

## **Title: Metrology for green maritime shipping: Emission control through traceable measurements and machine learning approach**

### **Abstract**

Green maritime shipping is moving towards alternative chemical energy carriers like green ammonia, green hydrogen, new synthetic fuels, power-to-X solutions (e.g., methanol), biomethane, etc. Primarily, the choice of fuel would mean that novel engine technologies will be needed to accommodate these choices, and secondly, traceable measurement systems are needed to support these developments to verify the system performance when put on the market. Therefore, support is needed to acquire knowledge and traceable measurements of in-cylinder dynamic processes to improve performance and reduce pollutants emissions from the power unit. The emissions should also be monitored and controlled through quantifiable methods, and the traceable temperature and species concentration measurements will allow the improvement of after-treatment technologies. The application of advances in artificial intelligence (AI) tools (e.g., machine learning approach) and modelling will contribute to optimise both products, the power unit, and after-treatment systems for any market launch.

### **Keywords**

Maritime shipping, pollutants emission control, engines, dynamic quantities, system metrology, green marine fuels, machine learning, performance optimisation

### **Background to the Metrological Challenges**

Maritime shipping contributes to transporting approximately 80 % of the trade volume around the world and 2 % -3 % of total greenhouse gas emissions. The International Maritime Organization (IMO) has set a target to reduce these emissions by at least 50 % by 2050 compared to the 2008 emissions. There are some other green initiatives such as the Fuel EU Maritime Initiative (by the EU within the “Fit for 55” package) to comply with the usage of renewable and alternate fuels (e.g., methanol, biomethane) with low-to-no carbon content. Using new renewable energy carriers would require new development of engine systems, and retrofitting existing power units but also after-treatment systems. Supporting services of metrological measurements and research deliverables are necessary to accelerate the deployment of sustainable fuels in the maritime sector.

The knowledge and measurement of thermo-chemical processes inside the engine and exhaust gas after-treatment systems will be critical to develop novel systems that can monitor and control the emissions from any sustainable fuels for future maritime shipping. Presently, the following is lacking and will be required a) online measurement of the reaction temperature at the surface of the selective catalytic reduction (SCR) unit; b) improvements in the dynamic surface temperature measurement capability up to 700 °C to monitor the SCR reactions; and c) traceability to a suite of emission components relevant to the renewable fuels such as NO<sub>2</sub>, NO, N<sub>2</sub>O (IMO MARPOL Regulation 13), NH<sub>3</sub>, CO, CO<sub>2</sub>, SO<sub>x</sub> (IMO MARPOL Regulation 14), particle mass fraction (IMO MARPOL Regulation 14) and particle number density.

Lowering the temperature of a catalytic process is a challenge to overcome when aiming for improved catalyst efficiency. Current state-of-art reactors mainly use multipoint thermocouples to monitor the temperature, which inadequately represents any local temperature offsets. Other non- or semi-invasive techniques, such as infrared and luminescence thermometry, have been suggested but lacks traceability. Currently, there are no direct temperature measurements on after-cleaning catalytic systems, which hinders adequate temperature control and potentially deteriorates performance. In practice, the only temperature probes are single-point thermocouples, before and after the reactors, which are prone to malfunction due to the harsh environment (e.g. high temperatures, erosion, and vibration). For monitoring of exhaust gases in maritime shipping, typically the rack-based gas analysers and Fourier Transform Infrared (FTIR) spectroscopic techniques are deployed

in current applications, where the deviation of the gas analysers is not more than  $\pm 2$  % from the nominal calibration point (alternately, 0.3 % of full scale).

