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

TCP - Energy Conservation and Emissions Reduction in Combustion

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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.
Outline

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

- General
- The Combustion TCP
- Main activities
- Objectives
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.

Today's 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
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.
- Explore advanced combustion strategies to achieve higher engine efficiencies with near-zero emission of NO\textsubscript{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.
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.
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.
- 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
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
IEA Combustion

Main challenges
ICE roadmap

Boosted Engine
Variable Geometry Turbo
12 Volt Elec System
Stop/Start
5% Bio fuel mix

Downsized 40% v Today
Turbo/Supercharged
48 Volt Motor/Generator
Low Cost Energy Store
10% biofuel mix

Downsized 70% v Today
Dual Stage Boost
Integrated Electric Machine
Thermoelectric Generator
25% biofuel mix

Extreme Downsizing
Advanced Cycle/Heat Rec.
Integrated Systems
Advanced Thermoelectrics
Synthetic fuel mix

Potential NEDC CO₂ Capability

Vehicle Weight Reduction:
Base
-9%
-21%
-34%
-41%
-45%
-48%

Increasing City/Low Speed Electric Drive Capability

NEDC Drive Cycle CO₂ (g/km)
IEA Combustion

Main challenges
ICE roadmap

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

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
- 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

EU Fleet Average CO₂ Targets (g/km)
- 2010: 130
- 2015: 95
- 2020: TBD
- 2025: TBD
- 2030: TBD
Main technology trends and the Vision of share of engines in Europe

New Passenger Cars & Light Commercial Vehicle (<3.5t)

- Gasoline technologies
- Gasoline + diesel technologies
- Diesel technologies

Road transport energy source

- Fossil diesel
- Diesel biofuel
- Fossil gasoline
- Gasoline biofuel
- Hydrogen & electric energy

Propulsion technology

- Advanced diesel
- Diesel hybrid
- Advanced flexible combustion techniques
- Advanced spark-ignition
- Spark-ignition hybrid
- Plug-in hybrid / range extender
- Full electric (incl. fuel cell)
- Adapted ICE

Percent of new vehicles utilising energy source / powertrain

- 2010
- 2015
- 2020
- 2025
- 2030

Paris EUWP Workshop, March 2017

Energy Conservation and Emissions Reduction in Combustion
World Final Transport Energy Demand by Scenario

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

Source: ETP 2016, IEA
Implementation barriers
• 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
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**
Divergence, real-world vs. manufacturers’ type-approval CO₂ emissions for various on-road data sources.¹

**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...”
Example of Realistic predictions

Worldwide Light Duty Vehicles (Millions)

- Mild and Full Hybrid
- Fuel Cell & Electric
- Alternative Fuels
- Diesel
- GDi Gasoline
- PFI Gasoline

Source: IHS Jul 2014

Barrier #3: ICE’s proclaimed dead sentence
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.
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, 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 optimized for each fuel.
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**
IEA Combustion

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 7series hydrogen vehicles with ICE..."
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.
- FIA - The User Perspective on Upcoming Innovation – 2017
- ERTRAC – Future Light-duty powertrain technologies and fuels – 2011
- UK Automotive Council – Advanced ICE workstream conclusions & consensus roadmap – 2013
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