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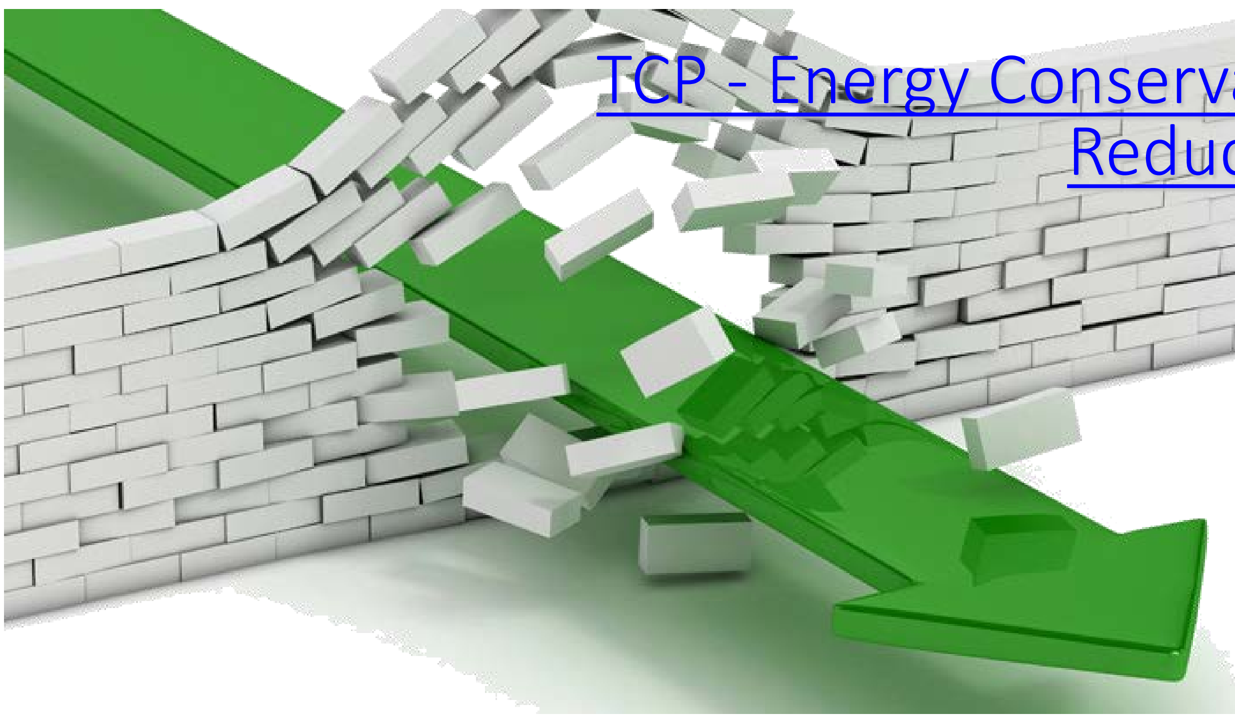
Workshop: Gaps and Barriers for Energy Technology Development and Deployment – a view from the TCPs



TCP - Energy Conservation and Emissions Reduction in Combustion

Dr. Jacobo Porteiro

Chair of the Executive Committee

Energy Technology Network

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Disclaimer

The opinions expressed in this presentation are the author's own and do not necessarily reflect the view of the countries and delegates that belong to the Combustion TCP

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Outline

- Introduction
- Technical knowledge gaps
- Implementation barriers
- Concluding remarks

Introduction

- General
- The Combustion TCP
- Main activities
- Objectives

Advanced Combustion Engine R&D | Industry

Fundamental Research | Applied Research | Technology Maturation & Deployment

- Combustion poses fascinating **contradictions**.
- It is literally **prehistoric**, yet it remains as **essential** to **modern life** as it was to the earliest humans.
- It is terribly **simple** yet profoundly **complex**.
- Todays **most modern techniques** are required to generate progress

Goal of the Combustion R&D: To develop the knowledge base for advanced combustion strategies and carry research results to products:

- ✓ Science-base for advanced combustion strategies
- ✓ Computational tools for combustion system designs and optimization
- ✓ Identify potential pathways for efficiency improvement and emission compliance

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- This Agreement (now TCP) began in 1977. It has been in continuous operation for 40 years.
- The complexity of combustion systems is increasing due to the need to rapidly adopt to changing fuel types such as biofuels
- The Combustion TCP generates knowledge that is immediately useful and applicable to current technologies, as well as provides a solid foundation upon which innovative, revolutionary, or advanced concepts can evolve.
- We are focused on the use of basic/applied science to improve the understanding of combustion processes and their use in today's and tomorrow's technologies.

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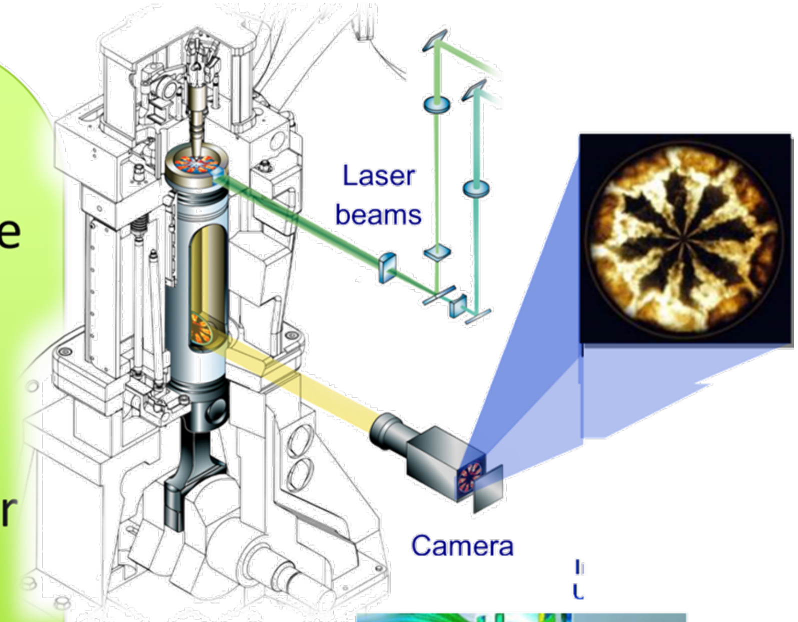
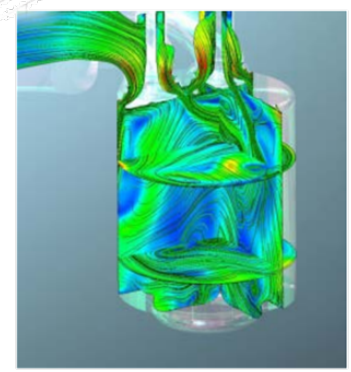
Combustion R&D

Objectives

- Explore advanced combustion strategies to achieve higher engine efficiencies with near-zero emission of NO_x and PM.
- Develop greater understanding of engine combustion and in-cylinder emissions formation processes.
- Develop science-based, truly predictive simulation tools for engine design.

