Clean Propulsion Technologies

a Finnish response to tightening emission legislation in marine and off-road segments

Maciej Mikulski

Professor (ICE Technology) University of Vaasa

CPT Consortium Leader, WP3 Technical Lead

Funded by BUSINESS FINLAND

Clean Propulsion Technologies

Vaasan yliopisto
UNIVERSITY OF VAASA

Clean Propulsion Technologies

to secure global technology leader position for the Finnish powertrain industry by creating common vision and sustainable business solutions.

Powertrain development in Finland

Finland 1#

in the EU in the quality of export products; European Commission

Finland 7#

in innovation capabilities and results; Global Innovation Index

Finland 9#

in Cleantech; Global Cleantech innovations

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Powertrain development in Finland

Proventia

Leading exhaust system integrator for NRMM market

Dinex

Expert in catalytic aftertreatments systems since 1980s

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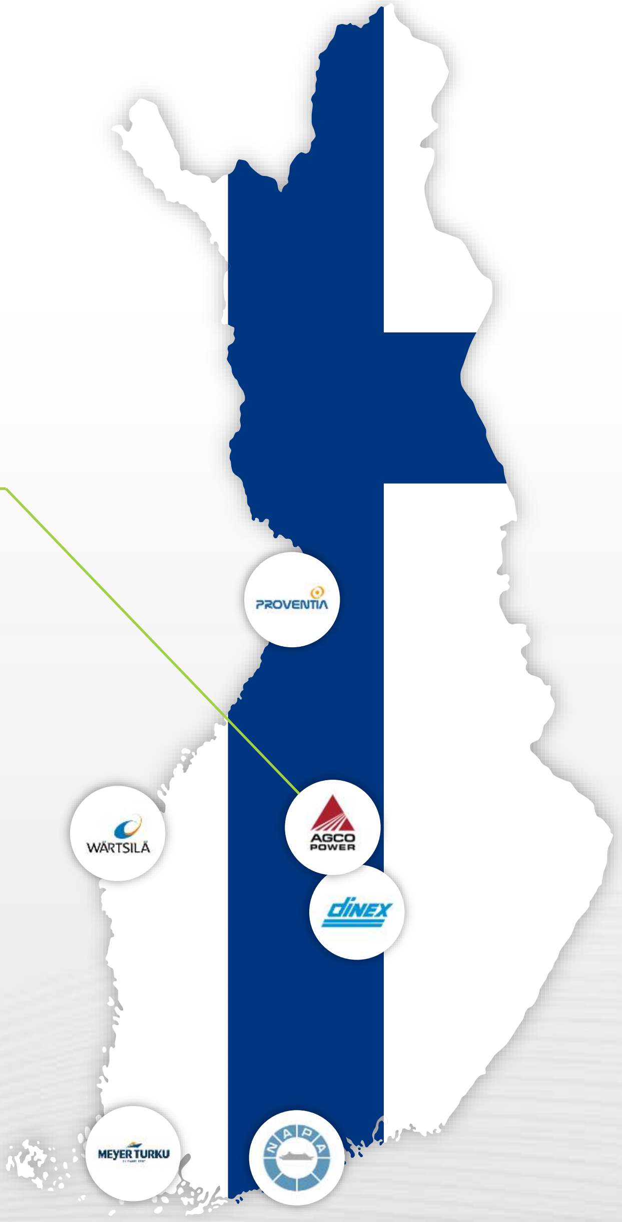
Powertrain development in Finland

AGCO Power

Clean and dependable power for working machines with 80 years of experience



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Powertrain development in Finland

Wärtsilä

Global leader in smart technologies and complete lifecycle solutions for the marine and energy markets

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Powertrain development in Finland

NAPA

95 % of newbuilds yearly built by NAPA customers

Meyer Turku

One of the market leaders in future-extrapolated cruise ships and other floating solutions

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Premise

Drivers

- High energy density required for marine transport and agricultural machinery
- GHG Reduction targets 2030/2050
- GHG Sulphur Cap 2020
- Tightening Emission Norms 2016–2030

Challenges for marine & off-road

- CO_2, CH_4, N_2O, Black Carbon reduction
- Diversifies the fuel market
- Euro Stage V→VI
- China II
- Zero-emissivity for urban areas

Challenges for Finnish industry

Transition is happening in shipping and off-road sectors!!!

Will affect the whole value chain + energy suppliers + land infrastructure + policy

There is no clear roapmap on how to stisfy all the challenges simultaneously on long term!!!

Look at the dates!!!

Already Short term solutions are required that simultaneously:

- **Promote fuel flexibility**
- **Reduce emissions** (GHG + PM + NO_x)

If we do not provide, Finland loses the frontrunner position in powertrain solu-tions

- The Goal of CPT is realized :
  - On a short term, by moving the most promising innovative (TRL3) powertrain technologies to TRL5-6.
  - On a long term, by maturing the common technological roadmap for the join marine and off-road sector

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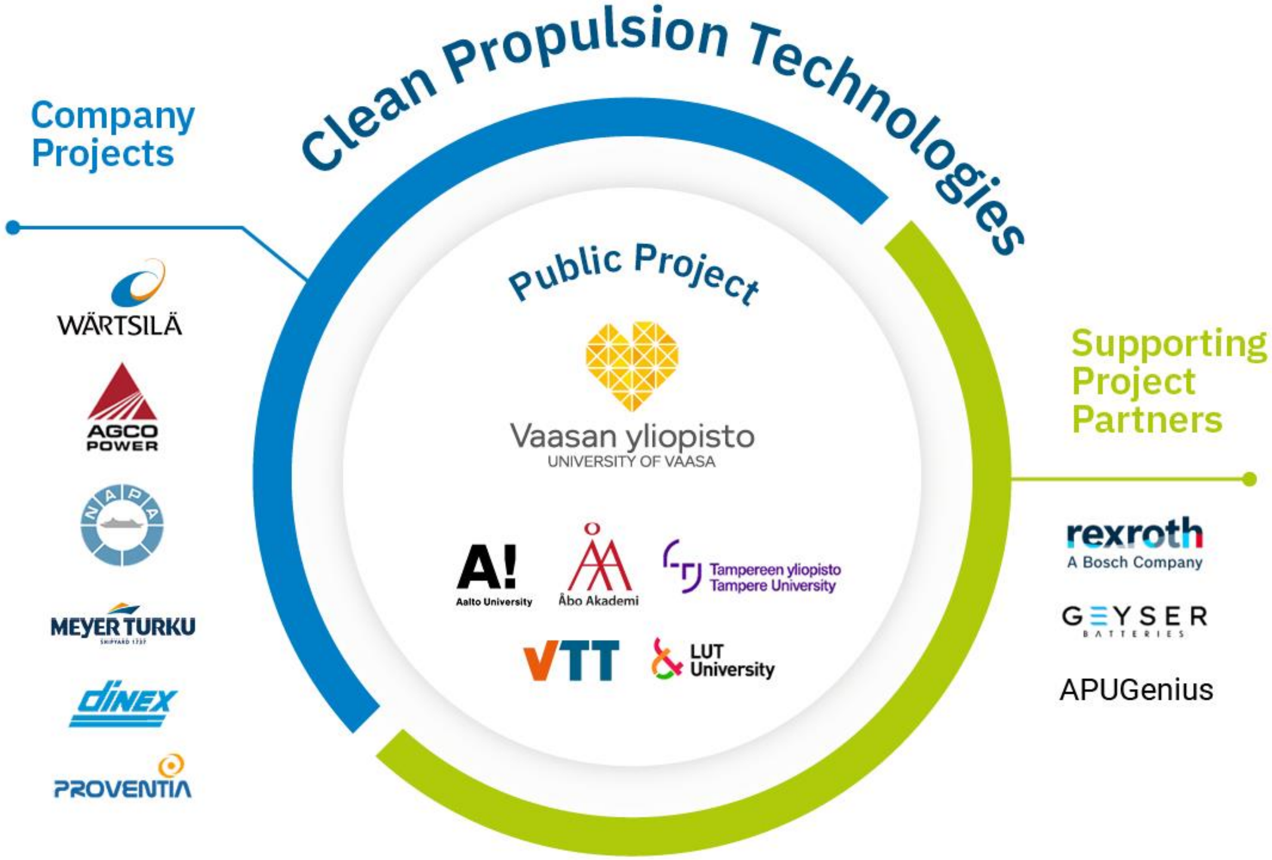
Clean Propulsion Technologies in numbers



