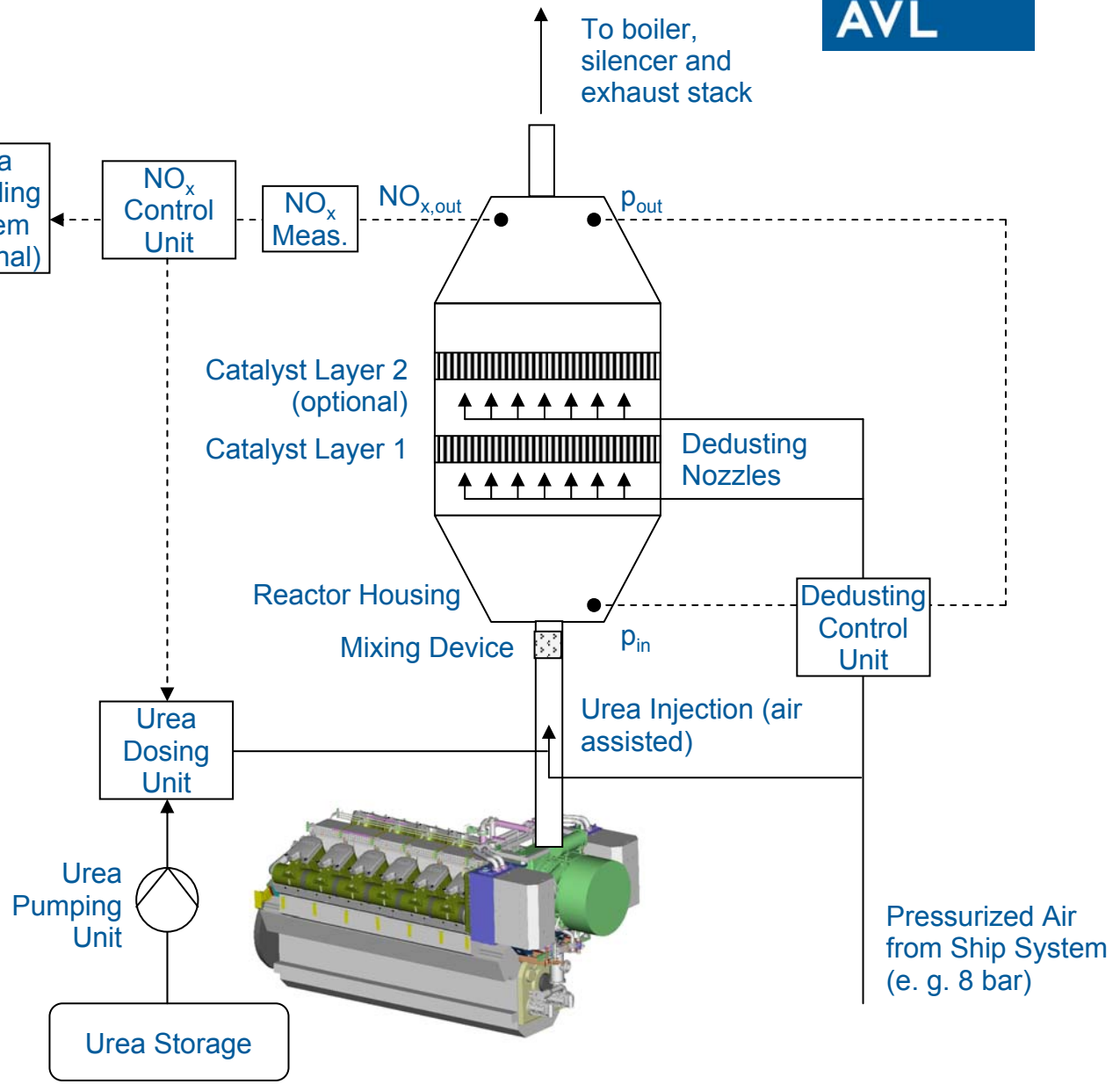
IMO3 DEMONSTRATOR SHIP
SCR APPLICATION FOR SEA-GOING VESSELS

SCR-System Overview

<u>Main Components:</u>