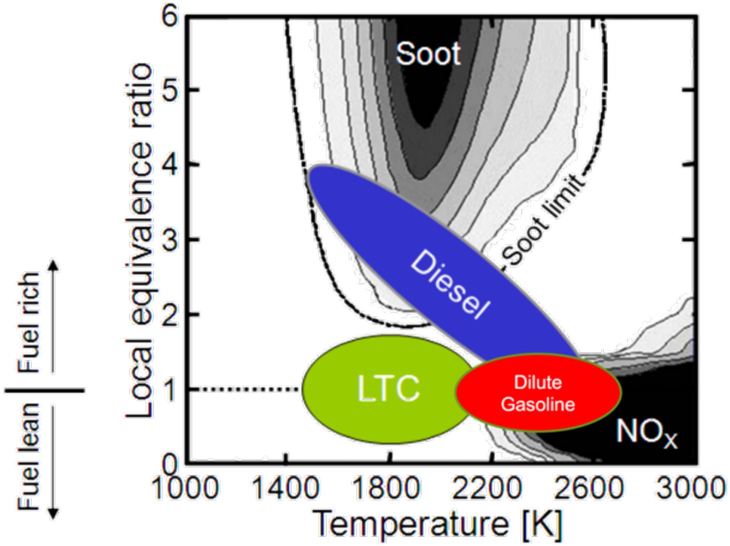




Engine Simulation

Combustion Strategies Enabling Improved Efficiency and Very-Low Emissions

- ❑ Low-Temperature Combustion (LTC):
  - Premixed-Charge Compression-Ignition (PCCI), PPCI, PCI, MK, … – “mixed enough”.
  - Homogeneous-Charge Compression-Ignition (HCCI) – “heterogeneous enough”.
  - Reactivity Controlled Compression Ignition (RCCI) – “dual fuel” combustion.
- ❑ Dilute Gasoline Combustion: Fuel-air mixing, ignition and flame propagation in stratified mixtures, stochastic misfire and knock challenges, fuels, emissions…
- ❑ Clean Diesel Combustion: EGR, high-pressure and multi-pulse injection, lifted-flame combustion, post injections for in-cylinder and aftertreatment emission control….



- ❑ LTC Challenges:
  - Combustion phasing.
  - Load range.
  - Heat release rate.
  - Transient control.
  - HC and CO emissions.
  - Fuel characteristics.

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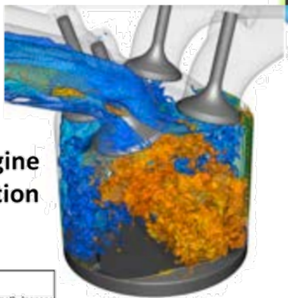
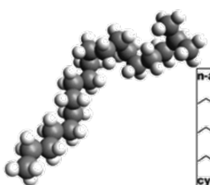
Combustion R&D

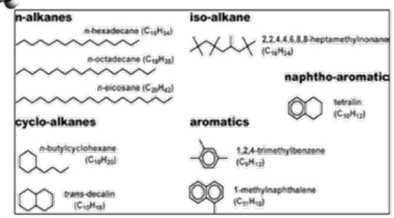
Research tools

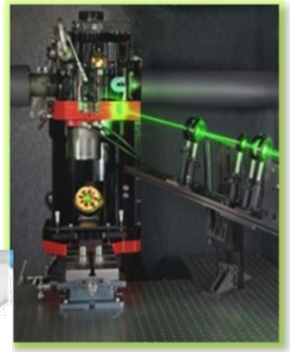
- Close coupled modeling and experiments:
  - Advanced diagnostics including optical, laser, x-ray, and neutron based techniques.
  - Multi-dimensional computational models and combustion simulators.
  - Fuel kinetics.



Engine Simulation

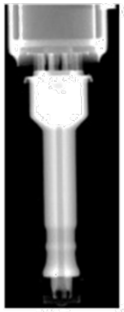




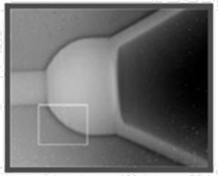


Optical Engine

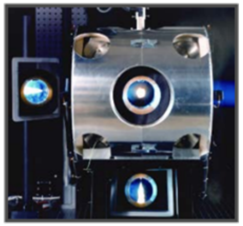
HCCI & Lean-burn Gasoline



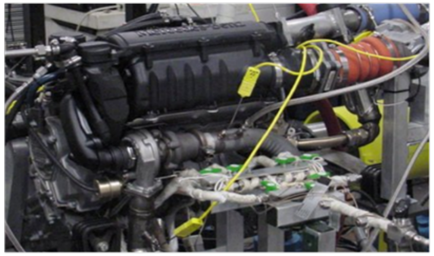
Neutron Imaging-GDI Injector



Nozzle Sac X-Ray Image



LTC Simulator



Multi-cylinder Engine Test Cell

  - Multi- and single-cylinder engines.

- Close collaboration between industry, national labs and universities.
- Cross-cuts light- and heavy-duty engine R&D.

Leading to engine modeling tools widely used in industry

Technical knowledge gaps

- Technical knowledge gaps
- Main challenges

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Technical knowledge gaps

Combustion - ICE

- From the **combustion** point of view
  - ✓ Understanding **knock** in the highly boosted gasoline engine
  - ✓ Defining precise **fuel specifications** for the highly boosted gasoline engine
  - ✓ Understanding and controlling **LTC** mechanisms
  - ✓ Definition of **surrogate fuels**
  - ✓ Understanding **soot formation** and possible ways for its mitigation
  - ✓ Understand/manage **fuel diversity**

- From **ICE** point of view
  - ✓ Implementation of robust **VCR** (Variable Compression Ratio) engines
  - ✓ Enabling **LTC operation** over a wide range of the engine map
  - ✓ Cylinder deactivation for **engine de-throttling**
  - ✓ Mid and strong **downsizing**
  - ✓ Engine **friction reduction**
  - ✓ Understand/manage **fuel diversity**
  - ✓ Model based **engine calibration**