15 Consortium Partners

6 Work Packages

Project timeline: 2021-2023

Total budget

15,1M €

- Public research project
- Industrial projects

INTERNATIONAL COLLABORATORS

National Technical University of Athens · INNAS · UNIVERSITY OF AGDER

ADVISORY BOARD

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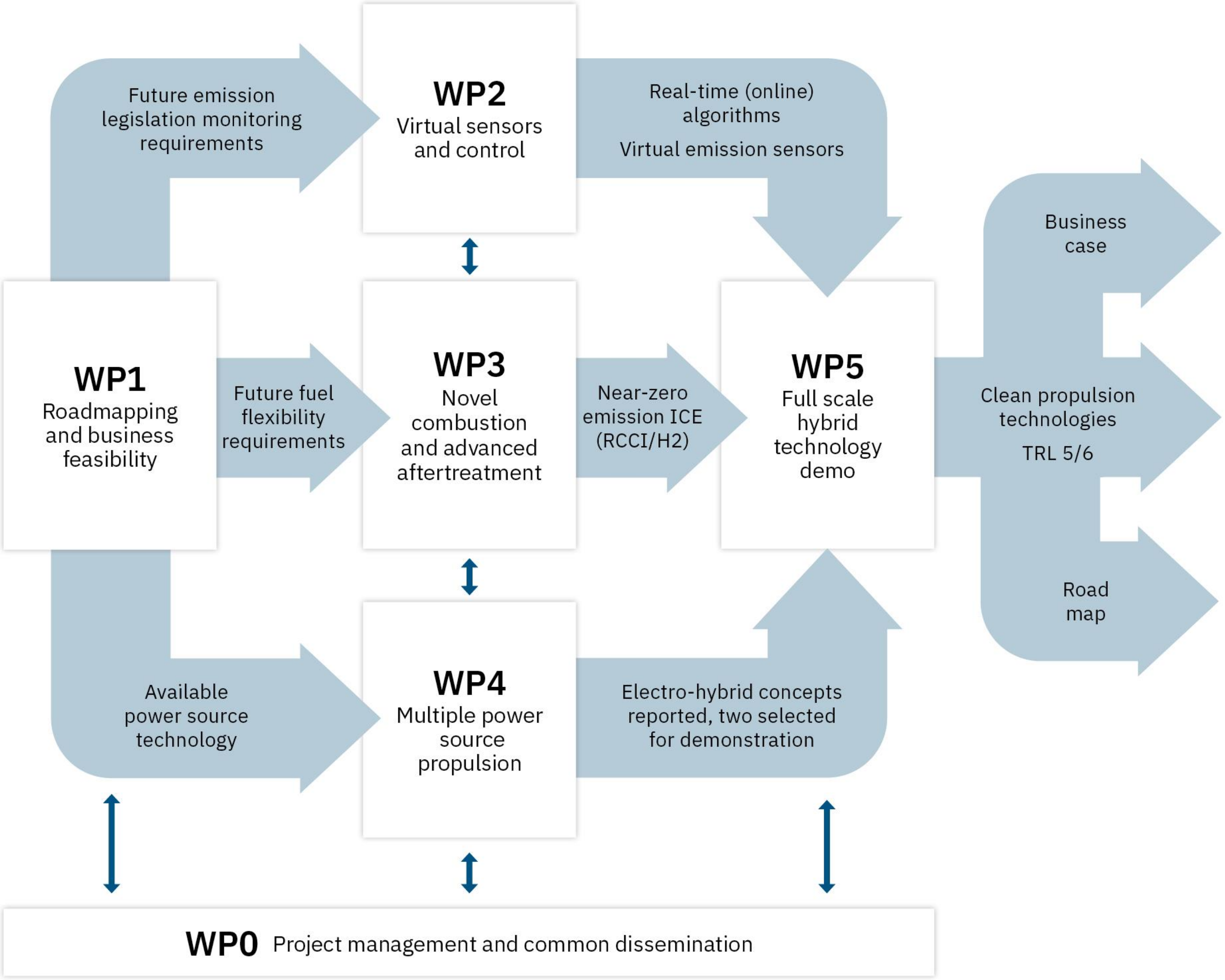
Way of working and high level objectives



- **Objective 1**: Establish a Technology Roadmap to direct current and future R&D efforts within a sustainable propulsion ecosystem.
- **Objective 2**: Develop new intelligent machine learning algorithms for virtual sensors, digital twins and control design of new combustion technologies.
- **Objective 3:** By combined engine/aftertreatment measures demonstrate min 30% GHG reduction with ultra-low NOx and PM emissions
- **Objective 4**: Design and implement an optimal control architecture for a hybrid system accounting for characteristics of different energy/power sources (GHG -20%)
- **Objective 5**: Build hybrid full-scale demonstrators of propulsion systems, show their functionality and preliminary performance and verify multi-engine and energy consumer models.

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WP1
Roadmapping and business feasibility

Magnus Hellström, Åbo Academy

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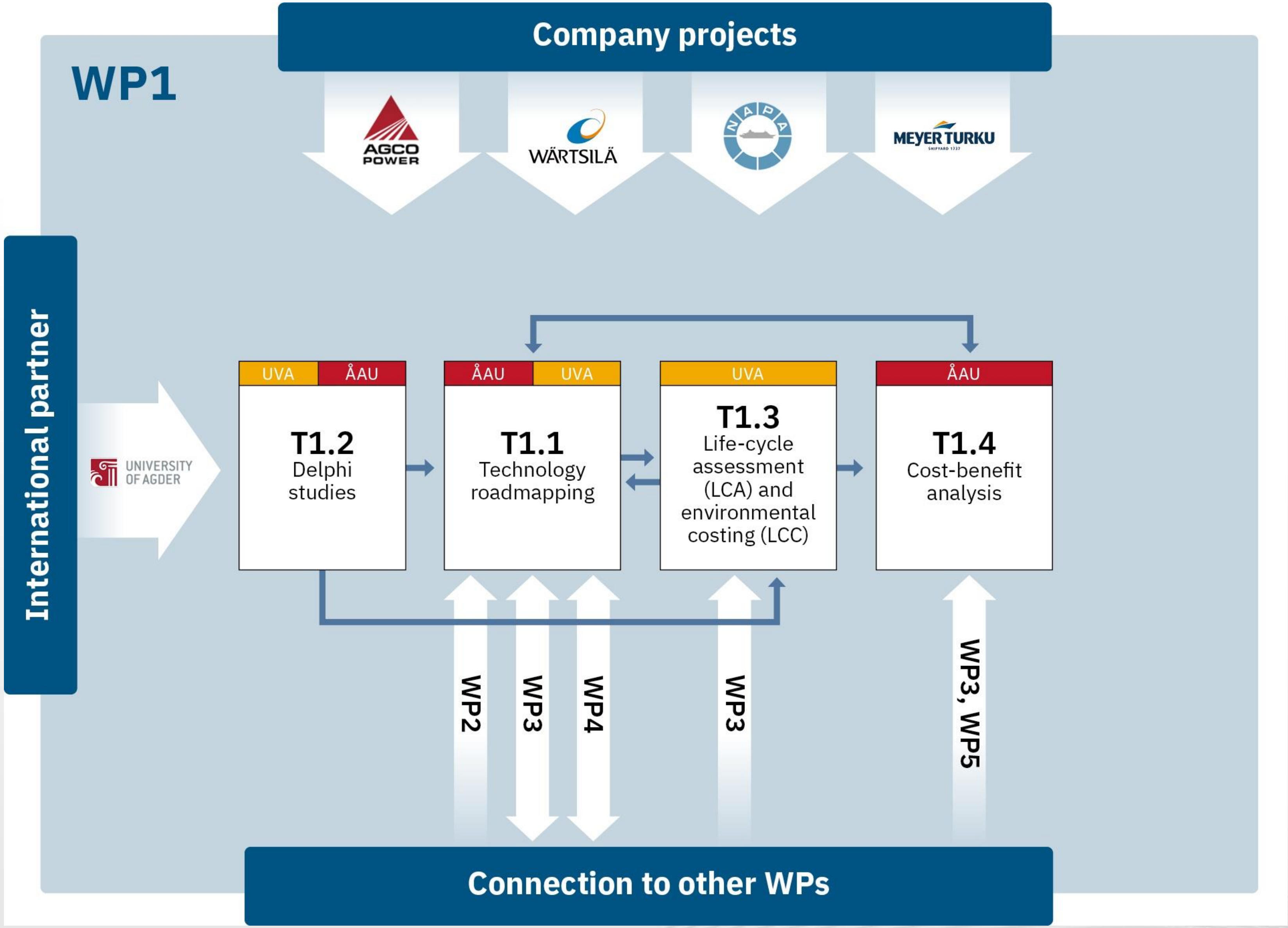

WP1 Scope

1) Define and narrow down the market needs driving the call for clean propulsion.
2) Build a vision for needed products and services to meet the market drivers.
3) Jointly define and narrow down the list of enabling technologies for developing the needed products and services.
4) Establish Technology Roadmap and R&D direction for a sustainable propulsion ecosystem.