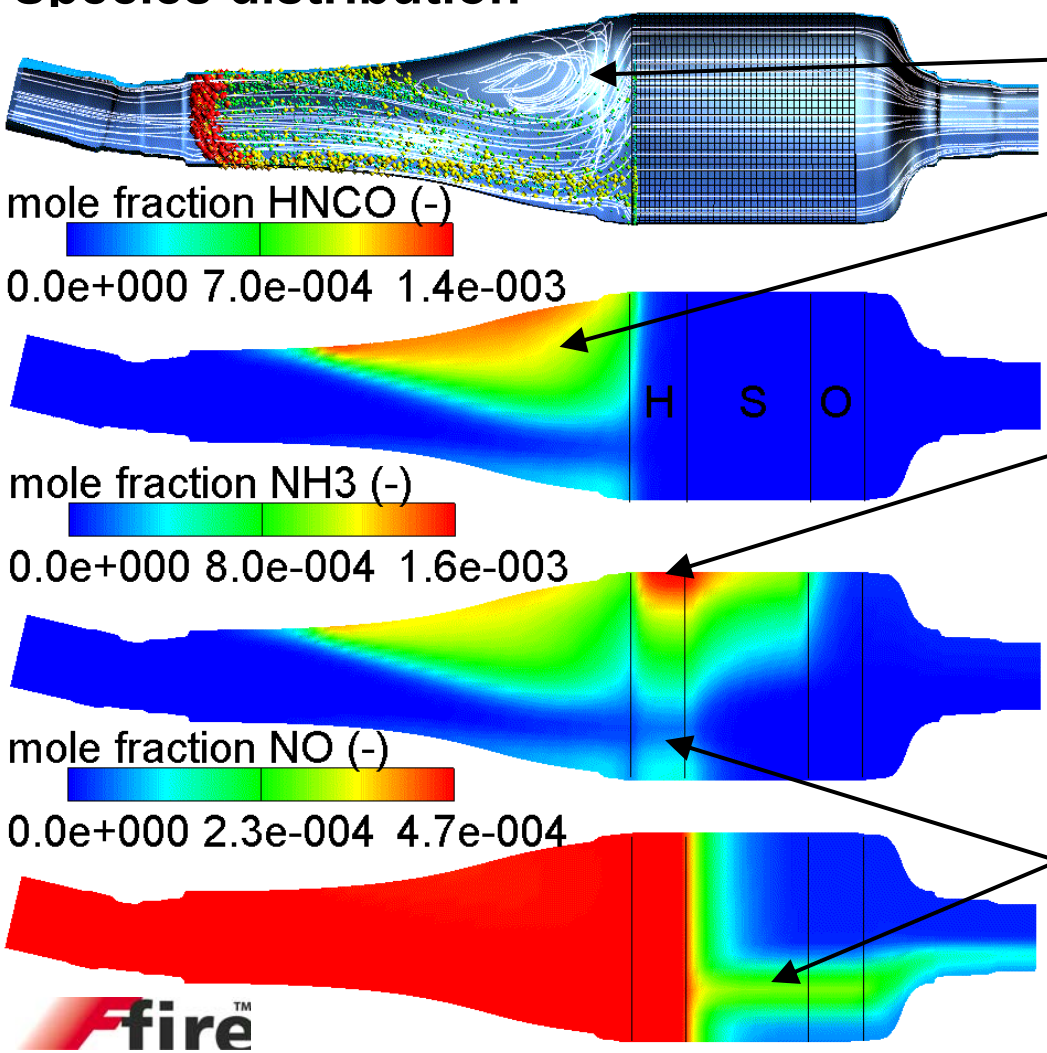
- Catalyst
- Reactor housing
- Dust/soot blowing unit *)
- Urea injection system
- NO_x control unit
- Data sampling system

