Technology Industries of Finland

4/5/2024

Combustion Engines a Key Part of Finnish Industrial Policy Strategy

Executive summary:
Decarbonization of hard-to-electrify applications such as majority of shipping, agriculture and many other mobile machines cannot take place without introduction of new sustainable carbon neutral or carbon-free fuels due to the special nature of their operations and operational environment. In addition, to reduce energy consumption the efficiency of internal combustion engines (ICE) needs to be improved. Simultaneously, pollutant emissions are to be reduced close to zero. This sets huge task for ICE related R&D&I efforts. Development is needed widespread the ICE industry from development of new simulation and modelling tools to new materials and combustion concepts and engine designs to fully deploy the potential of these new fuels. Furthermore, testing of new fuels and powertrains sets requirement for research infrastructures which needs to be built. Finland has in global perspective a great potential to produce significant handprint in decarbonization of maritime, ICE based power generation and mobile machinery sector via our basically fully export driven industry which had export of around 20 billion Euros in 2023 and provided workplaces for over 20 000 persons in Finland. To success in all this and to secure a bright future of the Finnish ICE industry, active collaboration and sharing, among the partners, experimental, modelling, simulation resources, data gathering and artificial intelligence, are essential. We (companies, universities and research centres) in Combustion Engines Finland group are committed for developing new carbon neutral and carbon-free ICE solutions to decarbonize maritime, power production and mobile machinery sectors by investing in approximately 1.7 billion Euros during the next five years in R&D&I and research infrastructures required for the journey of decarbonization. To succeed in this journey, public investments in the R&D&I actions, infrastructures and highly skilled professionals are also seen one of the key components in the transformation.

General view:
Global warming due to anthropic emissions of so-called Green House Gases (GHG) put an enormous challenge on Internal Combustion Engines (ICE) to become carbon neutral. Especially, in applications such as blue ocean shipping and agriculture machinery or other so called hard-to-electrify machines and vessels, ICE is a vital energy converter in foreseen future. Here the wide usage of ICE's, due to its versatility, is also in a pivotal position in enabling fast reduction of GHG emissions. To ensure this transformation, the emphasis should be put on introduction of carbon neutral and carbon-free fuels. The properties of these new fuels require dedicated and focused, Research and Development (R&D), effort within multiple fields of knowledge. To secure a bright future of the Finnish ICE industry, active collaboration and sharing, among the partners, experimental, modelling, simulation resources, data gathering and artificial intelligence, are essential. The full engine R&D tool chain from fundamental experiments, modelling and simulation, to full engine testing, is required together among the collaborating partners.

Statement:
For competitive and successful ICE research and development in Finland; collaboration, sharing, and long-term continuity are the basic building blocks. Efficient and high-level research and development cannot be intermittent, with starting and stopping activities based on temporary funding availability. Building-up research groups, the experimental and simulation infrastructure, and generating the know-how and skills takes time, which is lost if the activity is not continuous. Long term commitment from industry, research institutes, academia and public funding is required. Finland has in global perspective a great potential to produce significant handprint in decarbonization of maritime and mobile machinery sector via our basically fully export driven industry. In total, ICE related industry had export around 20 billion Euros in 2023 and Finnish ICE related industry belongs to the leading companies in global perspective within own areas. To

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success in this huge task of decarbonization the ICE powered vessels, powerplants and mobile machines, by introduction of both carbon neutral and carbon free fuels, will require a coordinated joint research and development effort in Finland. While the change to carbon free fuels is disruptive and the competitiveness and success of Finnish ICE based industry have to be secured, it is also at the same time an opportunity for fast reduction of carbon dioxide from transportation, off-road, and energy sectors where ICE's are today widely used.

Complexity increases:
Engine and combustion system development is a complex task. It requires a wide set of knowledge from areas as fluid and thermodynamics, chemical kinetics, mechanics and material sciences, tribology, mechatronics, and automation and controls, just to mention some. When introducing a new fuel, the impact on the different engine systems must be evaluated, simulated and understood, modifications and improvements implemented, tested and optimized, and validated for the lifetime of the engine in its intended application to secure performance, with desired robustness and quality. Consequently, engine development is time consuming and very much relying on iterative improvements by extensive testing supported by simulations. The accuracy of contemporary simulations is on a level it can replace testing in some specific areas, but far from all. Simulation is an established tool for initial optimization, where it supports solution and design iterations. However, final testing and optimization iterations have to be made with the real hardware. To enable faster and more efficient optimization iterations in engine R&D, focus on fundamental understanding of the new fuels impact on the different knowledge areas is required. This is done by a combination of basic testing in experimental rigs to describe the fundamental behaviour, generating the knowledge, and transferring the behaviour into models that later can be used in simulations. Hence, the engine development tool chain from establishing the fundamental understanding by initial concept testing, via models and simulations, to design, optimization and validation of the final product, is long and complex. Here joint effort by industry, research institutes, academia and public funding is the way forward to enable the success of Finnish ICE-based solutions.