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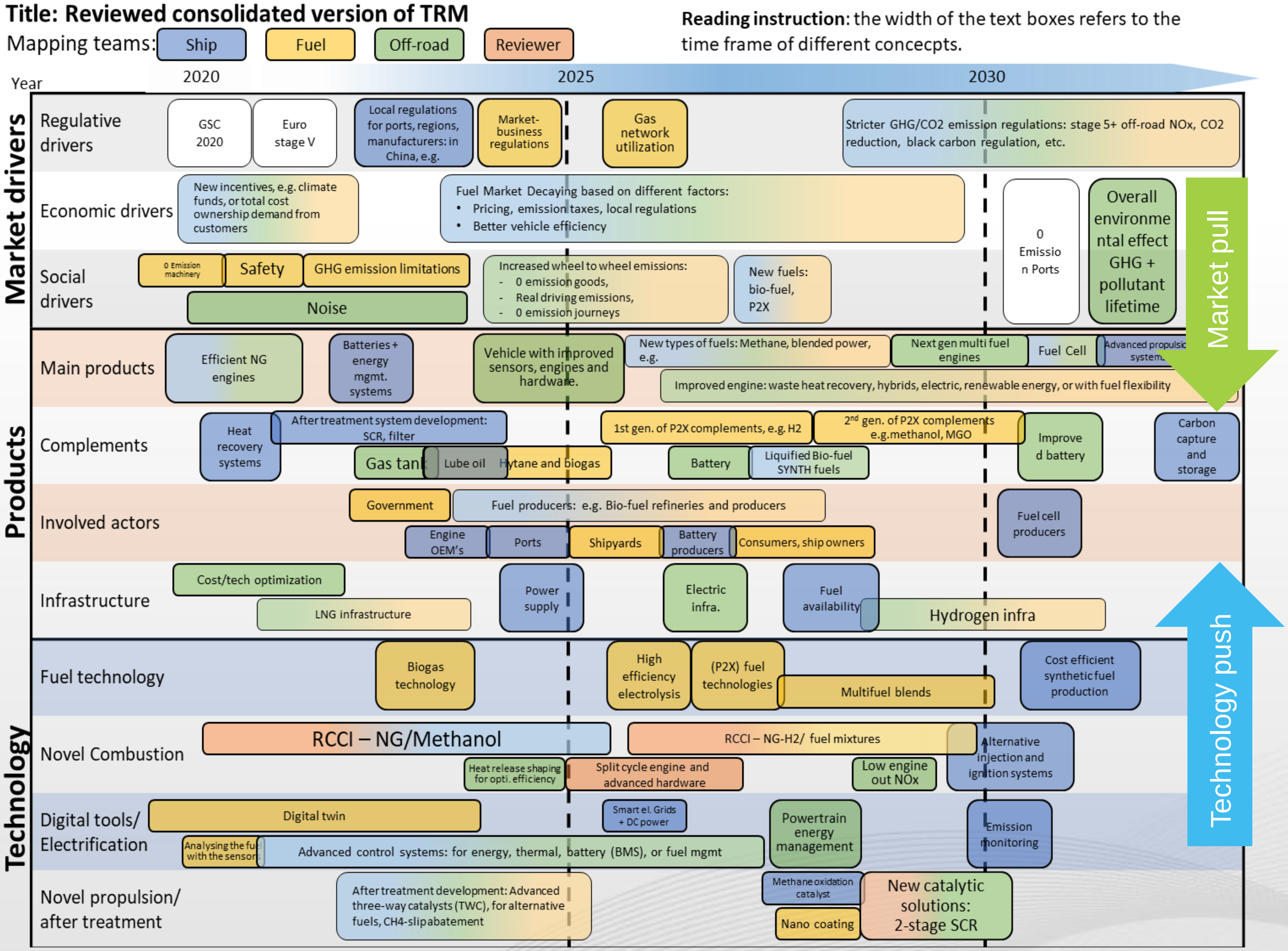

Highlights

- The 1st version of the common roadmap is already there.
- Vision Paper "*A New look on maritime propulsion roadmap – Exploring co-development with the off-road sector*"; will be presented in 2022.

CIMAC CONGRESS 22
BUSAN, JUNE 13 –17, 2022

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WP2
Virtual sensors and Control

Kai Zenger, Aalto University

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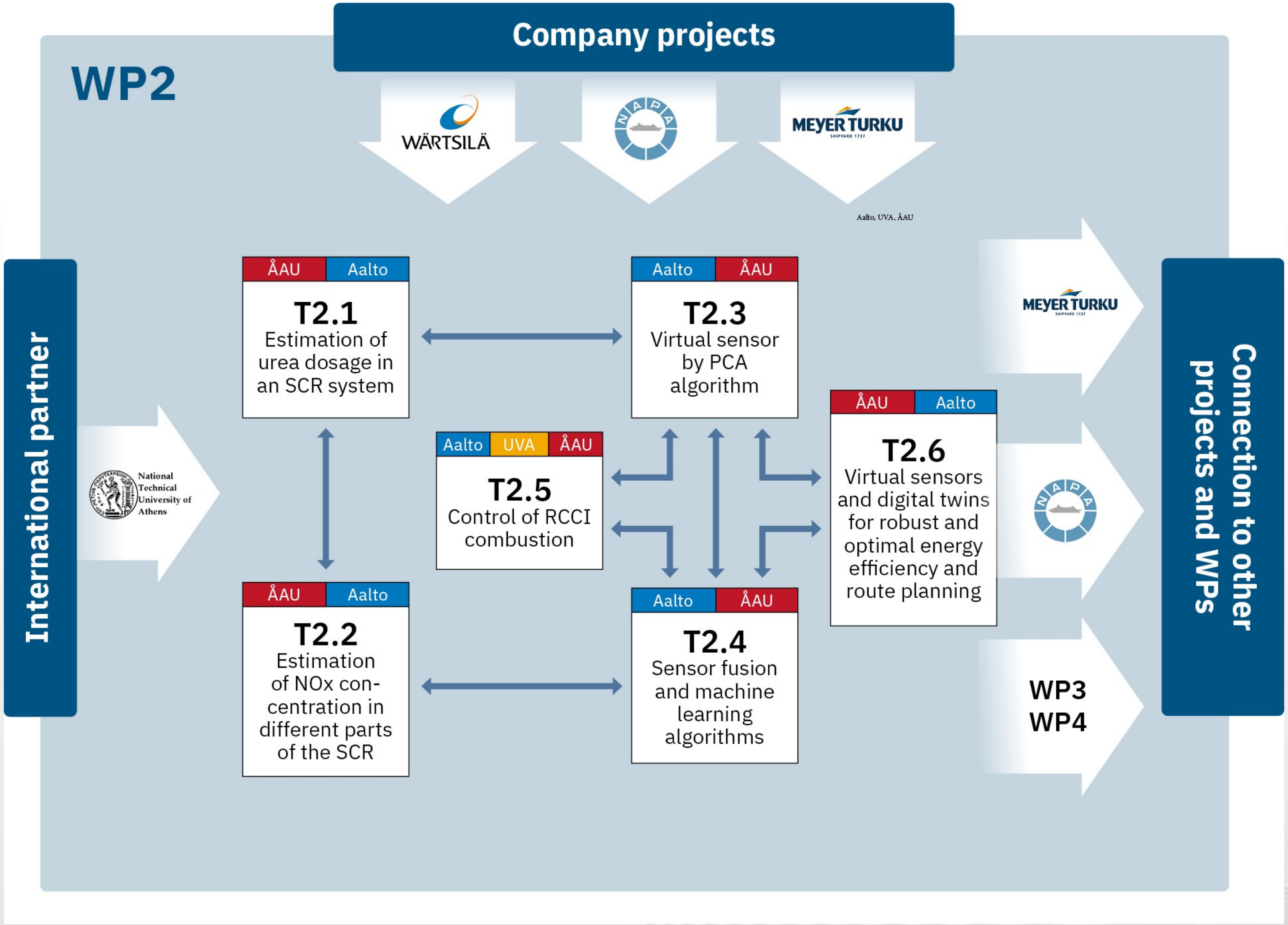


WP2 Scope

1) Real-time NOx estimation for small flow rates correction of SCR system.
2) virtual sensing and the related algorithms in soft sensors and sensor fusion
3) optimal controllers for multi-injection in RCCI
4) route planning algorithms in operation conditions with large uncertainties