*) fuel quality dependent



UREA INJECTION AND MIXTURE DISTRIBUTIONS

Species distribution



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

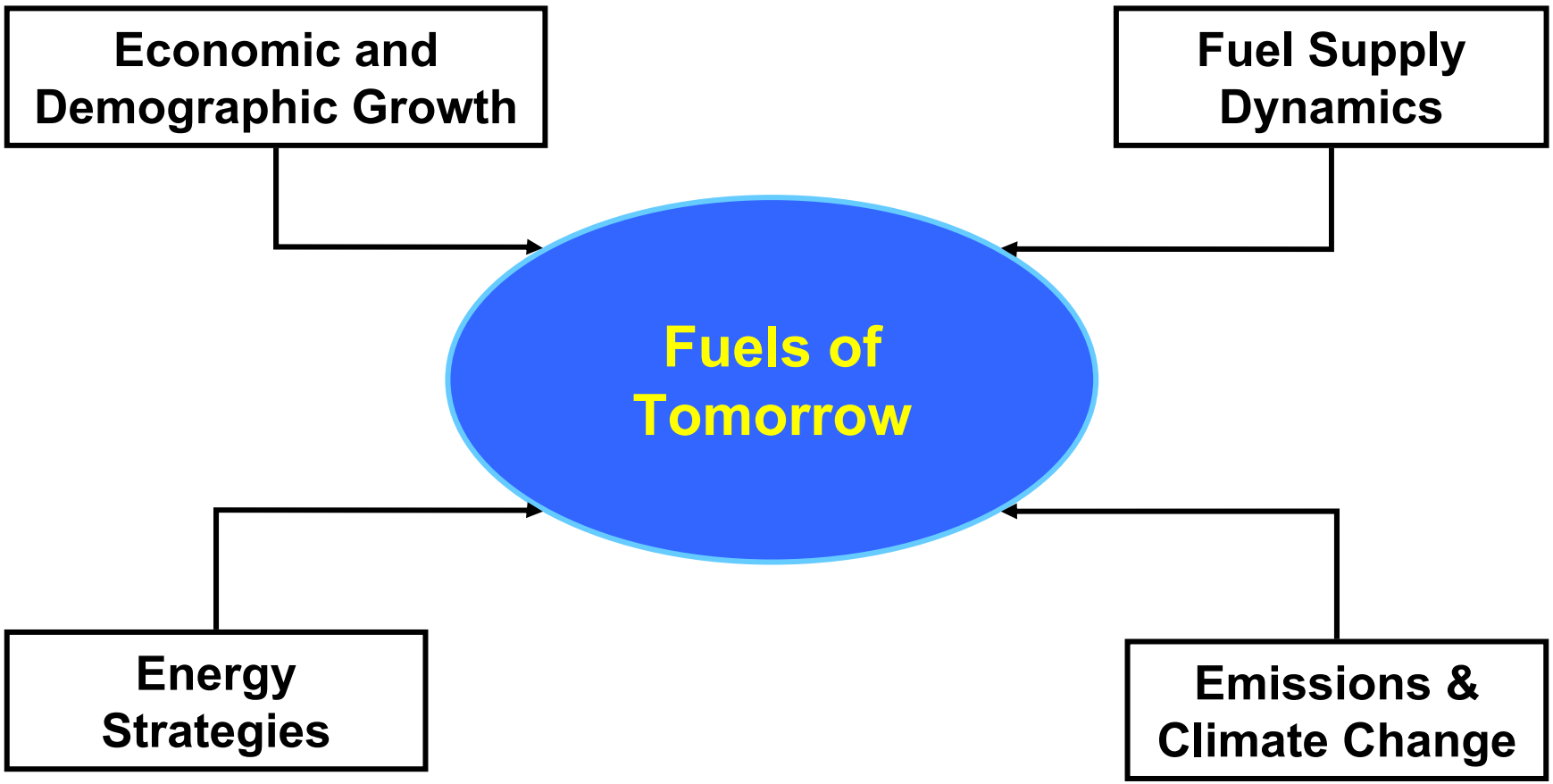
NH3 peak due to hydrolysis of HNCO

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

PRESENTATION ITINERARY

- 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

MAIN DRIVERS OF THE FUEL SELECTION



VARIATY 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*)

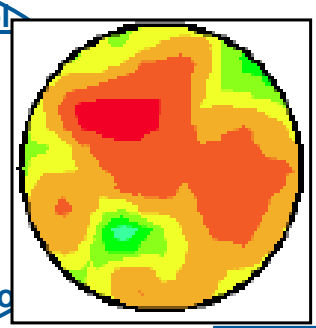
Derivate Fuels

- 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

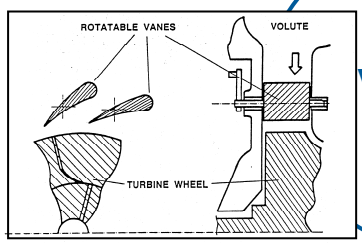
Combustion Control
- •Swirl& Tumble
- • Bowl geometry
- •Open Chamber
- •Pre-Chamber
- •Air/Fuel Ratio
- •Homogeneous Ignitio

