EUWP TECHNOLOGY COLLABORATION PROGRAMMES (TCPs)

ANNUAL BRIEFING

TCP NAME	Report Date
Clean and Efficient Combustion (Combustion TCP)	2/18/2019

Main Technology Policy Messages/Recommendations

Worldwide, more than 80% of the energy used is converted by combustion to usable forms in the areas of transportation, power generation, and industrial, commercial, and residential heat.

- Progress in fundamental combustion science remains critical. Research into combustion chemistry, fuel sprays, and particulate formation is providing knowledge required both for designing higher efficiency, low pollutant and CO_2 emission combustion technologies and for developing advanced commercially-marketed, computer-based design tools used in all advanced combustion system development.
- Natural gas engines will play an increasing role in both transportation and stationary power.
  - With technology advances, such as improved lean-burn natural gas combustion/ignition systems, high diesel-like fuel efficiencies are being approached while demonstrating substantial CO_2 savings and ultra-low emissions. When coupled with consensus predictions of a growing and reliable price differential between natural gas and diesel fuel, the economic pull for natural gas engines is even stronger.
  - Renewable natural gas can provide unparalleled well-to-wheels greenhouse-gas reductions, even relative to electric vehicles.
  - Fuel flexibility (e.g. bio-methane or land-fill gases) and rapid load uptake capabilities make stationary natural gas engines ideal for grid-balancing (large-scale as well as decentralized).
- Internal combustion engine powered vehicles will dominate transportation for many decades.
  - Pollutant emissions from light-duty vehicles with modern after-treatment can be lower than ambient levels in many locales. In effect, these can be negative emission vehicles.
  - The heavy-duty fleet is less amenable to electrification. Therefore, continued progress in fuel efficiency and emissions reduction is essential for meeting climate and pollutant goals.
  - Low Temperature Combustion (LTC) strategies continue to show potential for significantly higher fuel efficiency (20% to 25%) with lower CO_2 and pollutant emissions than current fleet averages.
  - An effective and optimal transition to alternative, renewable fuels, using LTC requires an assessment of conventional and new fuel performance metrics.
  - Dual fuel engine technologies can provide diesel-like efficiencies with less restrictive fuel property requirements, thereby expanding the pallet of viable current and future fuels.
- Solid fuel combustion technologies allow local use of biomass, contribute to waste management, and provide industrial and domestic consumers access to low CO_2 energy. Residential heating is the sector where biomass combustion is expected to contribute the most in the coming years. However, more demanding emission regulations are being applied to biomass combustion. Meeting these regulations will require a considerable upgrade in the understanding of biomass combustion to aid development of low-cost systems.
- The use of natural gas (methane)-hydrogen blends paves a path for early adoption of hydrogen and for reduced greenhouse gas emissions from the power sector. Gas turbines for electric power generation will play a vital role in this transition period and likely beyond. With their flexibility for quick load variation, they are an important element in stabilizing electric grid networks. Combustion of methane/hydrogen mixtures is a major challenge for all combustion systems, be it for heat and power generation or for industrial process applications. Pushing the tolerability limit for hydrogen to higher concentrations in the existing natural gas distribution networks will have a major impact on the introduction of hydrogen into our energy systems. Storage of hydrogen on a large scale and on a seasonal basis will become feasible with only moderate additional infrastructure investments.

Achievements *(recent developments in the last two years only)*

Scientific Focus

- Annual TCP gathering "TLM" redesigned to enable TCP wide discussions on enhanced collaborations and a stronger focus of task efforts on relevant goals and targets.
- Policy analysis further integrated into our TLM in 2018. Speakers invited on electrification (ETH Zurich, IFPEN) and alternative energy carrier scenarios (H2 TCP, SMARTCATS).
- Seeking increased industry participation in upcoming TLMs to broaden our impact and obtain industry perspectives on needed research.
- TCP leadership is exploring potential new tasks in Systems Analysis and After-treatment.

TCP renewal

- Highly successful strategy workshop held to plan "The TCP we would like to see." (Feb 2018)
- TCP leadership restructured to provide greater continuity and efficacy, with clarified roles, responsibilities and organizational structure. (ExCo meetings April & June 2018)
- Request for 5-year extension developed and presented to EUWP. (Sep 2018)

Dissemination and publications

- 40th TLM held in France with 39 technical presentations and intense discussions among tasks leaders, scientists and industry representatives. (June 11-14, 2018)
- Annual Spray in Combustion Task workshop held at the SAE World Congress. (April 2018)
- Gas Engines Task hosted its 2nd public workshop in Zurich. (June 2018)
- Increased TCP visibility in the scientific community with extensive publications of TCP related work in peer reviewed journals and presentations at conferences such as the Combustion Symposium; discussions initiated on how to more clearly identify TCP related work.
- TCP webpage redesign and continuous renewal is ongoing as budget permits. Work so far focused on updating the most frequently visited public sites and establishing a forum for TCP internal exchange of information.