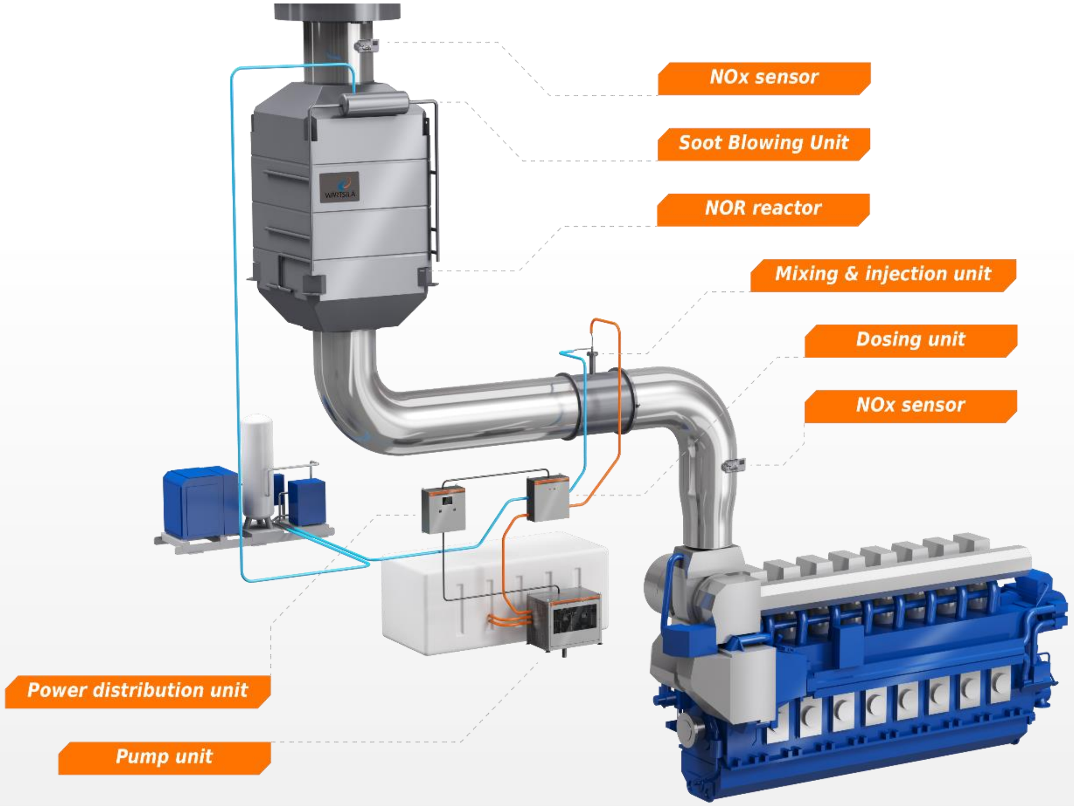
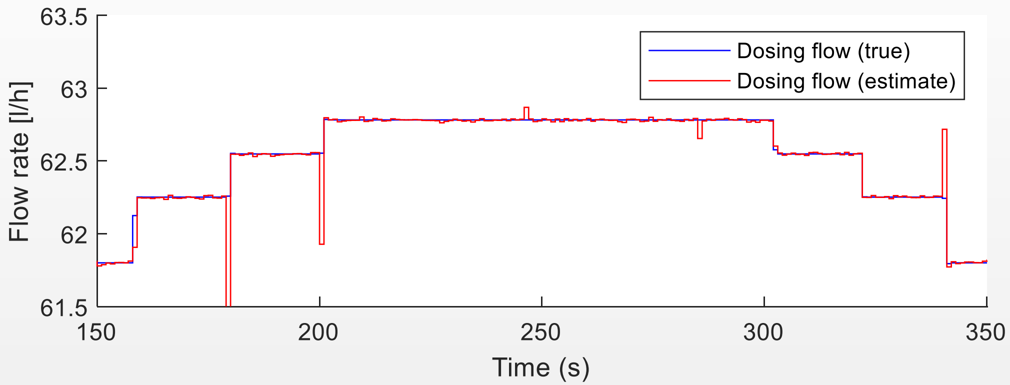
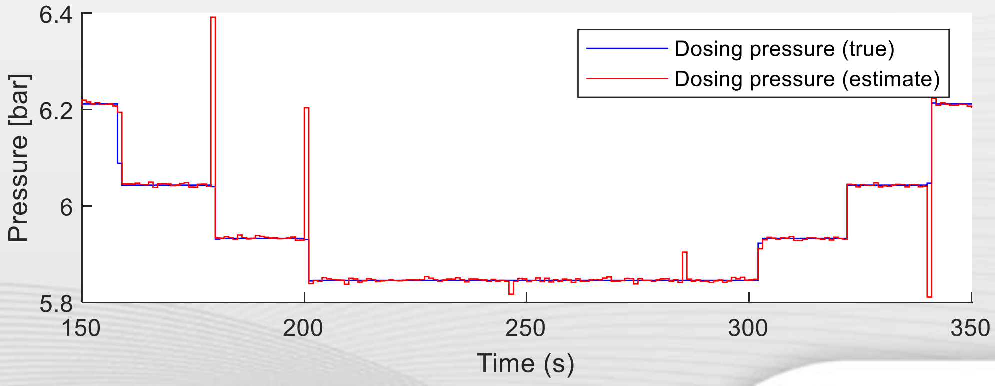


Image courtesy of Wärtsilä

Highlights

T2.1 – Delivered! : Virtual sensor for ammonia dosing pressure and flow rate control





Problem

- Flow-rate measurements are inaccurate at low flow rates.
- The position of control valves are uncertain
  - Backlash, hysteresis etc.
  - Valve failure not detected

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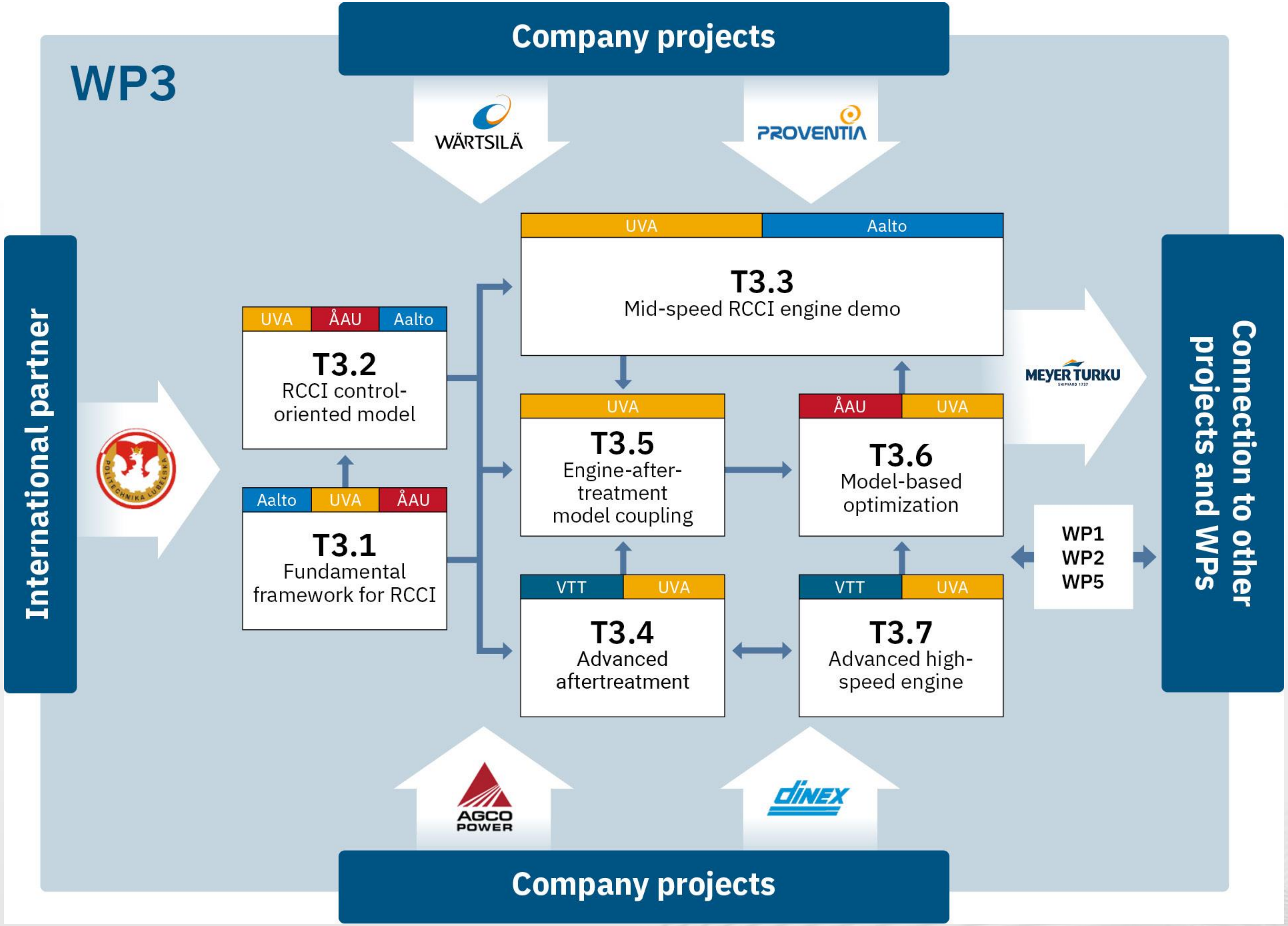
WP3
Novel combustion and advanced aftertreatment

Maciej Mikulski, University of Vaasa



WP3 Scope

1) Complete model-based design methodology used for the first time for powertrain development.
2) LNG/diesel RCCI demonstrated on a mid-speed engine across full operating envelope (TRL 5)
3) Advanced high-speed engine concepts developed; including H2 fueling (TRL 5)
4) Advanced aftertreatment systems developed for high and medium-speed engines (TRL 6)

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RCCI Control development in WP3 and WP2

T2.5
RCCI Closed-Loop Combustion Control Development

T2.5 Reduction mechanisms towards real time application

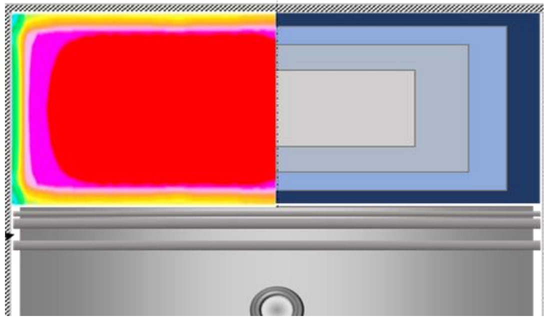
Aalto | ÅAU | UVA

WP2
Virtual sensors and control development

T3.3 HIL demonstration and validation

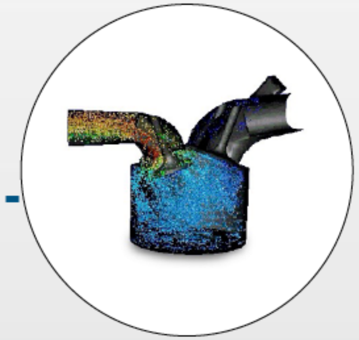
Computational Fluid Dynamics (CFD)
Time: Around 30 hours for single parallel simulation

Multi-Zone Model (MZM)
Time: <30 minutes for single, serial simulation (<10% error relative to CFD)



UVA | Aalto | ÅAU

WP3
Novel combustion and advanced EAT



RT Target Platform and in-cylinder pressure in all cyl.