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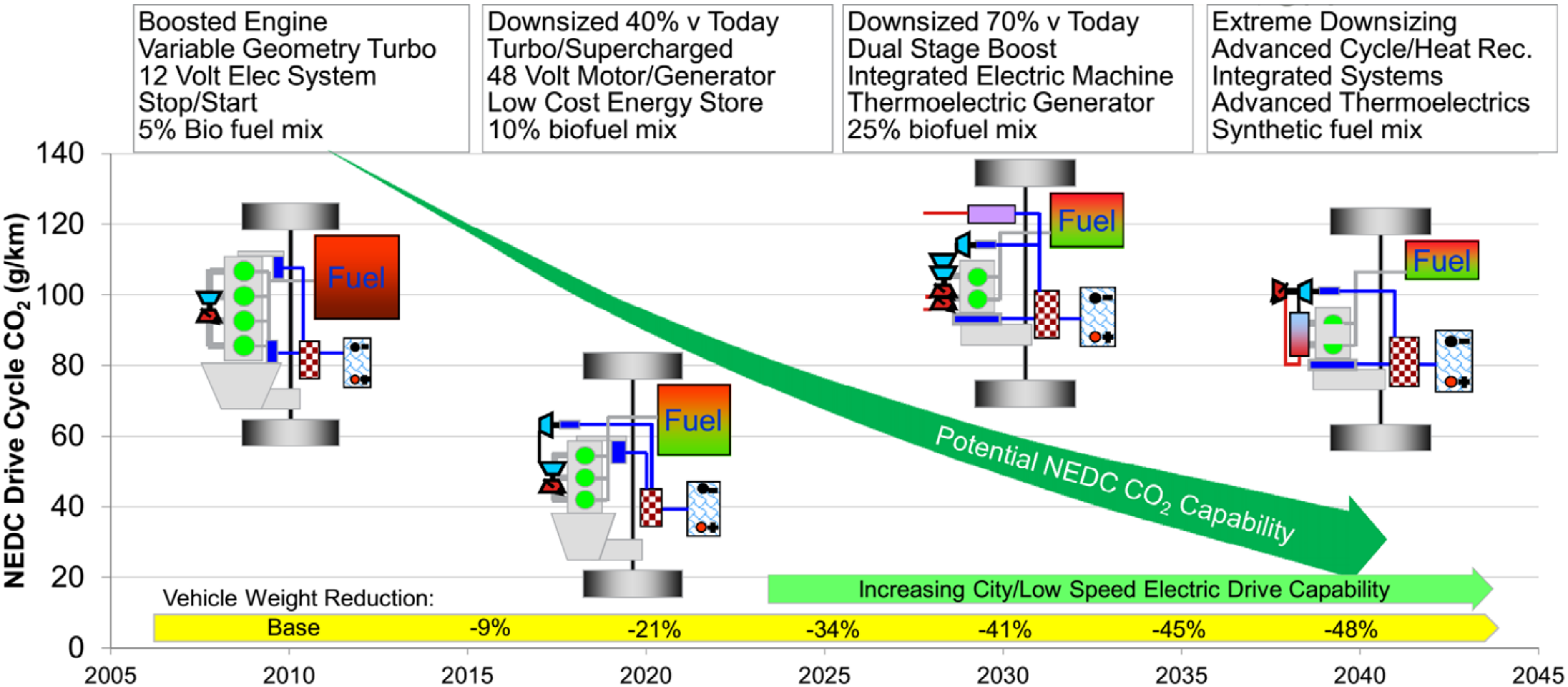
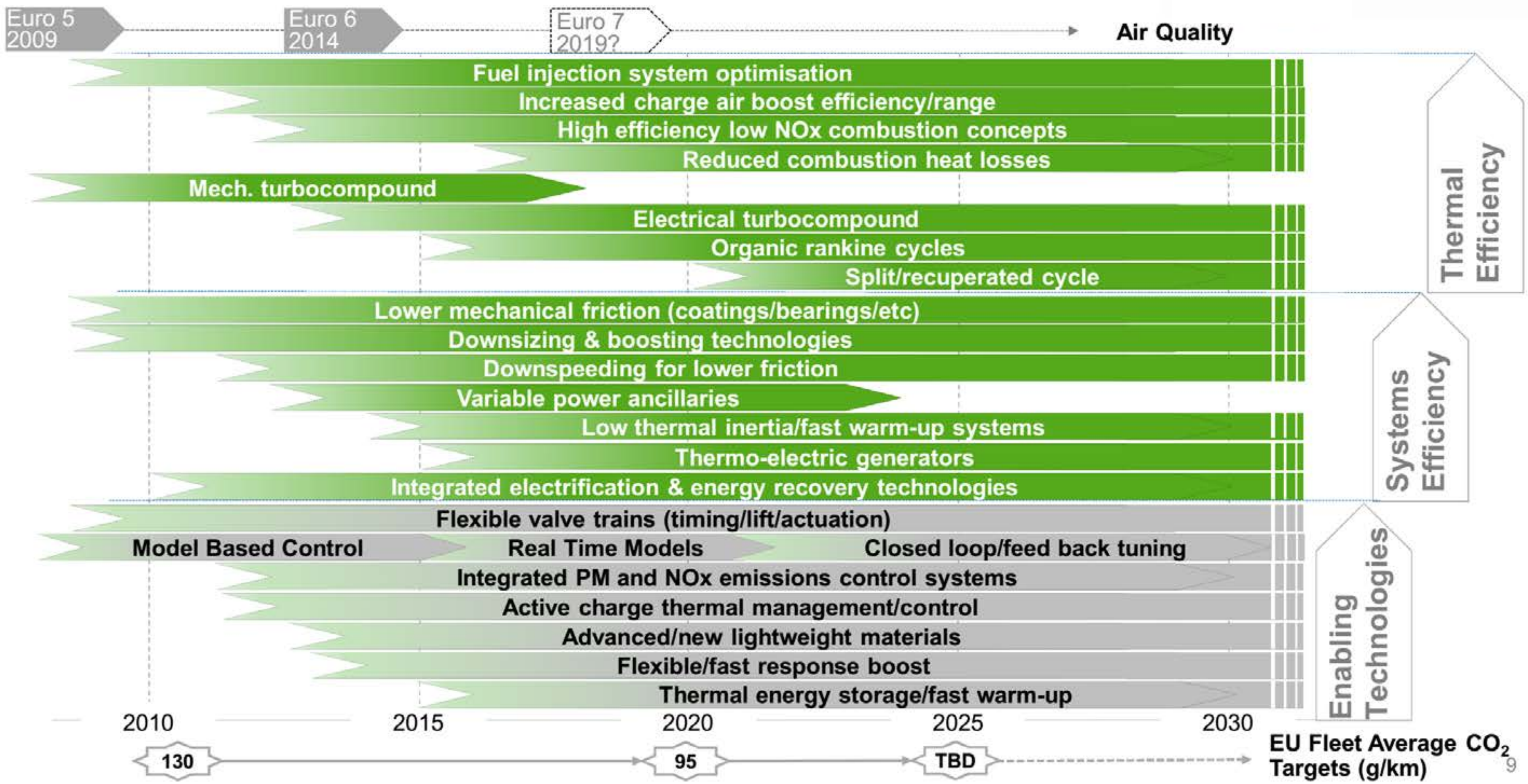
Main challenges

ICE roadmap




Euro 5 2009
Euro 6 2014
Euro 7 2019?
Air Quality
Fuel injection system optimisation
Increased charge air boost efficiency/range
High efficiency low NOx combustion concepts
Reduced combustion heat losses
Mech. turbocompound
Electrical turbocompound
Organic rankine cycles
Split/recuperated cycle
Thermal Efficiency
Lower mechanical friction (coatings/bearings/etc)
Downsizing & boosting technologies
Downspeeding for lower friction
Variable power ancillaries
Low thermal inertia/fast warm-up systems
Thermo-electric generators
Integrated electrification & energy recovery technologies
Systems Efficiency
Flexible valve trains (timing/lift/actuation)
Model Based Control
Real Time Models
Closed loop/feed back tuning
Integrated PM and NOx emissions control systems
Active charge thermal management/control
Advanced/new lightweight materials
Flexible/fast response boost
Thermal energy storage/fast warm-up
Enabling Technologies
2010
2015
2020
2025
2030
130
95
TBD
EU Fleet Average CO2 Targets (g/km)
9

