SMART MARITIME

sfi = Centre for Research-based Innovation

The Research Council of Norway

NORWEGIAN CENTRE FOR IMPROVED ENERGY EFFICIENCY AND REDUCED HARMFUL EMISSIONS FROM SHIP

ANNUAL REPORT 2020

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Cover picture: Building of BTG Ulrikken, JMU, Maizuru. Photo: Kristian Gerhard Jebsen Skipsrederi.

SMART MARITIME

SUMMARY

Sea of Heaven, Grieg Star. Photo: Reanmer Baldoza

ABOUT SFI SMART MARITIME

SFI Smart Maritime is a centre for research-based innovation dedicated to improving energy efficiency and reducing harmful emissions from ships. With particular attention to the Norwegian Maritime Industry, our mission is to provide our partners with technologies, tools and capabilities for effective identification, assessment and verification of performance optimization solutions.

Research activity is conducted in collaboration between SINTEF Ocean, NTNU and the Centre's 21 partners representing the entire maritime value chain: ABB, Bergen Engines, DNV GL, Jotun, Kongsberg Maritime, HAV Design AS, Norwegian Electric Systems, SIEMENS, Vard Design, Wärtsilä Mosst, the Norwegian Shipowner association, the Norwegian Coastal Shipowners Association, the Norwegian Maritime Authority, and 8 major Norwegian ship owners; Wallenius Wilhelmsen, Solvang, Grieg Star, Kristian Gerhard Jebsen Skipsrederi, BW Gas, Höegh Autoliners, Odfjell, and Torvald Klaveness.

The strength of the Centre is our network and the constructive dialog between our research community and industry partners. Smart Maritime has positioned as an attractive meeting place and platform for cooperation within energy efficient and environment-friendly shipping.

Since its establishment in 2015, the Centre har worked with pushing the state-of-the-art in each research discipline, provided insight on potential emission reduction from ships, tested out novel technology solutions, developed prediction models for hydrodynamics and power systems simulation, simulation tools for performance evaluation and benchmarking of designs on a full ship system level.

There is no doubt about the Norwegian Maritime Cluster's dedication to reduce GHG emissions from shipping and achieve IMO Goals, as testifies the number of spin-off research and innovation activities from the SFI Smart Maritime collaboration.

HIGHLIGHTS 2020

2020 has been a challenging year for all partners of SFI Smart Maritime. Nevertheless, thanks to high activity tempo, courage and confidence among the Centre's partners, Smart Maritime har maintained its course and reached several milestones. Here are the highlights for 2020:

• Further integration of Hydrodynamics and ship models (WP2) and power systems simulation models (WP3)

• The Centre has demonstrated the potential that can be reached when combining efforts, through Demo-cases of Deep Sea low Emissions ship concepts and one Zero emission cruise concept.