T2.5 Physics-based combustion model for Low temperature combustion concepts (DF RCCI)

T3.3 State of the art Dual-Fuel Platform realizing Low Temperature RCCI

... to calibration loop

T3.1
Detail 3D-CFD Simulations and optical engine studies

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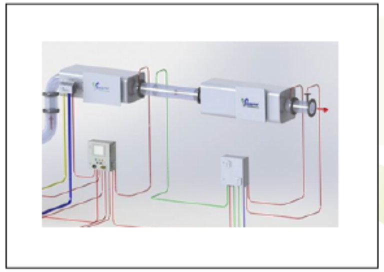
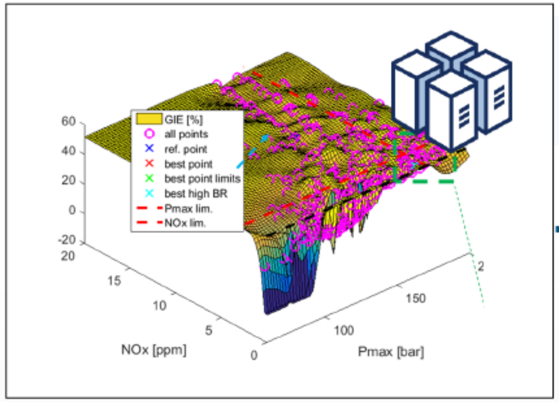
RCCI model-based calibration in WP3



T3.4 Advanced after-treatment

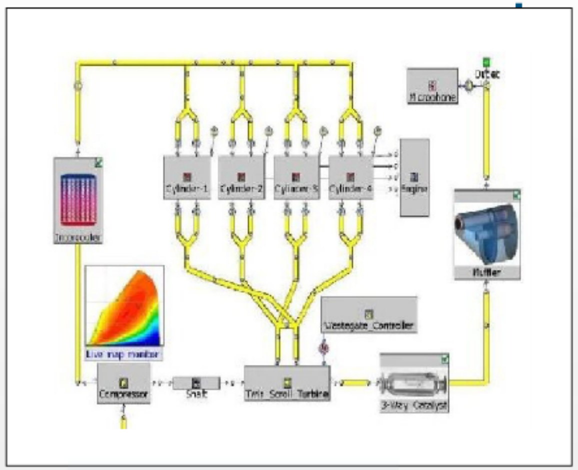


T3.6 Multi-objective optimization & super-computer simulations

T3.3 Validation of optimal parameters and outlook on RCCI with aftertreatment

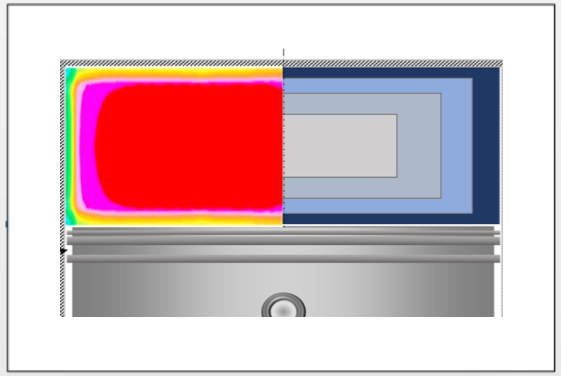
UVA	Aalto	ÅAU

WP3
Novel combustion and advanced EAT



T3.5
1D Engine/ Aftertreatment model

T3.3
State of the art Dual-Fuel Platform realizing Low Temperature RCCI



T3.2
Physics-based RCCI combustion model

... to development loop

... from CFD/Optical engine studies

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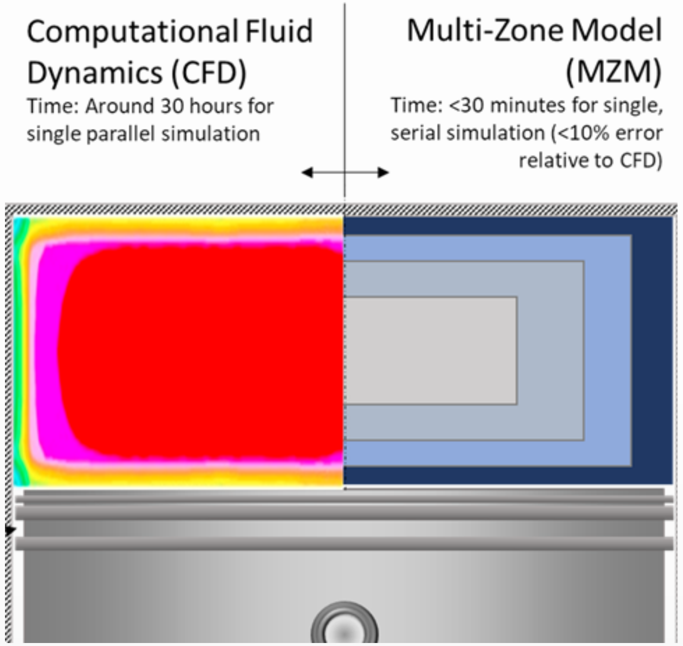
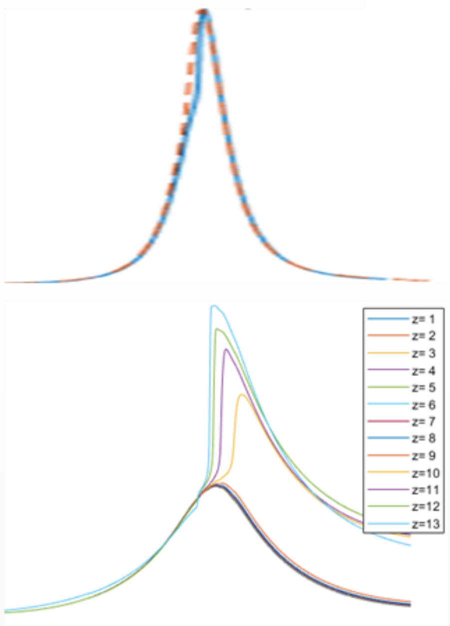




T3.2 RCCI control oriented-model vs CFD;

L. Ideological outline;

R. initial results:

Top. In-cylinder pressure (MZM vs RCCI Experiment);

Bottom. Simulated in-cylinder temperature by zone number;

Highlights

Engine Modeling Packages

- T3.2 Results; Submitted to:

Progress in Energy and Combustion Science

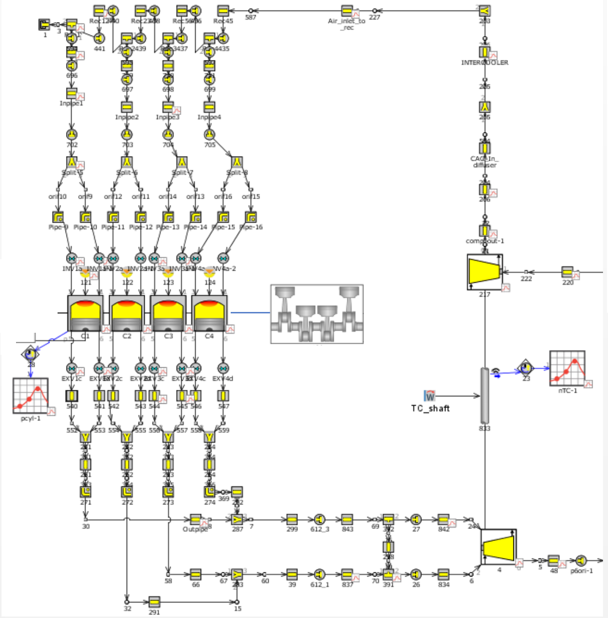
An International Review Journal

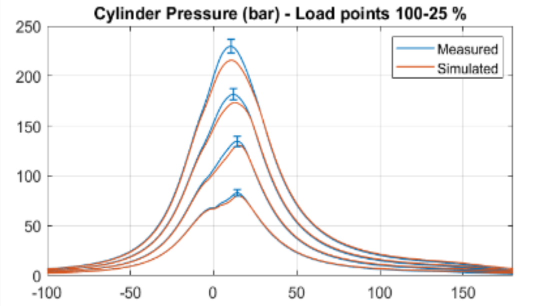
ⓘ Impact Factor

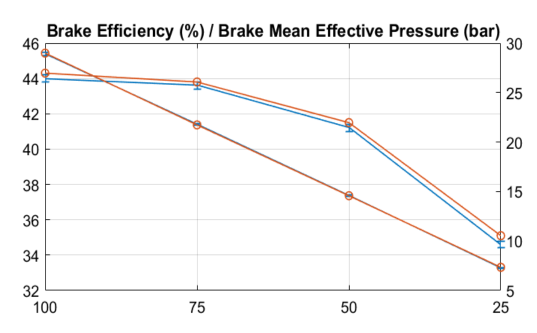
29.394

Thermo-kinetic multi-zone modelling of low temperature combustion engines

ISSN: 0360-1285







T3.5

L. Detail GT–Suite model of the test engine before the retrofit

R. Selected Validation results;

- T3.5 Results; Submitted to:

9th INTERNATIONAL CONGRESS ON COMBUSTION ENGINES

POLISH SCIENTIFIC SOCIETY OF COMBUSTION ENGINES

27th – 28th September 2021 Lublin, POLAND

PTNSS-2021-xxx

Towards a digital twin of a mid-speed marine engine: from detailed 1D engine model to real-time implementation on a target platform

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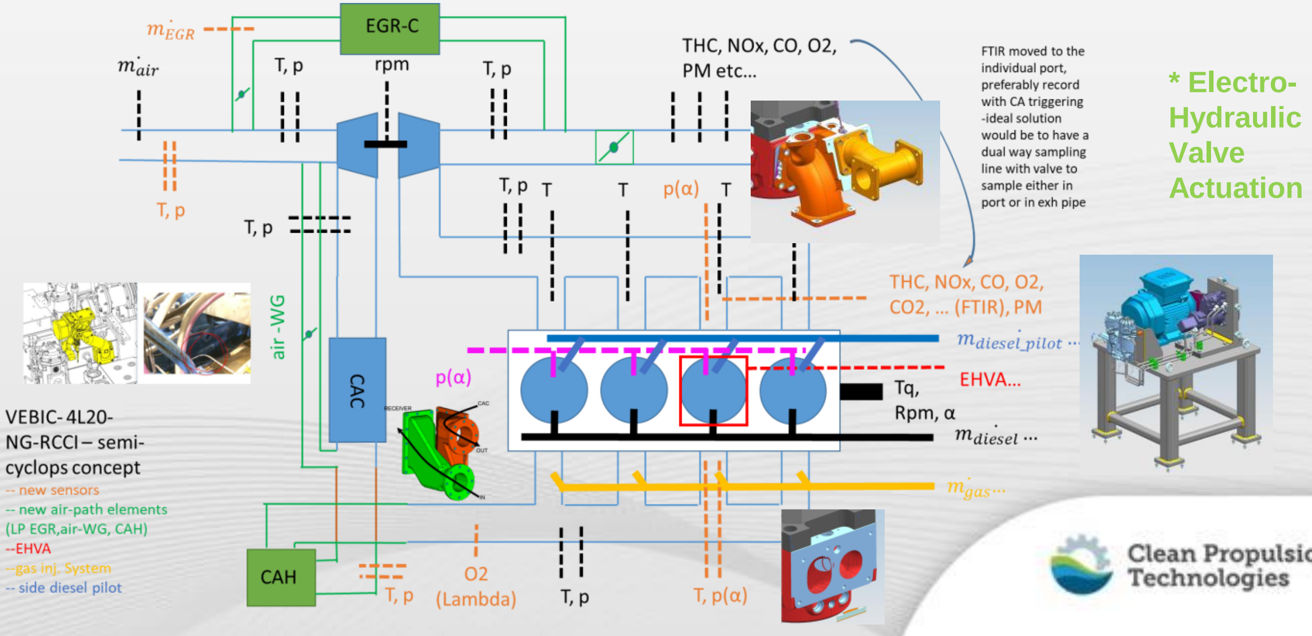
Highlights

RCCI Hardware Platform

- **Stage 1 –** gas/diesel RCCI Cyclops
  - LNG (bulk) + multi-stream gas-phase enrichment
  - Cyl_4 converted to DF with separate gas/diesel control
  - Boost via independent load control of Cyl_1-3;
  - Thermal Management / iEGR via EHVA*
  - Fast! intake/exhaust port pressure measurement
  - Fast! exhaust emission sampling system
  - FTIR! for detail exhaust composition

- **Stage 2** - Full RCCI Retrofit – based on model-based design;



WP4
Multiple power source propulsion

Kalevi Huhtala, Tampere University

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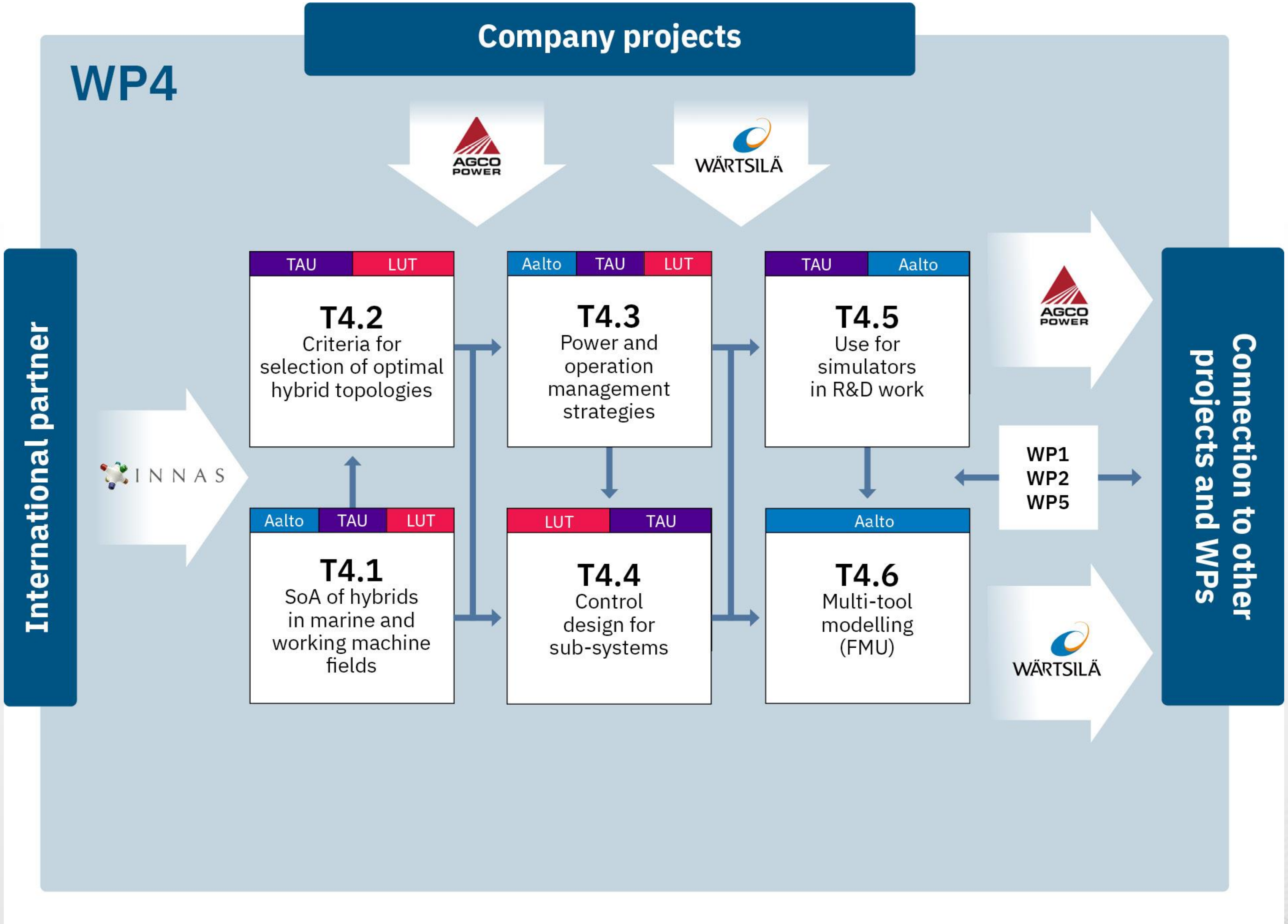

Scope

1) Model-based system engineering (MBSE), methodology for powertrain hybridization
2) Demonstrator – diesel-electric-hydraulic wheel-loader.
3) Integrated power-management system and advanced control