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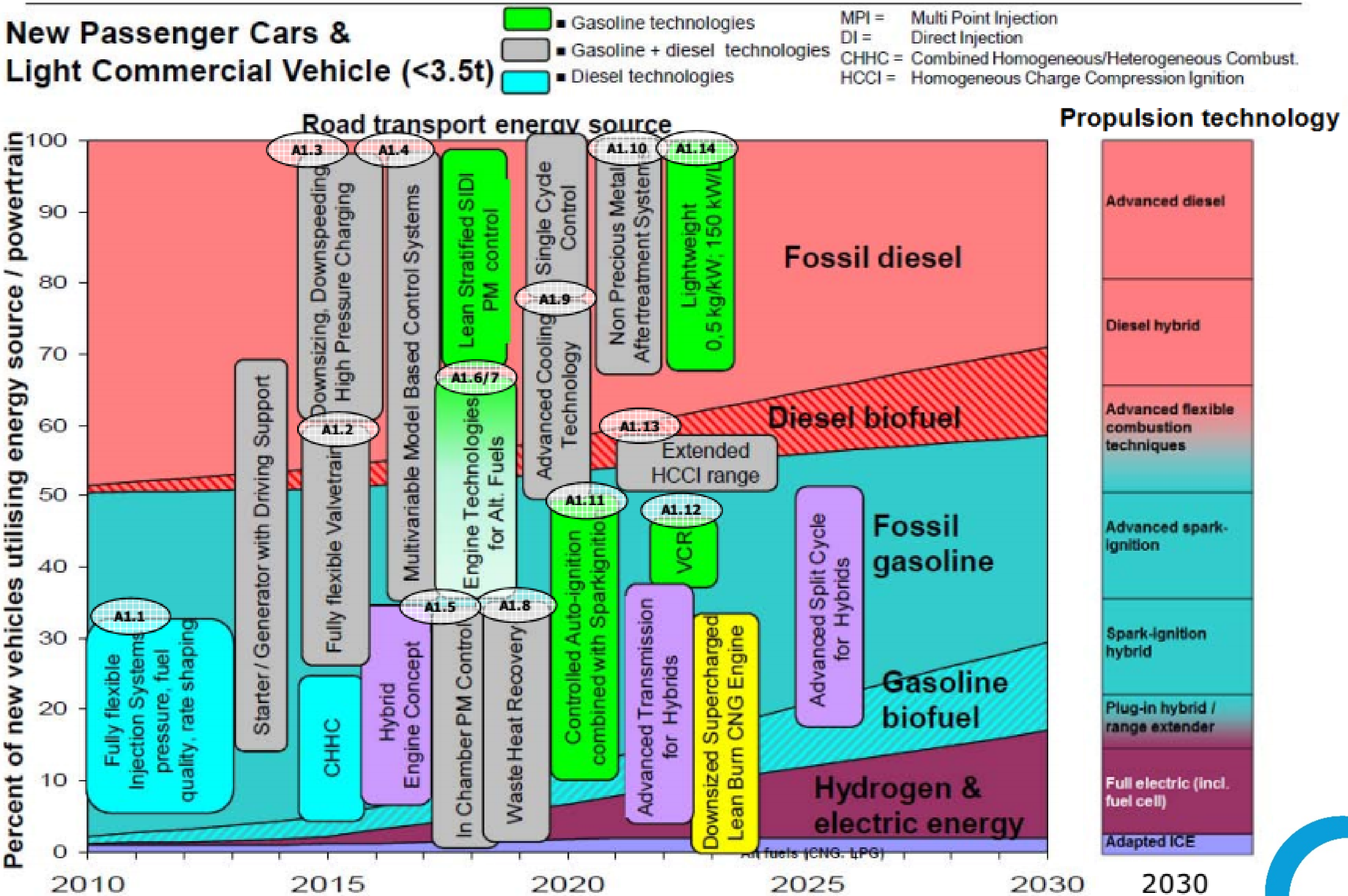
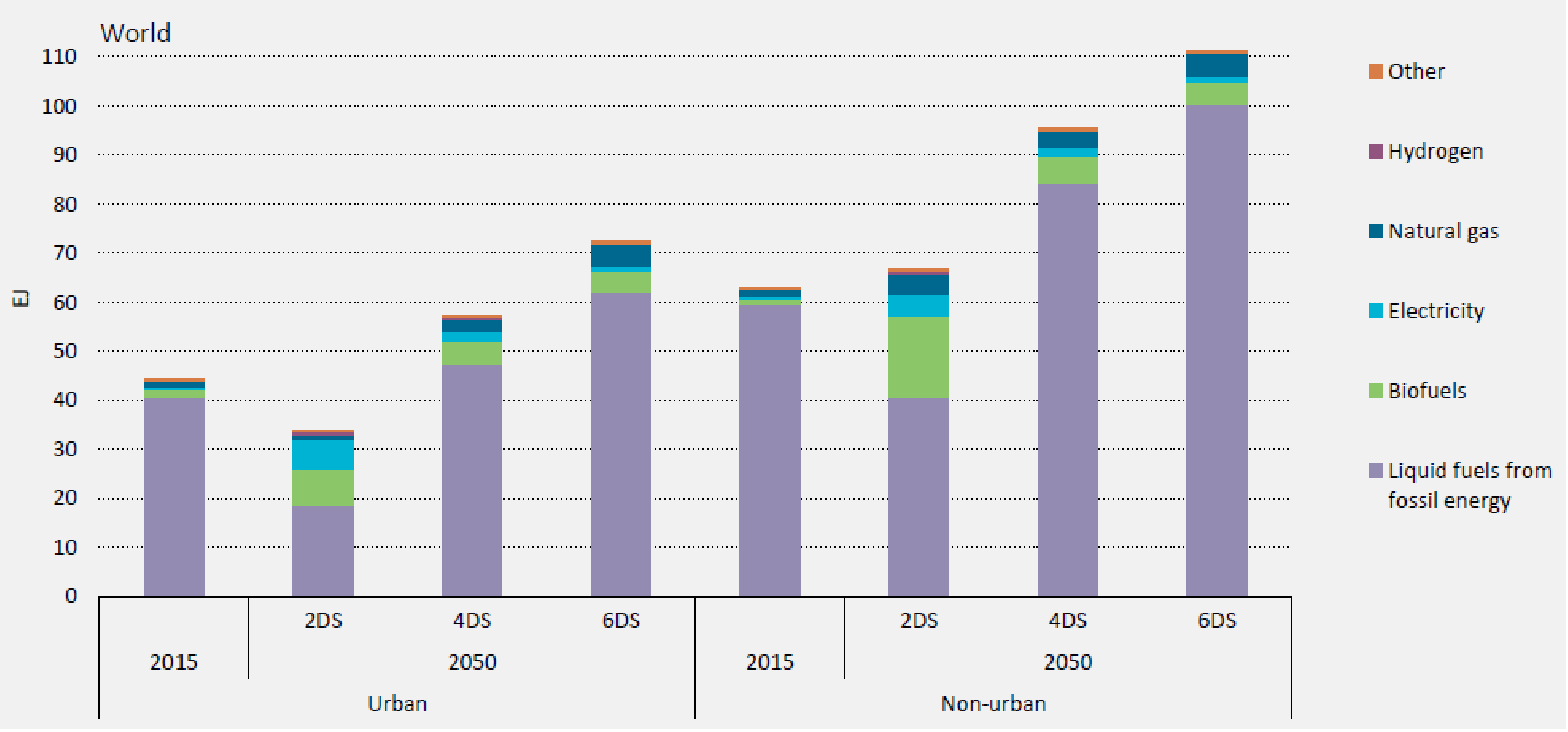
Main challenges
ICE roadmap

Main technology trends and the Vision of share of engines in Europe



World Final Transport Energy Demand by Scenario



Source : ETP 2016, IEA

- Transport sector has the largest share of oil demand for every scenarios
- 2DS requires more usage of electricity (urban) and biofuels (non-urban)