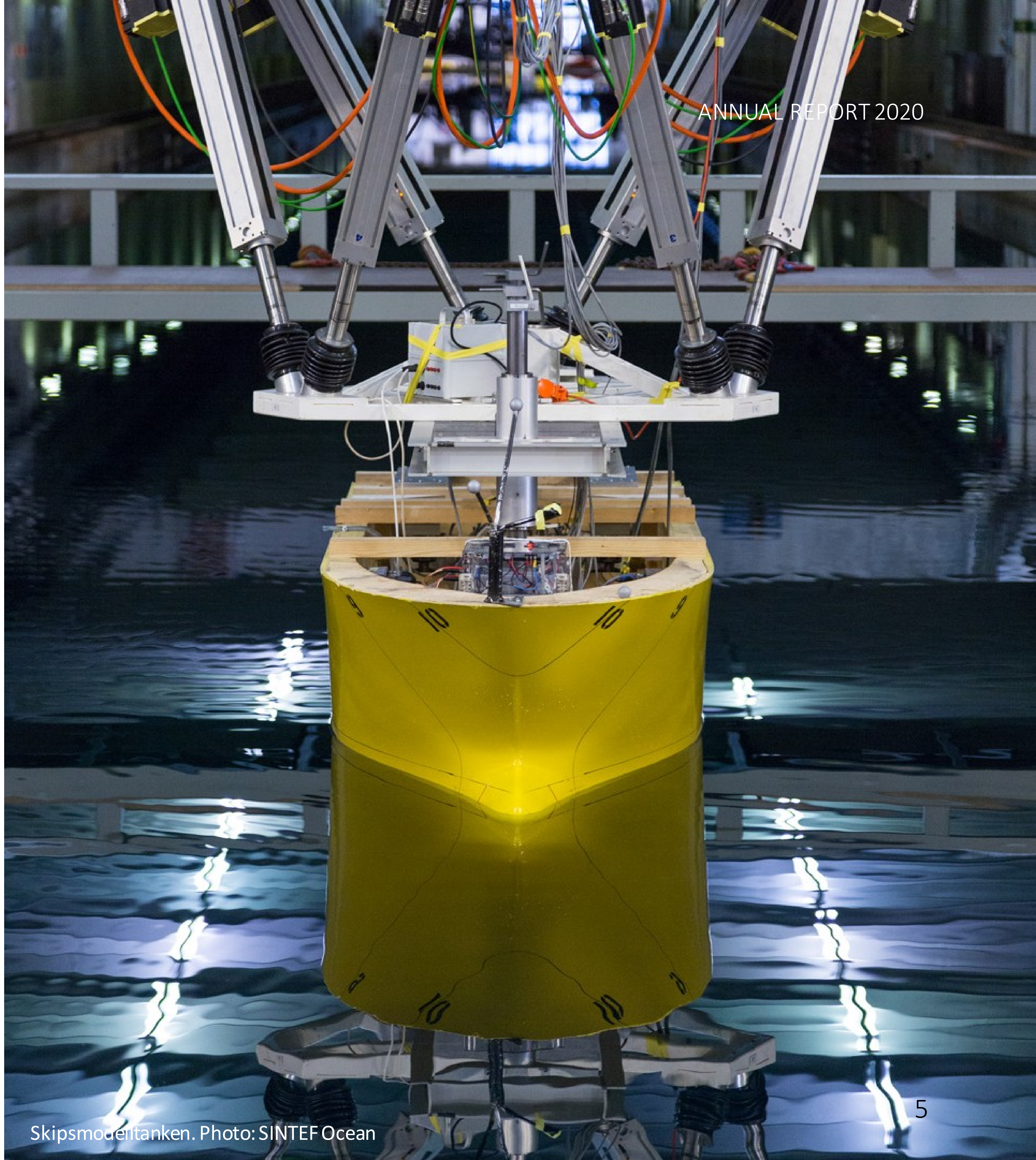
• The Centre research and industry partners have launched/ enrolled in 10 associated projects: 3 knowledge-building projects, 4 innovation projects with support from the Research Council, and 3 projects with support from EU H2020.

• We have reinforced our research team with 2 new PhD students, 1 postdoc researcher, and one new researcher i WP4.

• Smart Maritime Board har welcome 2 new members: Sverre Torben from Kongsberg Maritime and Ove Bjørneseth from VARD.

• Smart Maritime has been more present in the media and has disseminated regularly and actively through a series of 13 Webinars• Smart Maritime has been an active contributor to international policy making (IMO and EU); and strengthen presence in international forums.

Publication: xx scientific articles, xx conference articles, and xx academic lectures.



Skipsmodelltanken. Photo: SINTEF Ocean

SMART MARITIME

VISION AND OBJECTIVES

Our vision is the greening of maritime transport, and by that enabling the Norwegian maritime cluster to be world leading in environmentally friendly shipping by 2025.