Experimental research infra
Laboratories and experimental research infra are expensive both in cost of investment and operation. Especially the cost of full-scale engine testing that increases exponentially by the size of the engine. Measurement systems and equipment for detailed investigations are also expensive and requires often dedicated personnel to operate. To maximize the output of the money spent in these expensive infra, collaboration and sharing is the key forward. Sharing experimental facilities, sharing expensive measurement equipment, sharing test results in form of data, sharing resources required to operate, collaborating in joint projects, and sharing the success of achieved results. On the other side, smaller rigs and experimental setups for dedicated fundamental investigations that have lower cost and are easier to maintain, should be close to the researcher at respective research institute and university. We are today sharing pre agreed fundamental engine and rig test data for research purposes within common projects, to enable the generation of fundamental knowledge and development of simulation models, which in the next step can be used for optimization iterations to faster enable the introduction of decarbonized fuels. We are also providing access for researchers to specific experimental rigs in collaboration projects. Likewise, we promote the sharing of experimental infra and data between the research institutes and collaboration in research projects. Hence, it should be possible for a university or research institute to get access to research infra at a partner university or research institute based on fair and reasonable principles regarding cost and availability. The target would be to maximize the usage of the investments in experimental rigs to generate valuable data for post-processing and minimize the downtime. Research investment costs could also be shared to enable the investment to be realized. During recent years some bigger investments in infra have been cancelled or postponed due to the high cost for the individual research institute or university. We have in the past been involved and supporting medium speed research engine investments at VTT and Aalto, and more recently at Vaasa University. Discussions of new medium speed single

cylinder research engine investments at VTT and Aalto have also taken place some years ago, but not realized due to high cost compared to anticipated too low level of usage. This underlines the importance of collaboration between the industry, universities, research centres and the support from the public sector when investments for new experimental research facilities are planned.

As first step Combustion Engines Finland group could take a leading role to set-up the frame agreement among the partners i.e., research institutes, universities, and industry, for sharing data and giving access to engine and combustion laboratories, based on fair and reasonable cost. Joint staffing of the operations can also be considered. Second step would be to increase the usage of already today existing infra, by increasing their availability by securing staffing for maintenance and rebuilding, with the target to minimize downtime and having research campaigns back-to-back. The third step is to analyse what experimental capacity is missing taking into account foreseen research needs, especially regarding carbon neutral and carbon free fuels. Then make coordinated plans where to invest and collaborate to make it happen.

Modelling and simulation capabilities

Simulations are the cornerstone of engine research and development, to enable efficient optimization of engine processes. Validated models, with appropriate accuracy, is the cornerstone of simulations. For model development especially covering new carbon neutral and carbon-free fuels, fundamental experimental testing is required. For engine development, engine testing preceded by reliable simulations, is a target. Consequently modelling, testing, and simulations go hand in hand in different phases of the engine research and development process and can be described as a tool chain. Modelling and simulation activities do not need to be co-located with experimental facilities if validation data is shared and available. Combustion Engines Finland could contribute to the availability of knowledge and tools throughout this tool chain in the same way as experimental infra is listed, also modelling and simulation capabilities should be listed and maintained, often linked to expertise by individuals and research teams. Modelling and simulation gaps in the tool chain should then be addressed and invested into. By coordinating modelling and simulation capabilities the output of the full engine research and development tool chain can be maximized both regarding quality, depth, and capacity. The first step would be identifying and listing existing modelling and simulation capabilities. Second step, analyse the gaps in the tool chain considering foreseen research needs. Third step initiate activities to fill the gaps among the Combustion Engines Finland partners.

Closing words

Companies, universities and research centres in the Combustion Engines Finland group are committed for developing new carbon neutral and carbon-free ICE solutions to decarbonize maritime, power production and mobile machinery sectors. Partners are investing significant amounts of resources on this journey and collaborating in multiple fields from the fundamental research to high Technology Readiness Level (TRL) solutions. Based on current plans the total investment among the Combustion Engines Finland group partners in infrastructures and R&D&I is around 1.7 billion Euros within the upcoming 5 years. In addition, ICE related industry provides workplaces for over 20 000 persons in Finland requiring high-skilled workforce from the component manufacturing to the system production and up to the R&D&I tasks. To ensure competitiveness in the global field, public investments in the R&D&I actions, infrastructures and highly skilled professionals are also seen pivotal component in the transformation.

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