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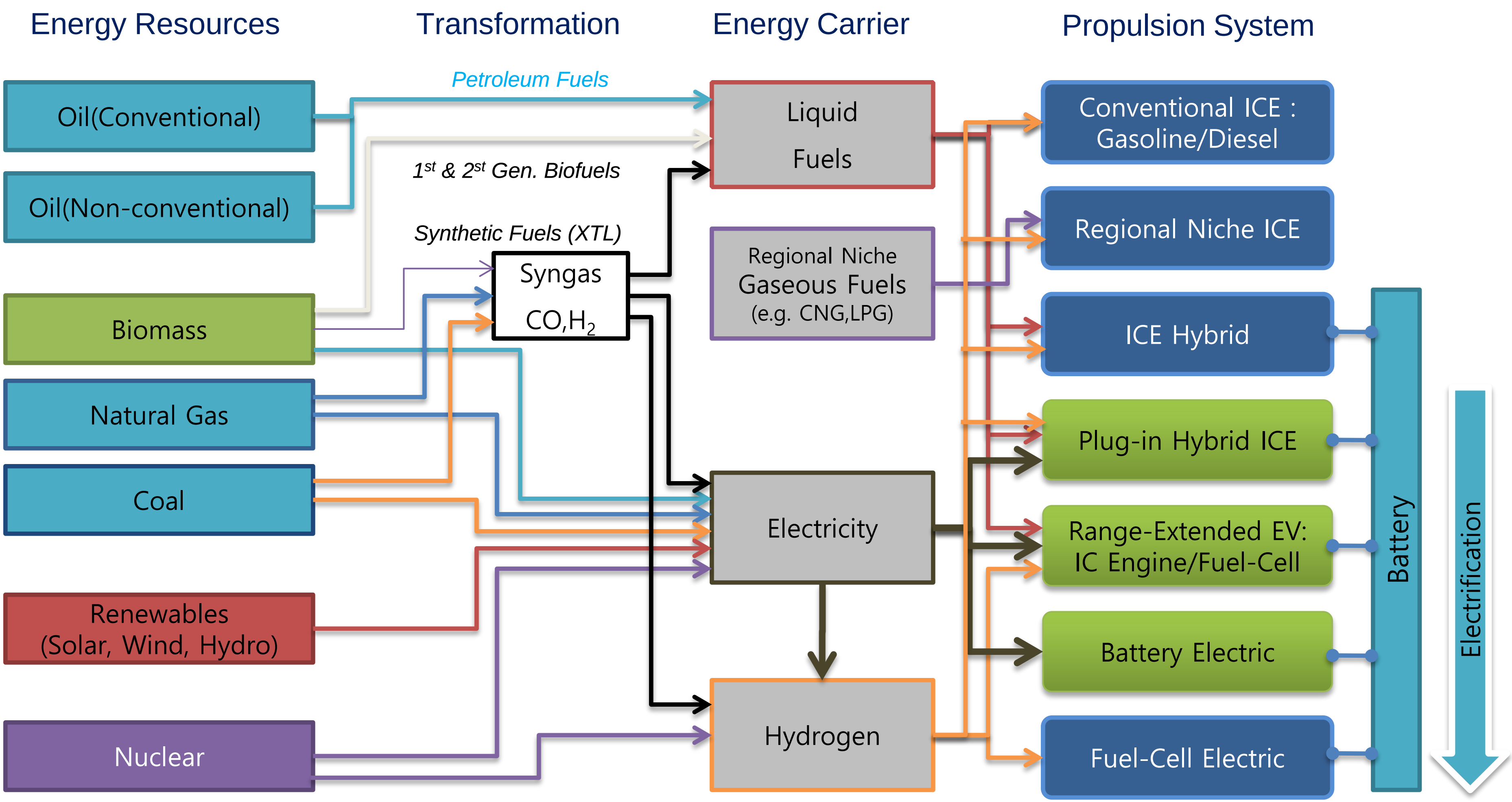
Main challenges

Fuel diversity



Implementation barriers

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Implementation barriers

Self-inflicted public distrust

- VW emission scandal had an enormous impact on the public opinion and diesel is now seen as a very pollutant system.
- It also affected the public perception towards the whole automotive industry
- Many big cities have started to develop actions to reduce the amount of diesel in their streets

European Commission - Press release

Antitrust: Commission fines truck producers € 2.93 billion for participating in a cartel

Brussels, 19 July 2016

The European Commission has found that MAN, Volvo/Renault, Daimler, Iveco, and DAF broke EU antitrust rules. These truck makers colluded for 14 years on truck pricing and on passing on the costs of compliance with stricter emission rules. The Commission has imposed a record fine of € 2 926 499 000.

MAN was not fined as it revealed the existence of the cartel to the Commission. All companies acknowledged their involvement and agreed to settle the case.

- VW emission scandal had an enormous impact on the public opinion and diesel is now seen as a very pollutant system.
- It also affected the public perception towards the whole automotive industry
- Many big cities have started to develop actions to reduce the amount of diesel engines in their streets
- New

Barrier #1: Self-inflicted public distrust

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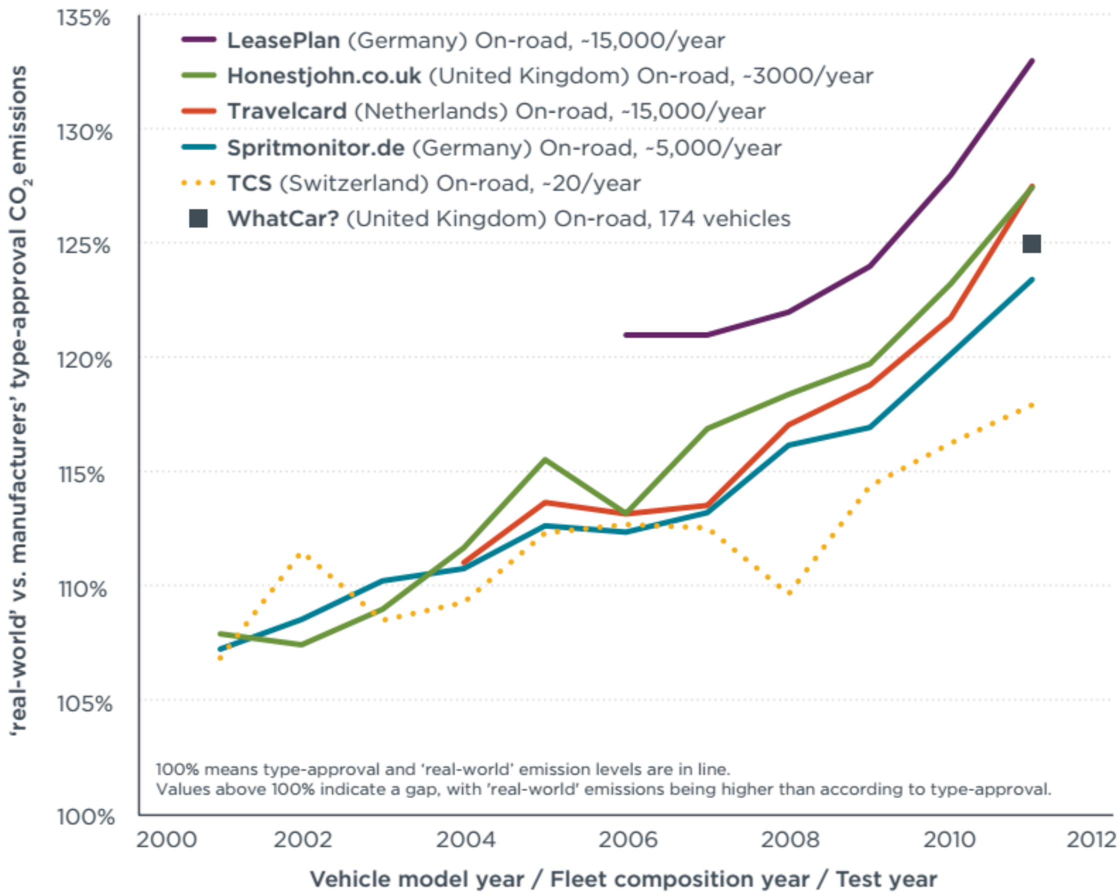
Implementation barriers

Misalignment of interests



Divergence, real-world vs. manufacturers' type-approval CO_2 emissions for various on-road data sources.[1]

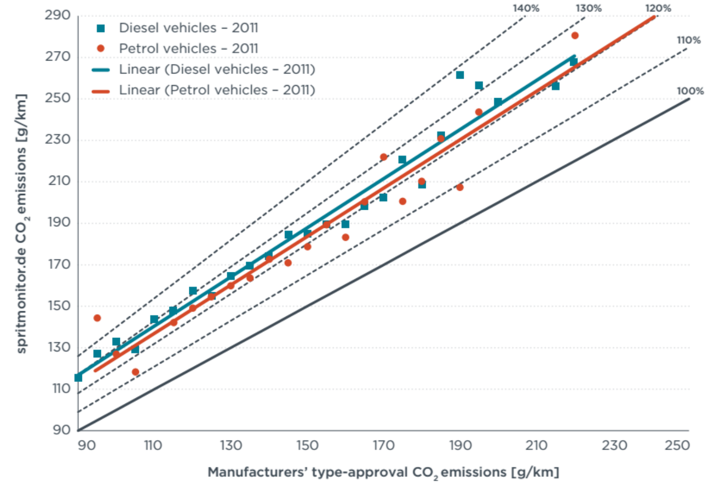


Figure 6. Correlation deviation, spritmonitor.de vs. manufacturers' type-approval CO_2 emissions by CO_2 emission category.