Collaboration and Co-operation

Other IEA network IAs and co-ordinating groups

- Engaged the Hydrogen TCP in our 2018 TLM and are continuing to reach out to them and the Bioenergy TCP to explore coordinated activities at ExCo and task/annex level.
- Initiated collaboration with AMF TCP on heavy-duty vehicle performance which shall include research results on fuel efficiency potential / CO_2 benefits of advanced combustion technologies; attended AMF Annex meeting. (Nov 2018)
- Planning for collocated TCP level gatherings in Switzerland in November 2019 with a day of joint workshops between AMF and Combustion TCPs is well underway.
- Participation in the EUWP Meetings. (March & Sep 2018)
- Participation in the CERT Strategic Session on the Transport Sector. (Feb 2018)
- TCP Presentation at the EUWP Transport Coordination Group Meeting. (Sep 2018)

IEA secretariat

- Participation of our desk officer in our Spring 2018 ExCo meeting; in depth review of our Request for Extension (RfE) documents with our desk officer and his team.
- Participation in the joint IEA/EC Electrofuels workshop. (Sep 2018)
- TCP Expert review of the Global Fuel Economy Initiative working paper on Benchmarking of Light-Duty Vehicles 2005-2017.

Membership

- Efforts continue to broaden participation in current member countries:
  In 2018, the TCP formally welcomed IFPEN (France) and CMT (Spain).
- Conversations to include new member countries were resumed with Portugal and Austria.
- Outreach to potential new member countries prioritized India, China, Brazil, Russia.

Management

- Request for Extension (RfE) 2019-24 submitted to EUWP with presentation on Sep 13, 2018.
- In the RfE process, extensive understanding and renewal of the TCP was developed concerning: a) strategic focus, b) organization, governance, roles and responsibilities, and c) outreach and communication.
- Work was initiated to update official TCP membership records with the help of IEA Legal.

Confidential information

Please treat all information wrt potential new members as confidential within the IA / the EUWP.

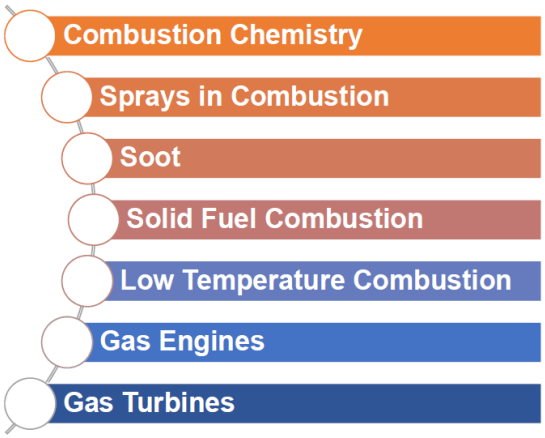
Meetings or Workshops hosted by the TCP

2018 TCP Management Meetings			2019 TCP Management Meetings	
Place	*Date*		*Place*	*Date*
Orléans, France (Strategy)	2/12-14/18		Paris, France (Strategy)	5/13/19
Paris, France (ExCo)	4/23-24/18		Paris, France (ExCo)	5/14/19
Fréjus, France (ExCo)	6/14/18		Montreux, Switzerland (ExCo)	11/7/19

TCP meetings to advance our scientific work	*Place*	*Date*
2018 Annual TCP Meeting "TLM" with specific sessions in each task / research area as well as crosscuttings session with external speakers / panelists.	Fréjus, France	6/10-13/18
2019 Annual TCP Meeting "TLM" with specific sessions for each task / research area and a day dedicated to joint workshops with AMF TCP.	Montreux, Switzerland	11/4-7/19

Current RESEARCH AREAS

Our research spans from combustion fundamentals to technical applications



(See tables on the following pages for details on each task.)

RESEARCH AREAS under consideration

Research Area	Expected start date	Expected end date	Collaboration	Technology Policy Message
After Treatment (of combustion exhaust gases)	2020	Tbd	Tbd	Exploring engine exhaust after-treatment systems for further reduction of emissions from engines employing advanced high-efficiency combustion strategies. Currently in the scouting stage. Details TBD.
Systems Analysis	2020	Tbd	Tbd	Assessing the impact of advanced high-efficiency combustion strategies in a broader vehicle context, either as stand-alone task or integrated into existing tasks. Details TBD.