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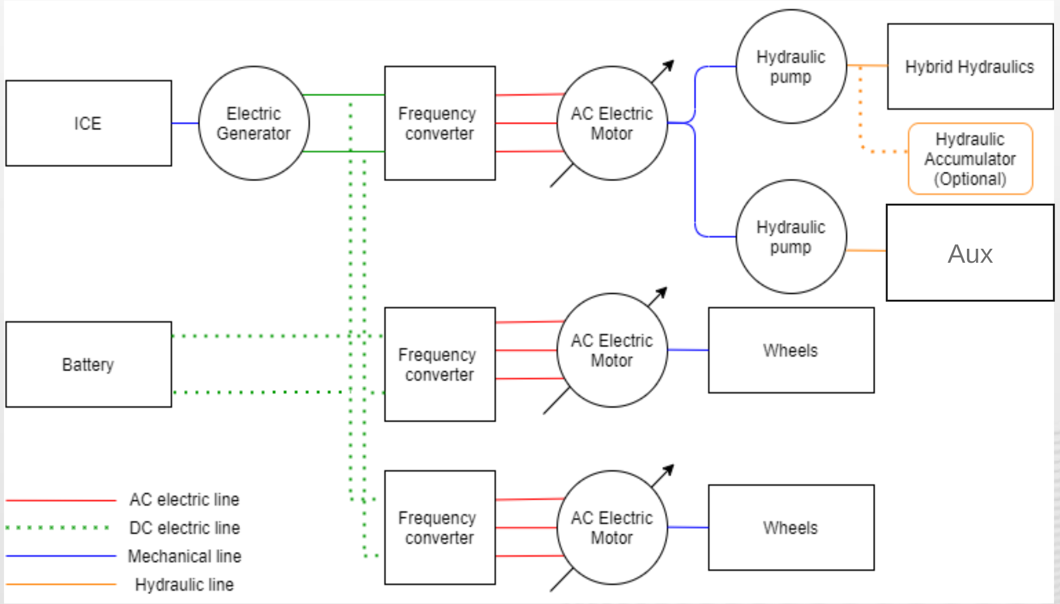
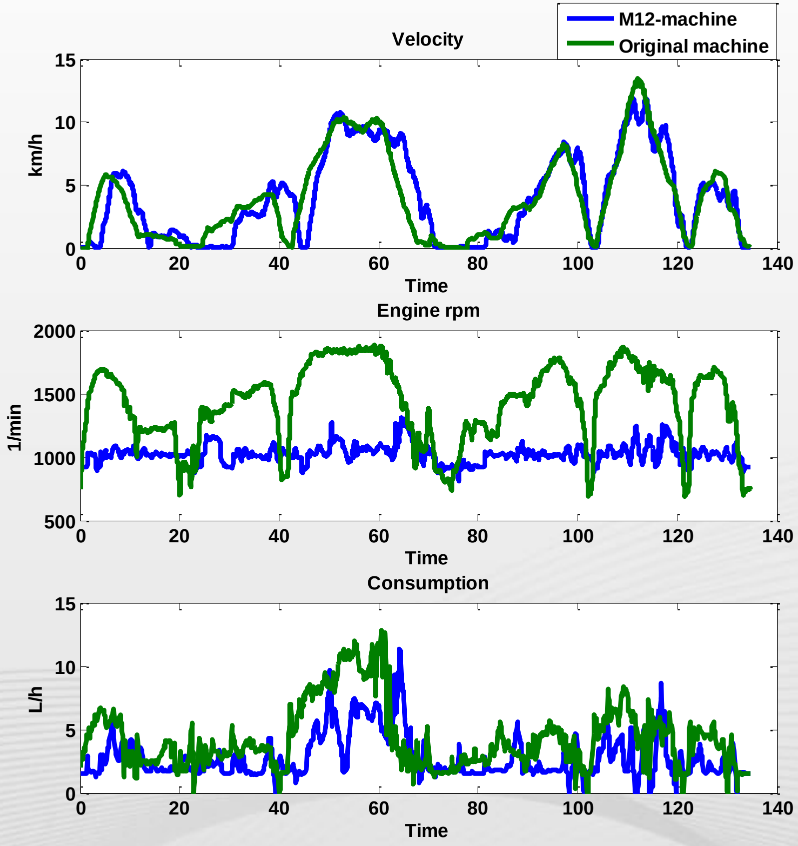


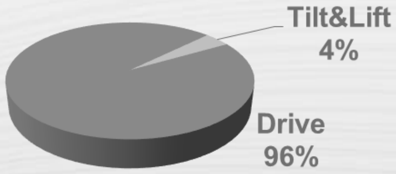
Highlights

- Review of State of the art concluded
- Stage 1# serial hybrid build for model validation!
- Operational Profiles examined



- Work cycle 135 s
- Load weight 1500 kg
- Consumption
  - Original machine 0,162 L
  - M12-machine 0,104 L

→ Fuel saving 36%



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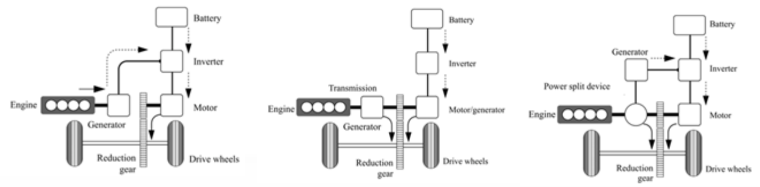
Highlights - Analysing/sizing different hybrid solutions



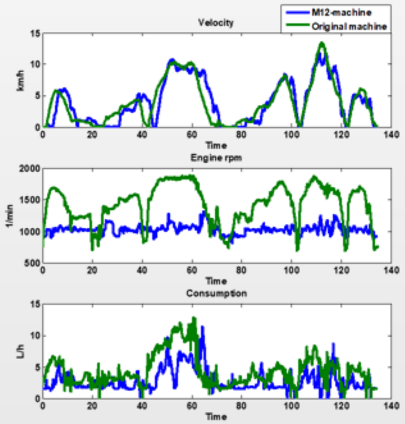
Conventional wheel-loader and stage#1 hybrid
Loading profile / Work cycle data

Actuator 1: *F, v*

Actuator 2: *F, v*

Analysing tool
- Models of different hybrid topologies
- Different power management strategies

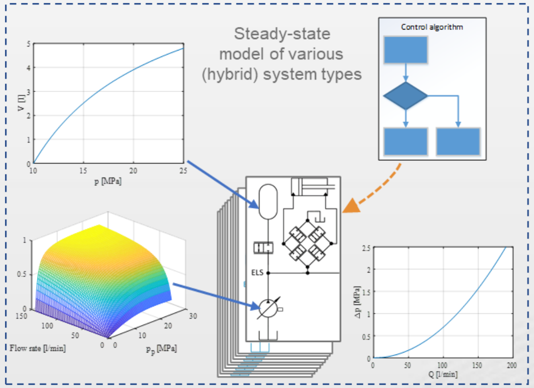
Results
- Requirements for diesel engine, electric motor, batteries, …
- Comparison different topologies and power managements by means of e.g. energy consumption



Powertrain topology

Technology and sizing

Integrated energy management strategy



Features of series, parallel, and series-parallel HEVs.

Powertrain	Advantages	Disadvantages
Series	• Optimised efficient traction driveline (engine downsizing) • Modular power plant possibilities (space packaging advantages) • Long operational life • Excellent transient response • Zero emission operation possible	• Larger traction drive system • Multiple energy conversions
	Application: Larger vehicles such as heavy-duty buses, trucks and locomotives.	
Parallel	• Economic gain at high cost • Zero emission operation possible	• High voltages needed for efficiency • Complex space packaging
	Application: urban passenger cars.	
Series-parallel	• Zero emission operation possible	• Very expensive system • Control complexity • Complex space packaging
	Application: passenger cars, light duty vehicles.	

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WP5
Full scale hybrid technology demo

Seppo Niemi, University of Vaasa

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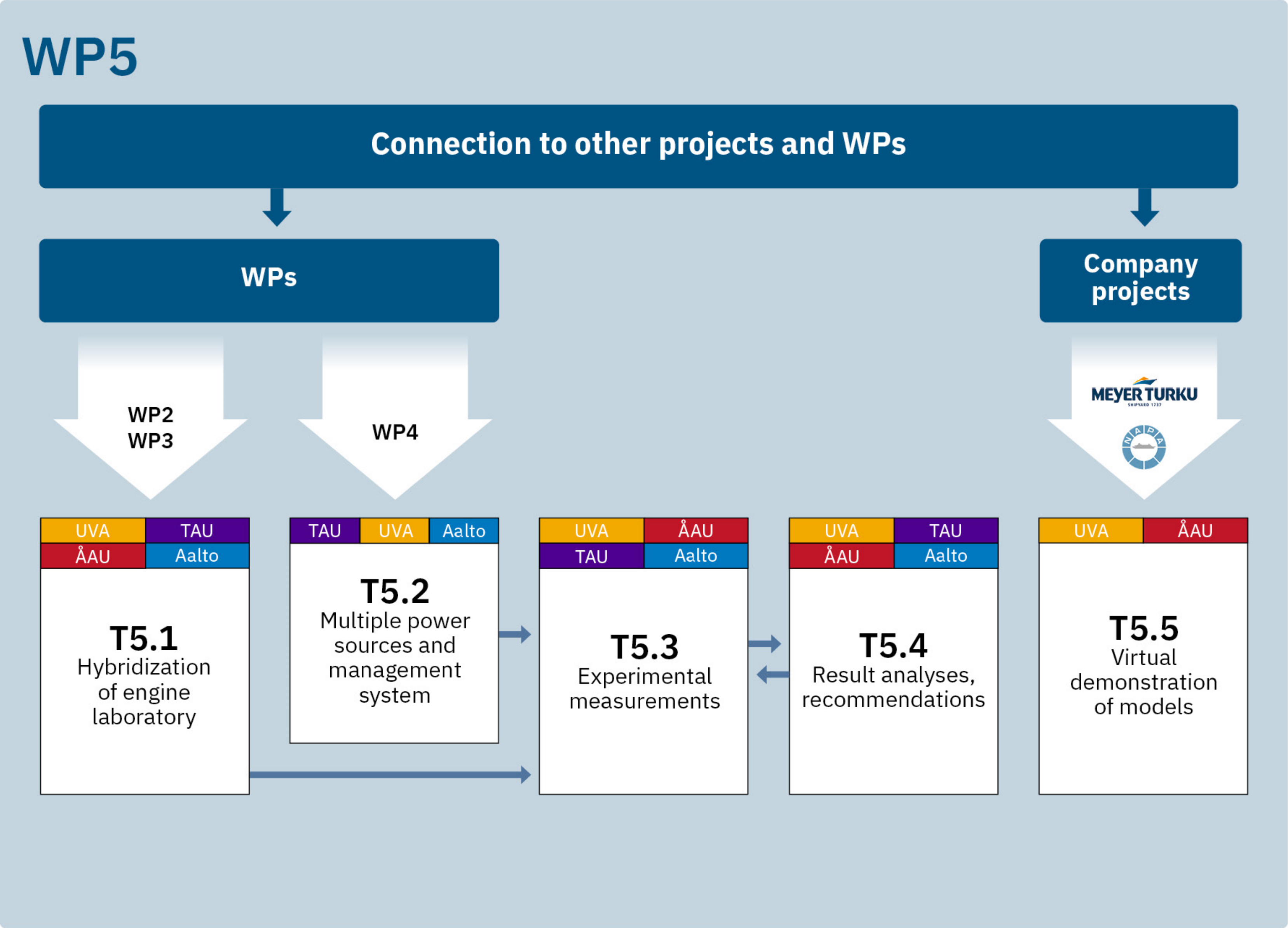