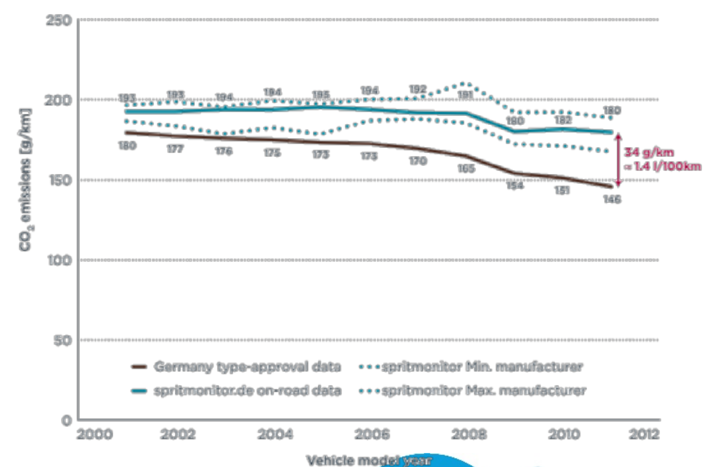


Figure 9. Average CO_2 emissions of new cars in Germany according to type-approval and spritmonitor.de data.

Barrier #2: Misalignment of interests

Example of wrong expectation

- Past forecast of current powertrain technologies:
  - **1975**: In the year 2000 we will not drive with cars, which are driven with ICEs (no petroleum anymore)
  - Daimler **1995**: "In the year 2010 there will be an annual production of 100,000 vehicles with a Fuel Cell at a cost of 100$/kW …"
  - Daimler **1997** and VDI **2000**: "Electric vehicles with Fuel Cells will be in series production in the year 2004 …"
  - BMW **2001**: "During the life time of the actual 7-series hydrogen vehicles with ICE will be on the road ..."
  - **2008**: The rate of small cars with low power engines will increase significantly, while the rate of cars with big and powerful engines will be reduced in the next years
  - Daimler **2009**: "This year the series production of the B-class Fuel Cell vehicle will begin …"
  - Daimler **01/2010**: "2010 is the year of electro-mobility: Mercedes-Benz Cars expands its model range to three electric vehicles..."

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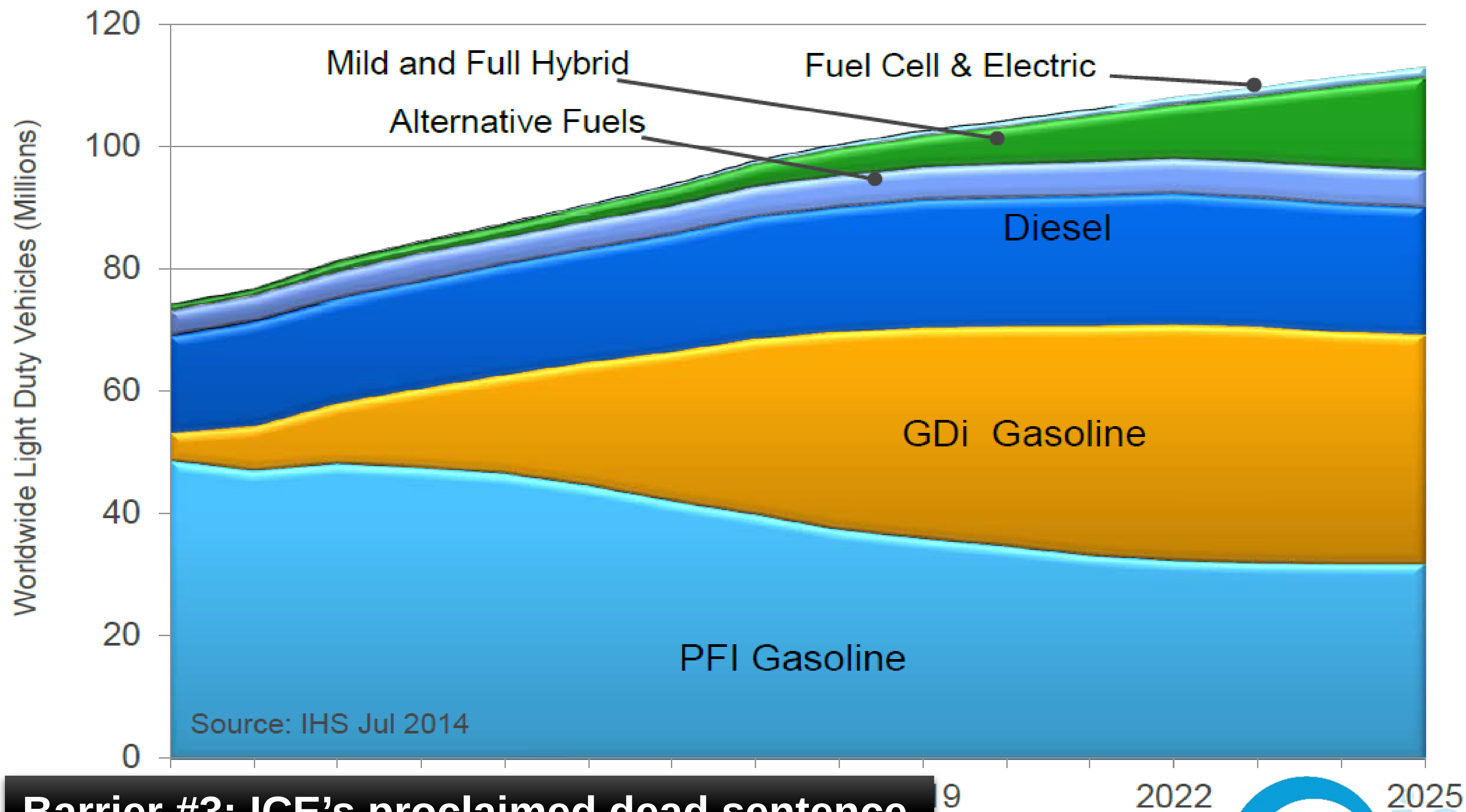
Implementation barriers