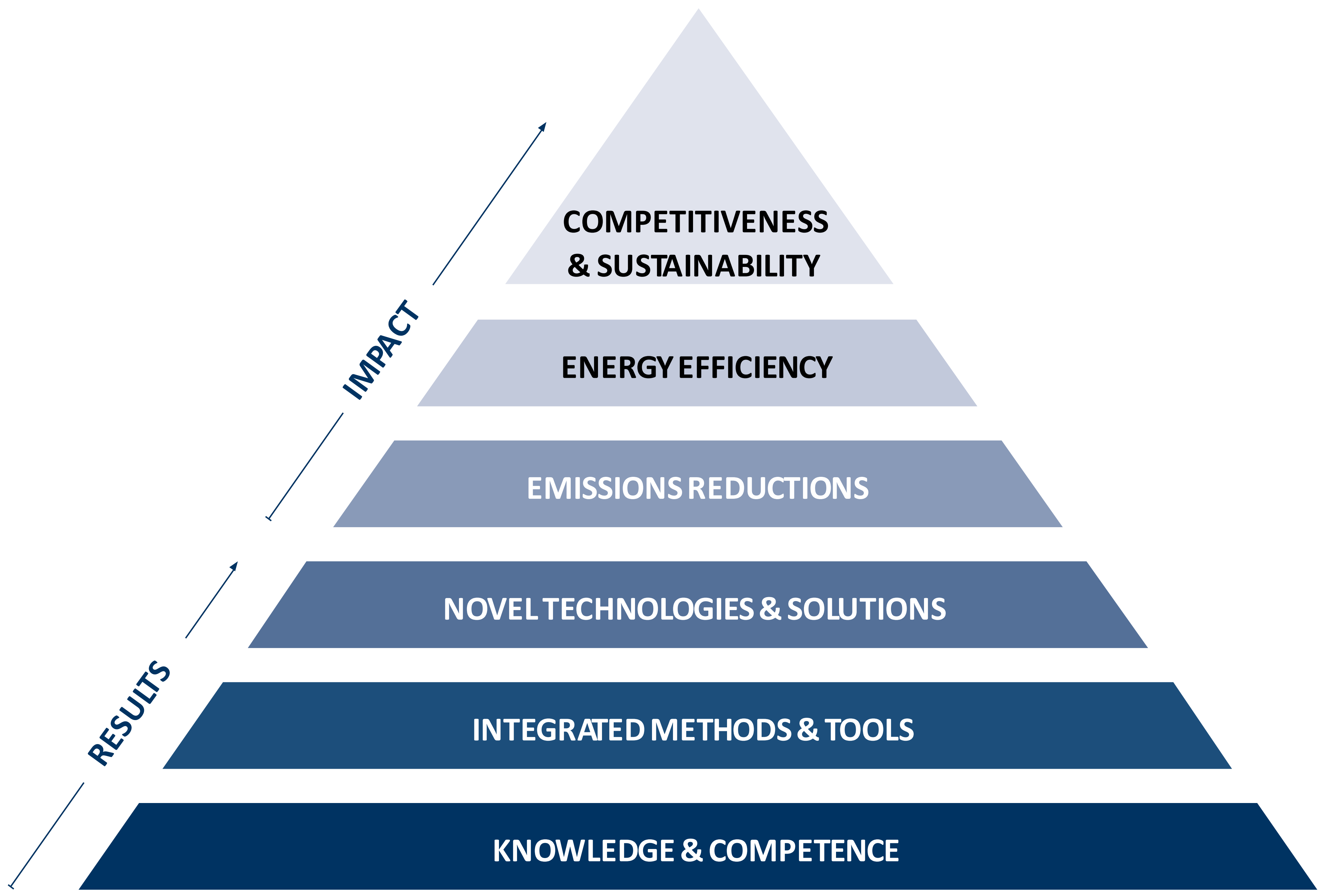
Our mission is to provide the Norwegian maritime sector with knowledge, methods and tools for effective identification and assessment of solutions and technologies.