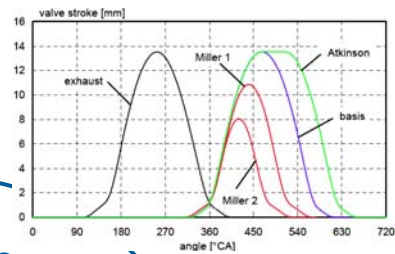


Electronic Controls
- •Cyl. Press. Sensors
- •NOx Sensors
- •A/F Ratio
- •Ignition
- •Cooling

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

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



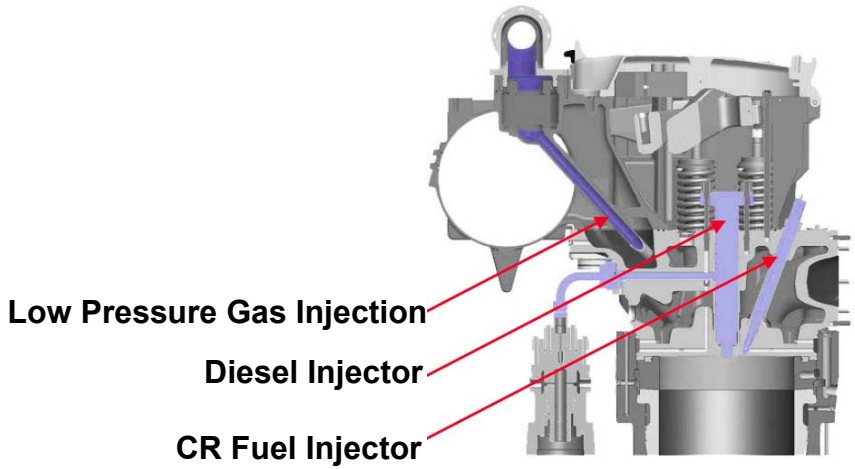


Air Systems
- •Miller/Atkinson
- VTG for A/F Ratio Ctrl.
- •High Boost Ratio
- •Waste Gate/Bypass

WORLD WIDE “GAS ECONOMY” DRIVES GAS ENGINE TECHNOLOGIES

Large Bore Dual Fuel Engines for Gas Tankers

Abbildung 1: Foto ALSTOM Marine LNGC, M32-Projekt (Yves Guillotin)



Source MAN

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

WHAT ABOUT FUTURE FUELS ?

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

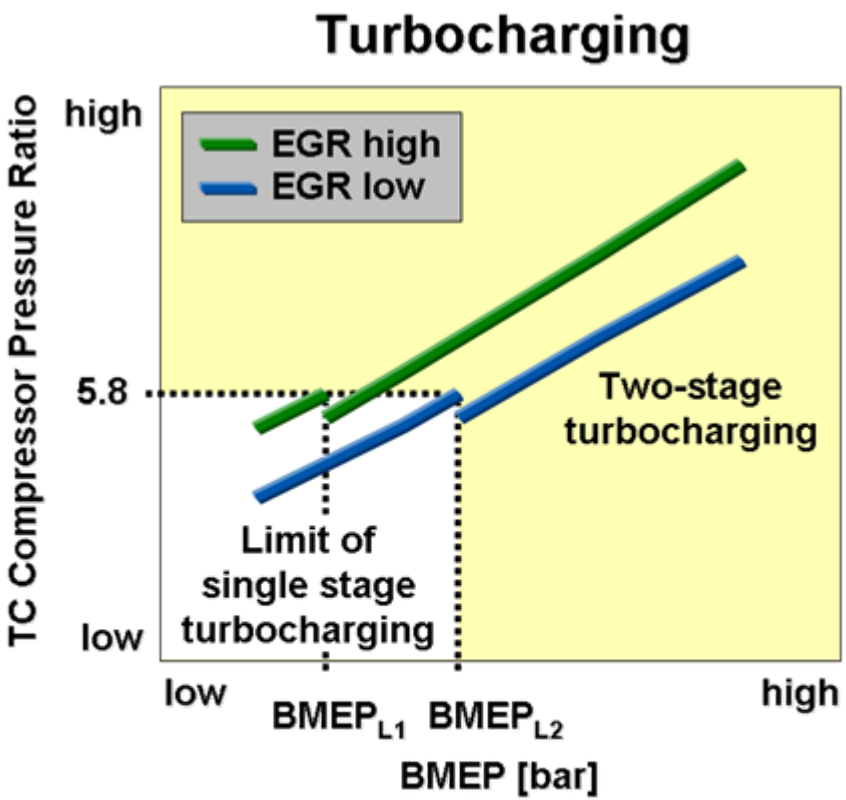
- Biofuels and Derivate Fuels A Complementary Resource to Reduce Supply Vulnerability and Environmental Impact