Scope

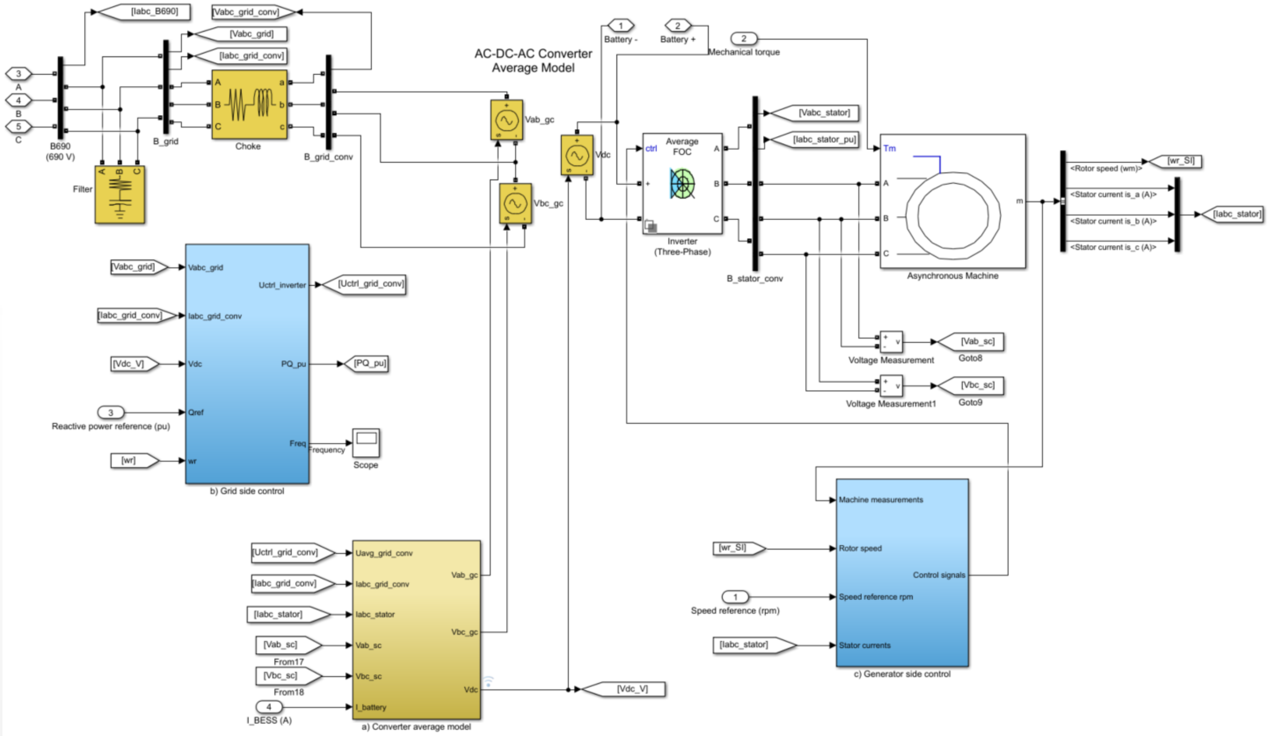
1) Full-scale hybrid energy generation plant with Battery Storage and advanced combustion (WP3)
2) Experimental Benchmarking of Hybrid Wheel-Loader (WP4) and hybrid power plant (T5.1) against state of the art conventional variants.
3) Feasibility of Clean Propulsion Technologies in Vessel-level simulation

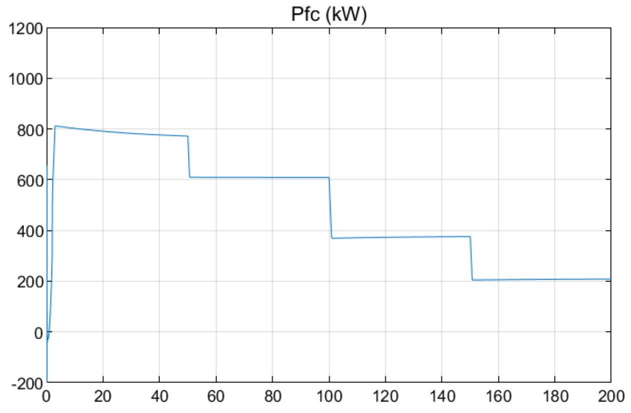
Highlights

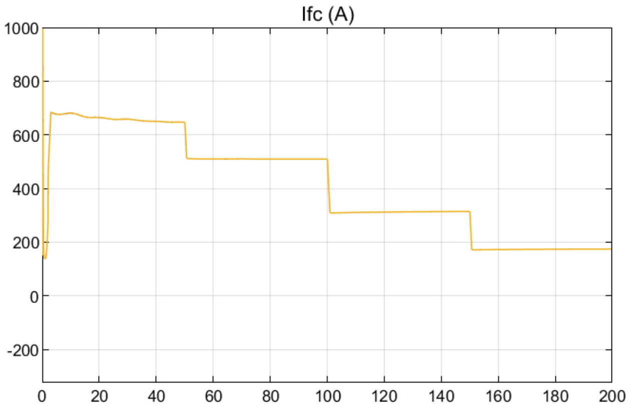
- T5.1 Simulation results submitted to:

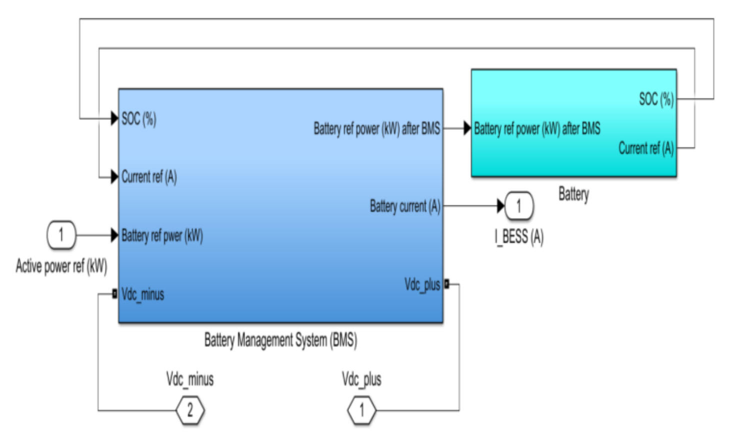
Energy
The International Journal
Impact Factor
7.147

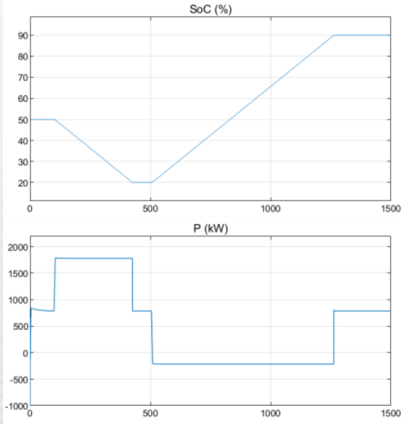
Towards a real-time capable digital twin of a combustion engine-based power-plant with battery storage and grid coupling











T5.1

Left - Generator, Frequency converter and grid coupling circuit and including results after coupling with a physics-based engine model towards complete powerplant representation;

Right – Battery Storage model with BMS; and combined power output in the same test run. management

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Thank you for your attention

Visit us at:

www.CleanPropulsion.org

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