Bow Summer., Odfjell. Photo credit: Christian Dahll

The three expected impact of SFI Smart Maritime are *increased competitiveness of the Norwegian maritime industry*, *increased energy efficiency in shipping* and *reduced harmful emissions from ships*. This will be achieved through three types of results from the Centre: *knowledge and competence, integrated methods and tools* and *novel technologies and solutions.*

The expected outcomes include:

1. More efficient and accurate early stage assessment of new ship designs.
2. Introduce new validation methods, such as correlating data from real-life conditions with simulation- and experimental data.
3. More accurate predictions of fuel consumption and emissions from alternative hull, propulsion and power system configurations and operational profiles.
4. Improved optimization of ship performance vs. cost profile at various operational profiles and sea states.
5. Improved methods and tools for cost and fuel optimization – on unit level and on fleet level.



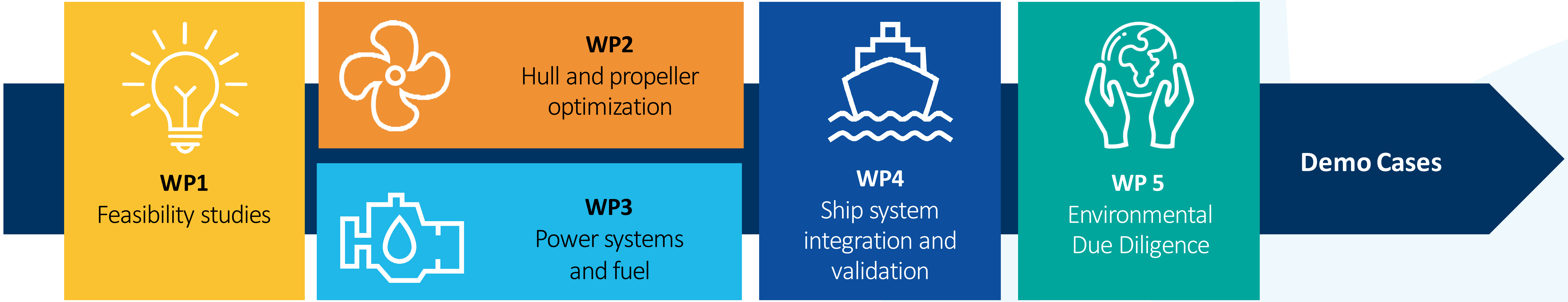
SMART MARITIME

RESEARCH STRATEGY

ANNUAL REPORT 2020

TK Cabu, Photo: Torvald Klaveness

WORK PACKAGES / RESEARCH AREAS



The research strategy relies on five interconnected research areas (Work Packages, WP). WP1 serves as screening work package for identifying and assessing potential technologies and designs. WP2 and WP3 respectively develop models and tools for assessment of technologies and designs. These models are further integrated into a ship system simulation platform, enabling the virtual design and optimization of a ship by help of numerical simulation model (WP4). This holistic system-centred ship design method uses a modular simulation and analysis framework for accurate performance assessment for ship and ship systems under realistic full-scale operation-al conditions. Finally, hybrid LCA methods are used in combination with profit and opportunity cost models to verify environmental and economic benefits (WP5).

WP1: Feasibility studies

Objective

Develop assessment model and method for effective investigation of alternative designs at an early stage. Test and validate through series of feasibility studies.

Research need and background

There is a lack of assessment methods and tools to enable comparison of alternative designs at the feasibility stage of the design process. Current studies and state-of-the-art design practice regarding concept, speed and capability tends to be based on marginal improvements of existing designs and solutions instead of challenging todays practice. One explanation is that most vessels for the merchant fleet have been built by shipyards according to quite standardized designs to minimize building cost while more specialized vessels generally have been improvements and amendments of existing designs.

Research tasks

- Feasibility studies method & tool
- GHG emissions reduction potential
- Feasibility studies (cases)

WP2: Hull and propeller optimization

Objective

Identify potential for energy savings by means of hull and propulsion optimization, and introduce novel approaches to improve efficiency.