ICE's proclaimed dead sentence

Example of Realistic predictions

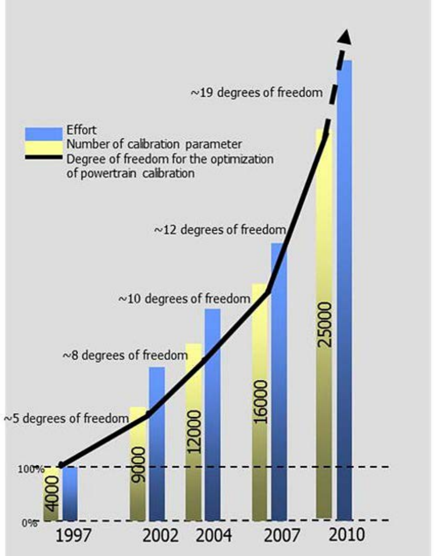


Barrier #3: ICE's proclaimed dead sentence

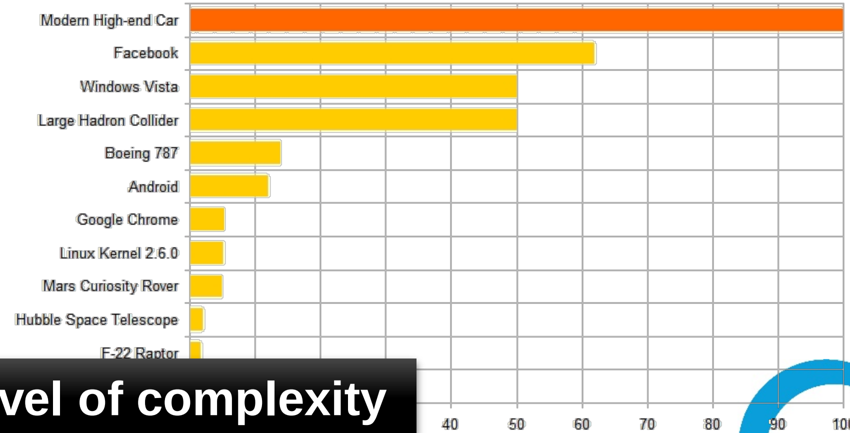
Implementation barriers

Engine calibration effort

- The complexity of an engine ECU (Engine Control Unit) increases exponentially as new degrees of freedom are added.
- A modern ECU requires enormous amounts of engineering, testing and computing hours.
- Engine's efficiency is based on the precise control of every influencing parameter.
- The level of detail is so deep that minor changes in any environmental parameter or property of the fuel may have an enormous impact



Complexity in engine control



Barrier #4: ICE's current level of complexity

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Implementation barriers

Half measures may be counterproductive

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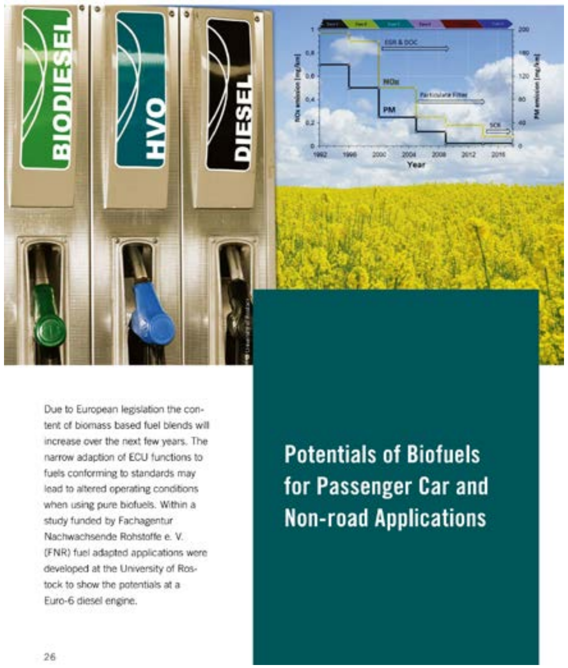
FUTURE FUELS BIOFUELS



Due to European legislation the content of biomass based fuel blends will increase over the next few years. The narrow adaption of ECU functions to fuels conforming to standards may lead to altered operating conditions when using pure biofuels. Within a study funded by Fachagentur Nachwachsende Rohstoffe e. V. (FNR) fuel adapted applications were developed at the University of Rostock to show the potentials at a Euro-6 diesel engine.

26

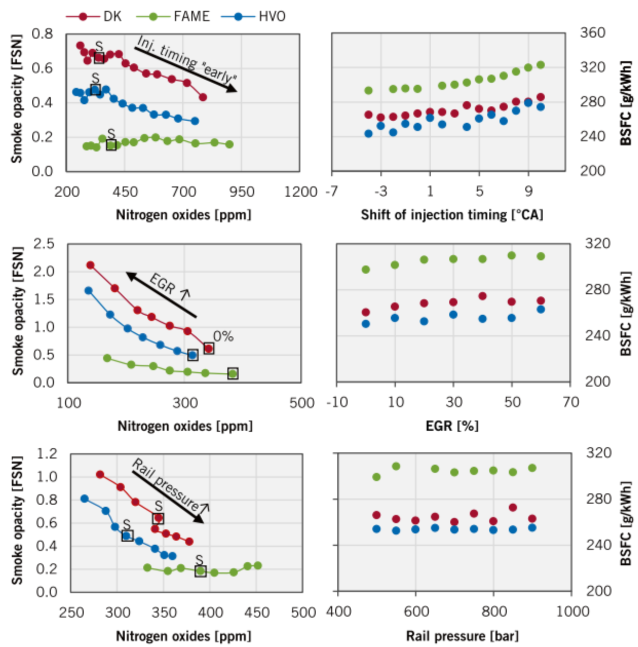


FIGURE 4 Variation of parameters at IMEP = 4.9 bar, n = 1500 rpm (R = regular setting) (© University of Rostock)

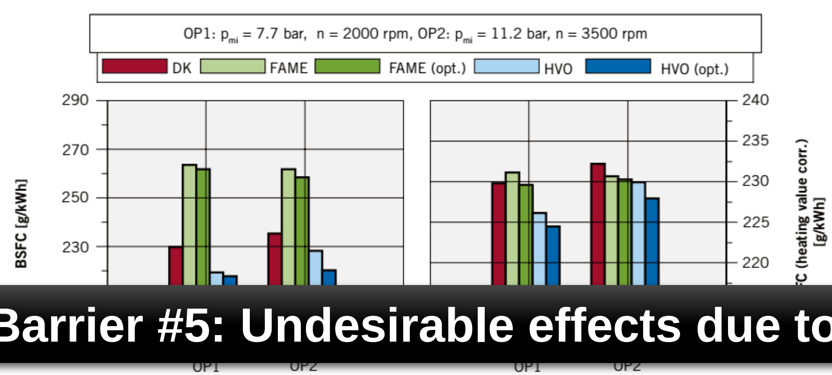


FIGURE 5 Fuel consumption with regular and fuel adapted ECU application (© University of Rostock)

SUMMARY AND OUTLOOK

Short-term engine experiments were conducted at a Euro-6 passenger car engine to analyse the influences of biofuels on engine and emission behaviour. It was possible to operate the engine with both FAME and HVO without trouble. Shifts of operation points within the ECU maps could be observed for FAME operation. This is caused by different fuel properties (e.g. heating value, oxygen content). Fuel impacts on injection timing and combustion was quantified using cylinder pressure indication. HVO showed a decreased ignition delay for all operation points, while FAME impacts on combustion behaviour was interfered by altered boundary conditions (EGR, ... The

could confirm these observations. Biofuel consumption could be reduced using a fuel adapted ECU application without exceeding emission limits of the reference diesel. By the use of sensor systems for the determination of certain fuel properties appropriate ECU settings could be chosen to ensure an ... mized for each fuel.