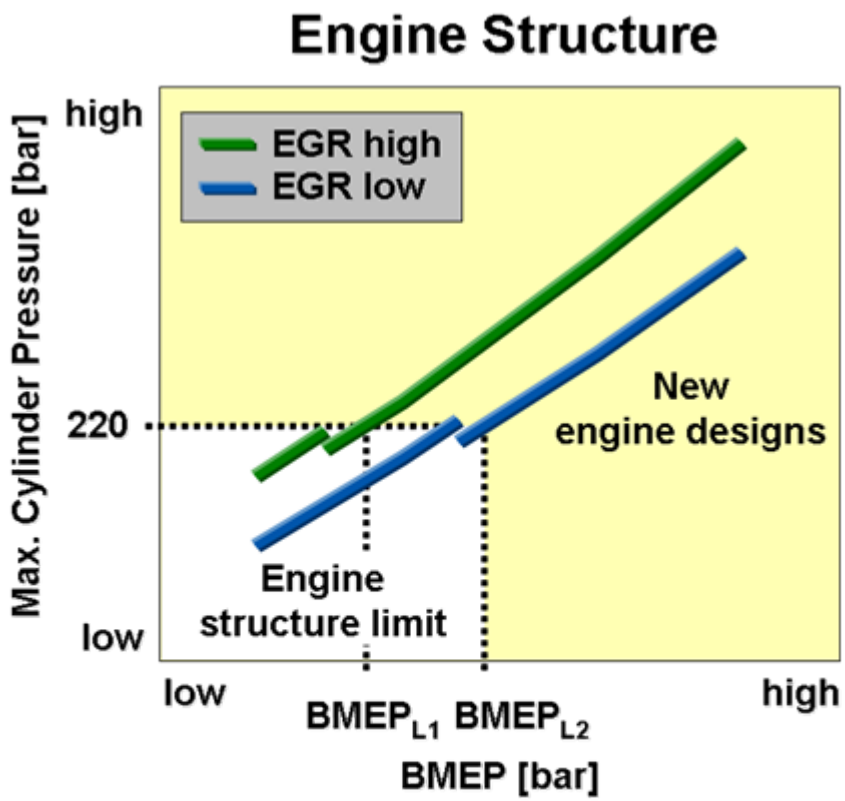
- The Right Investments in Efficiency, New Technologies and New Infrastructures Are Vital

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 / Technologies	IMO 3	US EPA Tier 4	Non-road Tier 4 C&I	Powerg.	EU Stage IIIB	US EPA Tier4
Optimized Combustion System	✓	✓	✓	✓	✓	✓
Miller Cycle & VVT	✓	✓	✓	✓	✓	✓
2-Stage Turbocharging	✓	✓	✓	✓	(✓)	✓
High Cylinder Pressure	✓	✓	✓	(✓)	✓	✓
High Injection Pressure, Common Rail FIE	✓	✓	✓	✓	✓	✓
Cooled HP EGR	✓ or SCR	✓ or SCR	✓	(✓)	✓	✓
Diesel Particulate Filter	(✓)	✓	✓	(✓)	✓	✓
SCR	✓ or EGR	✓ or EGR		✓		(✓)