The first steps to establish metrological traceability for dynamic pressure and temperature have been taken in the EMPIR 17IND07 DynPT project where calibration and measurement techniques and sensors were developed for measuring dynamic pressure and temperature in the range relevant for internal combustion engine applications, i.e., 5 MPa – 30 MPa and up to 2 500 °C. The reported measurement uncertainties for dynamic pressure and temperature were around 2 % and 5 %, respectively, which is insufficient considering the target uncertainty of 1 % in engines. Nevertheless, the measurement methods were developed for engines running on diesel and methane and the findings indicated that the combustion conditions, e.g., temperature and measuring media (combustion species), significantly influence the sensor response. Therefore, new techniques and further development of existing ones are necessary for measuring dynamic pressure and temperature in engines running on renewable fuels.

Measuring thermo-chemical processes inside the engine is vital to understanding its varying operating conditions. There is potential to improve the system control by deploying sensors that cope with demanding conditions of high pressure, temperature, and chemical reactivity. Accurate control of the energy conversion process inside the power unit requires dynamic pressure and temperature measurements at an accuracy level of 1 % at pressures of 5 MPa – 30 MPa and frequency up to 100 kHz, and temperatures up to 2 500 °C, which is not yet achieved with current calibration and measurement technologies. The power unit and the after-treatment systems can also be done by modelling and simulating them at relevant conditions. Primarily this is done through fundamental measurements of various parameters on oxidation and developing chemical kinetic models to simulate the fuel behaviour. Recently, the application of predictive models using a machine learning approach which vastly reduces the computational effect of the simulations and reduces the design iteration periods has been also suggested.

No existing metrological infrastructure is available for renewable fuels as most of them are mainly based on conventional fuels used in the maritime sector. The need for further development of metrological infrastructure has been recognized in previous projects (EMPIR 17IND07 DynPT, 16ENV02 Black Carbon, 19ENG09 BIOFMET, 19ENV09 MetroPEMS, and 16ENG09 LNG III) and EMNs (Energy Gases, Climate and Ocean Observation and Mathematics and Statistics). Furthermore, the research and innovation proposed here will enable manufacturers to develop new sensors on solid grounds. The ability to measure temperature traceably in chemical reactions and to distinguish competing exothermic and endothermic reactions will enable catalyst developers and manufacturer to develop novel catalytic materials for a range of applications that conforms to the goals of the European Green Deal agenda, e.g., for improved carbon capture, production of power-to-X-fuels and improved hydrogen fuel cell efficiency.

## Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable measurement and characterisation of pollutants emission control for green maritime shipping.

The specific objectives are

1. To develop traceable emission measurement methods for dynamic quantities of typical emissions, e.g., NO<sub>2</sub>, NO, N<sub>2</sub>O, NH<sub>3</sub>, CO, CO<sub>2</sub>, SO<sub>2</sub>, particle mass fraction (PM), black carbon, and particle number density (PN). The methods will be applied for dynamic emission measurements and to identify and quantify the sources of measurement uncertainty.
2. To develop traceable calibration measurement methods and standards for dynamic quantities (i.e., in-cylinder pressure and gas temperature) to assess and optimise the quality and efficiency of the energy conversion processes using renewable fuels. Traceability will be established for pressure (up to 30 MPa) and temperature (up to e.g., 2 500 °C) with a target uncertainty level of 1 % and a bandwidth of 100 kHz.
3. To optimise the marine engine efficiency and reduction of emissions by developing predictive models using chemical kinetic mechanisms and machine learning algorithms. The emission control (objective 1) and dynamic measurements (objective 2) will improve the performance of the developed models and the models will be validated against the demonstration power unit and refined through iterations.

4. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e.g. accredited laboratories, instrument manufacturers), standards developing organisations (e.g. IMO, CEN/CENELEC), end users (e.g. marine, power and aviation industries) and via the EMNs (such as Energy Gases, Pollution Monitoring, Climate and Ocean Observation, and Mathematics and Statistics).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMPIR projects 17IND07 DynPT, 16ENV02 Black Carbon, 19ENG09 BIOFMET, 19ENV09 MetroPEMS, and 16ENG09 LNG III and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

## Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the 'end user' community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the marine, power and aviation sector.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of the Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

## Time-scale

The project should be of up to 3 years duration.