Barrier #5: Undesirable effects due to partial-measures

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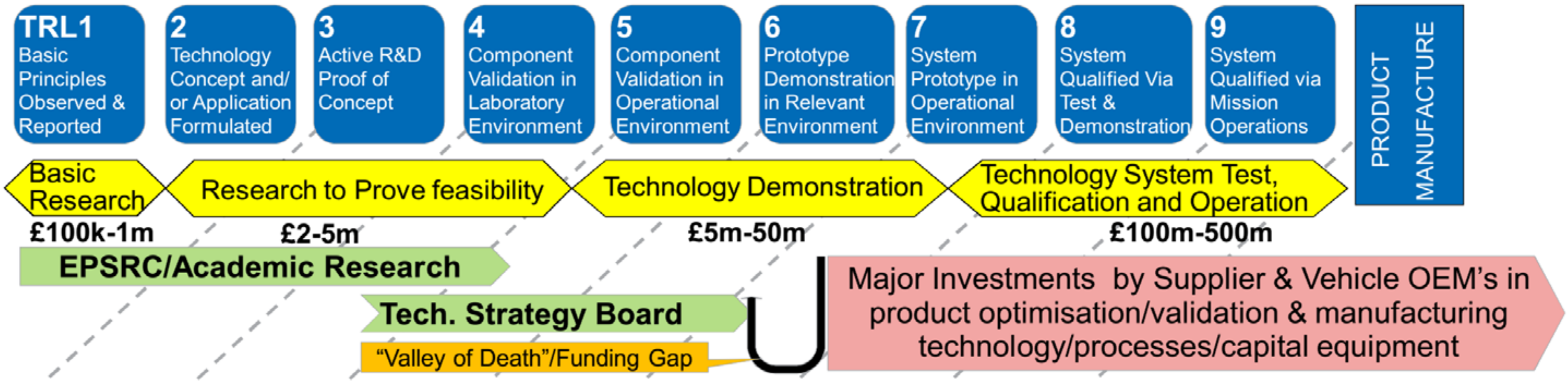
Implementation barriers

Need of a long term planning



- Due to the **maturity** of ICE's and combustion research, a multi-level process is required to get a new technology from its basic research to its implementation
- The potential of new developments is **difficult to assess** in the early stages of development since they will be applied after intensive optimization
- **Unstable** predictions and policies lead to uncertainties in the sector
- Engine developers need to decide whether they should **prioritize** engine efficiency or pollutant emissions (e.g. compression ratio reduction of the diesel engine)

Barrier #6: Science to market distance + copyright

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Implementation barriers

Summary

Barrier #1: Self-inflicted public distrust

Barrier #2: Misalignment of interests

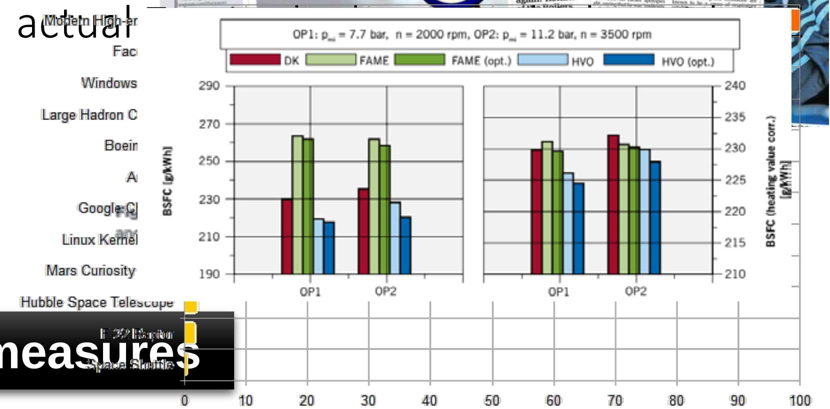
Barrier #3: ICE's proclaimed dead sentence

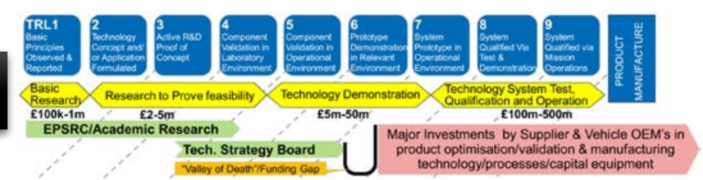
Barrier #4: ICE's current level of complexity

Barrier #5: Undesirable effects due to partial-measures

Barrier #6: Science to market distance + copyright

BMW 2001: "During the life time of the actual





Concluding remarks

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Concluding remarks

- Combustion is a simple yet very complex process that we haven't completely understood yet
- The Combustion TCP generates knowledge that is immediately useful and applicable to current technologies, as well as provides a solid foundation upon which innovative, revolutionary, or advanced concepts can evolve.
- Combustion is the core of most of today's and tomorrows heat production and transportation systems
- Regarding Internal Combustion Engines, several gaps and challenges can be identified
  - Managing and exploiting the full potential of future's fuel diversity is of key importance
- These **gaps/challenges** require a dedicated effort to understand better combustion and the joined collaboration of every institution, government and TCP
- In addition, several **barriers** exist that endanger that ICE's get to their full potential

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References

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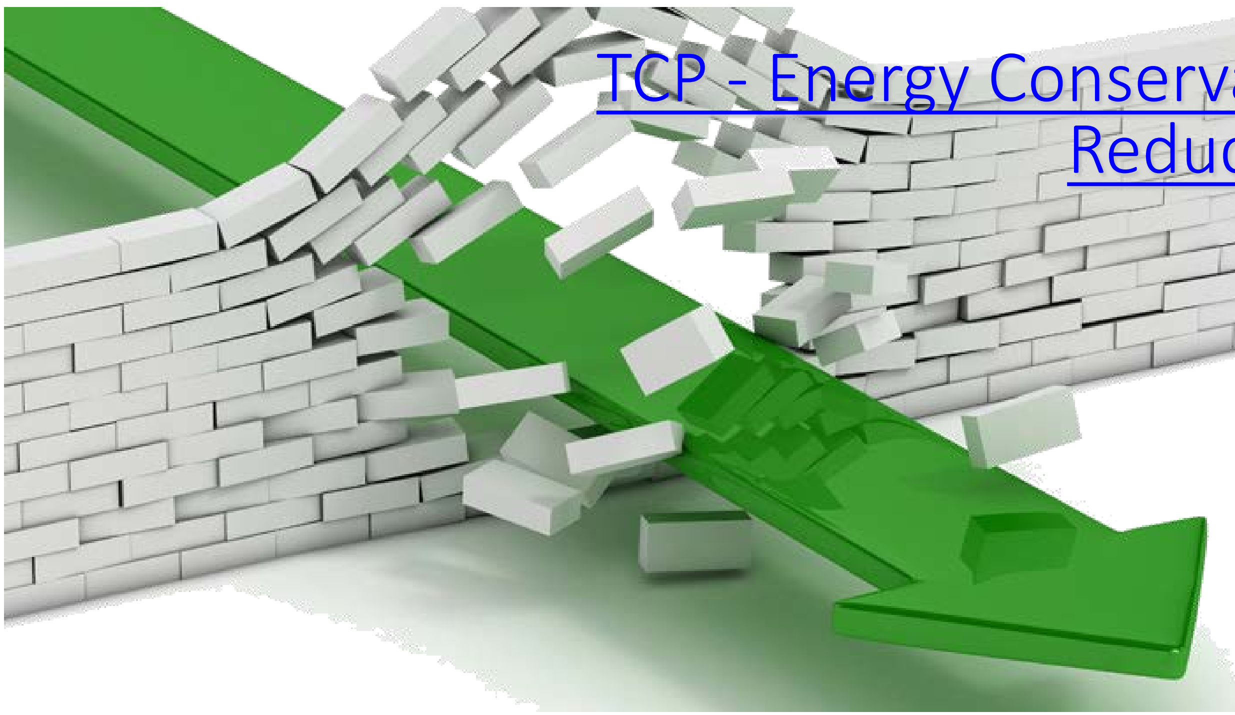

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Dr. Jacobo Porteiro
Chair of the Executive Committee

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