LARGE ENGINES TECHNOLOGY EVOLUTION SCENARIO

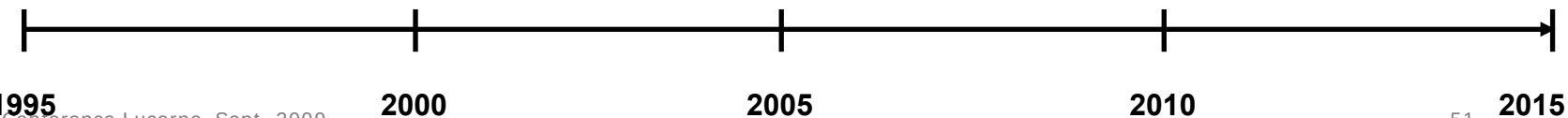
- **Deep Integration of All Engine Related Systems**
- **Cogeneration, Combined Gas & Steam WHR Systems**
- **Energy Storage & Hybrids**

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

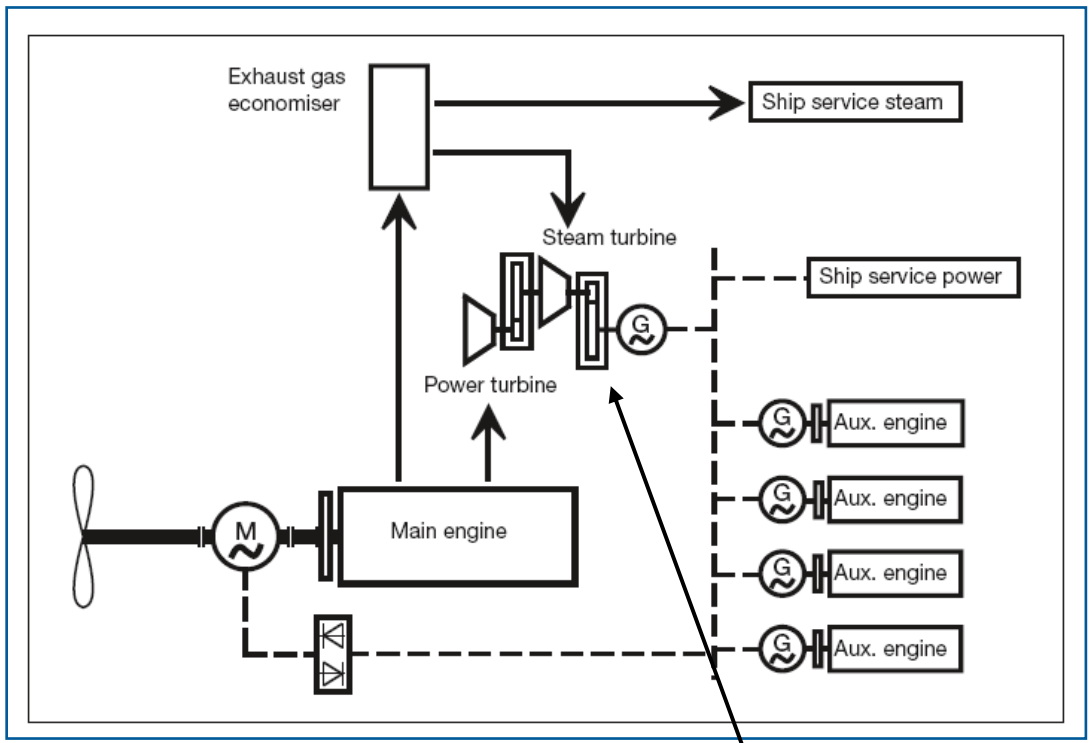
3. Exhaust Gas *Aftertreatment* Becomes Essential for Near Zero NOx & PPM

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

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



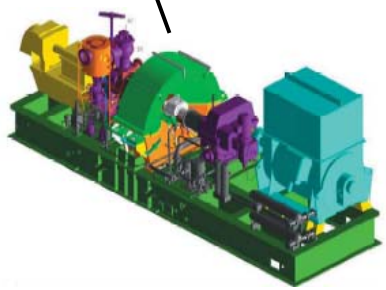
SHIP PROPULSION ENERGY SYSTEM



- 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
- Key Technologies: Fuel Inject. Systems, Air Systems, EGR, Electronics, Aftertreatment
- 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!

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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**

1998 – 2004**: Manager Large Engine Development, AVL List GmbH**

1990 – 1998**: Different Assignments in Project Management, Thermodynamics, Combustion and Fuel Systems**

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