Current RESEARCH AREAS

Research Area	Date Approved	End date	Participants	Milestones		
				Latest Workshops	Interim results so far	Expected final results
Combustion Chemistry	2014	Tbd*	Finland France Japan Sweden Switzerland USA	June 11-14, 2018	• Chemical kinetic model developed for diisobutylene, a high-octane, bio-derived fuel component based on: ○ Species concentrations measured in a jet-stirred reactor and a shock tube. ○ Measured flame speeds. • Identified previously unknown decomposition pathways for diisobutylene • Developed techniques to measure rate constants of single isomer reactions selectively • Kinetic mechanism developed for anisole, a high-octane fuel component of biomass-derived fuels.	**Objective**: Predictive chemical kinetic models for renewable fuels and their blends with petroleum fuels to support computational optimization of combustion devices. **Key deliverables**: • Quantitative data on species concentrations, flame speeds, and ignition delay to support the development of chemical kinetic mechanisms. • Identification of important oxidation pathways needed for model development. • Validated kinetic models.
Sprays in Combustion	2014	Tbd*	Germany Spain USA Japan France Switzerland Finland	June 11-14, 2018	• Several new state-of-the-art spray research facilities have been installed worldwide recently, including in Spain and the USA. These new capabilities are now generating data crucial for developing and validating computational models. • Developed the capability for micron-scale measurements of internal fuel injector nozzle geometries. The geometries of canonical diesel and gasoline nozzles have been released worldwide to facilitate their use in computational simulations. • Completed a study of the influence of spray evolution on combustion in large-bore marine engines. • Results are contributing to the growing use of coupled Eulerian-Lagrangian simulations of fuel injection. These simulations more accurately capture the influence of fuel injector nozzle geometry on the fuel spray, increasing the overall predictive power of spray and engine simulations.	**Objective:** Develop a foundational scientific understanding of spray formation and mixing and a concurrent capability for computationally designing fuel and air mixing processes in combustion systems with fuel sprays. **Key deliverables**: • Utilizing both experiments and simulation, develop an understanding of the influence of sprays on advanced combustion strategies that promise clean-burning, highly efficient combustion engines. • Conduct experimental measurements and computational simulations on common engine fuel injection cases, such as those promoted by the Engine Combustion Network. Worldwide efforts such as this focus the research community on solving fundamental problems that speed the advancement of fuel injection and spray combustion technologies. • Develop a fundamental understanding of cavitation in fuel injector nozzles, its effect on sprays, and its propensity to damage nozzles over time. • Advance the state-of-the-art of computational simulations of sprays relevant to engine designers.

Research Area	Date Approved	End date	Participants	Milestones		
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Soot	2016	Tbd*	US Japan France Spain Sweden	June 11-14, 2018	• Established working group among TCP participants using Converge CFD code, collaborating through monthly and bi-monthly web meetings. • Constructed novel flame-sampling tandem mass spectrometer and identified aliphatically-bridged polycyclic aromatic hydrocarbons (PAHs) and PAHs with aliphatic side chains for the first time in flame samples. The key discovery supports modeling of the soot particle nucleation process. • Measured binding energy of coronene using scanning tunneling microscopy and density functional theory – also key to particle nucleation. • Quantified the effect of small amounts of oxygen addition to fuel sprays on soot formation, establishing a 1450 K temperature limit for soot formation during the pyrolysis of alkane fuels and 1600 K as the soot limit temperature when oxygen is present.	**Objective**: Leverage international collaborations on experiments and modeling toward a foundational scientific understanding of soot formation/oxidation processes that will enable prediction of soot mass, particle number, and particle structure for a variety of fuels. Expand the current understanding of how soot toxicity and environmental impact change with fuel and combustion concept. **Key deliverables**: • Detailed predictive models describing formation of gas-phase species leading to soot formation, the soot nucleation process, and soot particle oxidation. • Reduced complexity engineering models with sufficient accuracy for design optimization. • Characterize and understand the effects of engine parameters on formation, oxidation, and emissions.
Solid Fuel Combustion	2016	Tbd*	Germany Spain Japan	June 11-14, 2018	• Advanced models for bed-furnace integration, particle dynamics in the combustor bed and prediction of fouling and slagging of biomass boilers. • Assessed solid fuel feeding strategies on combustion performance. • Developed particle reactor coupled with spectroscopy-based diagnosis technologies to investigate the pyrolysis and char oxidation processes in thermally thick particles.	**Objective**: To gain a better understanding of the combustion of solid fuels that is required to develop more flexible, cleaner and efficient Combined Heat and Power systems. **Key deliverables:** • Improved designs of solid-fuel combustors. • Advanced models for solid fuel gasifier or combustor pyrolysis and char oxidation that: ○ Incorporate improved chemical kinetic mechanisms accounting for secondary reactions. ○ Include high inorganic content agricultural residues. • Advanced process monitoring sensors.

Research Area	Date Approved	End date	Participants	Milestones		
				Latest Workshops	Interim results so far	Expected final results
Low Temperature Combustion (LTC)	2014	Tbd*	France Japan Norway South Korea Spain Sweden USA	June 11-14, 2018	• Demonstrated soot-free combustion with Gasoline Direct-Injection Compression-Ignition experiments. • For Reactivity Controlled Compression Ignition combustion, research has revealed many different physical and chemical processes that contribute to mixture formation and ignition/combustion. • Spark Assist Compression Ignition experiments suggest that the current Octane-Index is applicable for rank ordering fuels for autoignition quality, but confirmation is needed over wider ranges of fuels and operating conditions. • For LTC concepts, the effect of ozone on autoignition can be strong, but the underlying chemistry is complex and dependent on both the LTC concept and fuel used. More research is needed to fully assess the use of ozone for control. • For lean stratified spark-ignition operation with exhaust gas recirculation, engine-out soot can be reasonably well correlated with the fuel's PMI, but with shortcomings for alcohol-containing fuels, which suggests further development of fuel property metrics for alternative fuels is required.	**Objective**: Examine a wide range of LTC engine concepts to gain fundamental understanding of the in-cylinder processes governing efficiency and exhaust-emissions formation, and assess their technical potential for increasing energy efficiency in vehicle applications. **Key deliverables**: • Assessment of the drive-cycle fuel consumption of LTC and advanced spark-ignition combustion systems. • Evaluation of fuel effects on LTC operation and appraisal of the effectiveness of standard fuel quality metrics like Octane Number metrics. • Evaluation and further development of LTC combustion timing control methodologies. • Further development of LTC by examining different exhaust gas recirculation (EGR) concepts and multiple injection strategies. • Clarification of the connection between local fuel-to-air ratio and ignition.
Gas Turbines	2014	Tbd*	France Switzerland Japan UK Sweden France Norway	June 11-14, 2018	• Improved models can predict instabilities in gas turbines, which enables more reliable and safe operation of gas turbines in order to stabilize electricity networks with high shares of variable renewables. • Addition of up to 20 % volume H_2 to H_2/CH_4 mixtures showing potential for immediate fuel carbon reductions without significant negative impact on efficiency/operation. Recent combustion technology development points to even higher H_2 content (40% volume) being acceptable to be distributed in public networks.	**Objective**: Develop combustion technologies for high efficiency, ultra-low emission gas turbine engines for power generation/industrial processes/transport (air, sea). **Key deliverables**: • Understanding needed for adoption of low carbon fuels, including the extension of operational limits (flashback, blow-out, maximum load gradients) for: ○ CH_4/H_2 (Methane/Hydrogen) fuel mixtures. ○ H_2-carrier fuels (ammonia, methanol). • Predictive models for flame instabilities. • Quantitative species, flow, and temperature measurements supporting design evaluation and model development.

Research Area	Date Approved	End date	Participants	Milestones		
				Latest Workshops	Interim results so far	Expected final results
Gas Engines	2014	Tbd*	Finland France Japan Korea Switzerland USA	June 11-14, 2018	• Advanced wall heat transfer model validation using Direct Numerical Simulation data completed. • Dual-fuel engines: ○ Advanced laser-based optical diagnostics specific for dual-fuel micro pilots developed. ○ New dual-fuel combustion model developed. ○ Database generated for wide range of conditions in a Rapid Compression Expansion Machine (RCEM). ○ Sooting propensities of micro-pilot injections characterized. • Un-scavenged pre-chamber ignition: ○ Characterized two production pre-chamber spark plugs in RCEM for a variety of conditions. ○ 3D simulation platform developed and validated using engine and RCEM data. ○ Phenomenological turbulence model for engine pre-chambers developed. • New optical test rig further developed with engine-relevant pressure/temperature/turbulence levels suitable for premixed conditions.	**Objective:** Support the development of future ultra-low emission natural gas engine combustion systems with Diesel-like efficiencies suitable for surface transport as well as co-generation/grid balancing. **Deliverables:** • Optical diagnostics for lean premixed natural gas engine ignition systems (pre-chambers, dual fuel micro-pilots). • Characterization of non-premixed high-pressure direct injection (HPDI) combustion concepts that offer reduced methane emissions. • Predictive computational tools for pre-chamber, dual fuel and HPDI combustion for engine optimization. • **I**mprovement of chemical kinetic models for lean premixed natural gas and bio-derived fuels. • Improved understanding and models for flame–wall interaction, heat transfer and CH_4/NH_3 slip. • Identification of factors leading to auto-ignition (knock).

* Note: There are no fixed end dates. Instead, every research area is routinely evaluated at the annual TCP strategy meetings.