Research need and background

Currently, most merchant vessels are designed for optimum performance in calm water. There is an increasing understanding of the importance of including sea- keeping and manoeuvring-related aspects, but it has not found its way into practical design work yet. The tools currently used in design of offshore vessels have a potential for being applied in the design of merchant vessels. Despite this, design for a balanced set of operational conditions is still at the development stage even for offshore vessels. Hydrodynamic performance and propulsion systems, with emphasis on operation in waves, are specially addressed in WP2.

Research tasks

Calm water performance	Energy-saving devices	Novel propulsion systems	Operations in waves
Friction-reduction Novel overall-design (main dim.)	Effect of waves and off-design operation Evaluation of in-service performance	Wave-foil propulsion Optimization of sail-assisted merchant vessels	Speed loss Interaction with engine Operational profile Above-water geom.

WP3: Power systems and fuel

Objective

Improve current designs and explore novel technologies, systems and solutions for energy efficient low- and zero-emission power and propulsion systems. Improve autonomy and reliability of power system.

Research need and background

Reducing fuel consumption and harmful emissions for different vessel types at different operation profiles and modes to comply with current and future IMO legislations is currently the main challenge for maritime transport. Traditionally the power solutions for seagoing vessels have been designed to ensure that the vessels have the required power to be seaworthy in rough weather and to achieve its desired design speed utilizing 85 % of its installed power resources on calm water.

Research tasks

Power system optimization	Combustion engine process	Waste Heat Recovery	Hybrid power systems
Modeling and simulation of power components and systems Fuel consumption estimation Steady-state and transient operating modes Alternative and emerging propulsion concepts	Advanced combustion control Novel injection strategies Alternative fuels (LNG, biofuels, alcohols, hydrogen, ammonia) Exhaust gas cleaning	Energy recovery Alternative power cycles and power system arrangement Thermoelectric power generation Heat management	Energy storage systems (batteries) Hybrid power generation, converters and distribution (AC and DC) Shore-to-ship battery charging

WP4: Ship System Integration and Validation

Objective

Enable performance evaluation and benchmarking of designs on a ship system level by combining monitoring data and simulations in a framework where component and subsystem models can be combined in a full ship system. Validate the results through laboratory and full-scale tests.

Research need and background

The research activity in WP 4 will consider how to technically integrate the components and sub-system developed in WP 2 and 3 in one simulation framework where the full complexity of the future operational profile of the vessels is considered. This holistic system-centered ship design process will enable accurate performance assessment of full ship systems in realistic operational conditions, and assessment of effects of energy efficiency improving measures. In addition, continuous optimization of these systems can be achieved by the combination of real-time monitoring and appropriate system simulations.

Research tasks

Simulation framework	Virtual ship design testing	Simulator validation
Open framework connecting physical domains and modeling regimes Support of Discrete-event simulation to enable long simulation durations Model library database	Methods for assessing system performance against operational profiles KPI's for benchmarking of alternative designs Ship configuration and scenario management	Methodologies for collection, filtering and use of full-scale measurement data Validate and calibate the ship system simulations

WP5: Environmental Due Diligence

Objective

Systematically assess the environmental and economic performance parameters of different ship and shipping system designs.

Research need and background:

Both international trade and maritime transport have increased at tremendous rates in the past decades. Maritime transport is estimated to contribute 3.3 % to the global anthropogenic CO_2 emissions, and the environmental consequences of increased trade are an important factor in the current climate debate. There is a need for detailed harmonized environmental and economic assessment of current and novel ship designs. In addition, there is a lack of suitable approaches for integration of such assessments with ship design and engineering workflows. WP5 will integrate state of the art methods for detailed climatic, environmental and economic analyses, primarily through the development and analysis of a fleetwide emission model - MariTEAM.

Research tasks

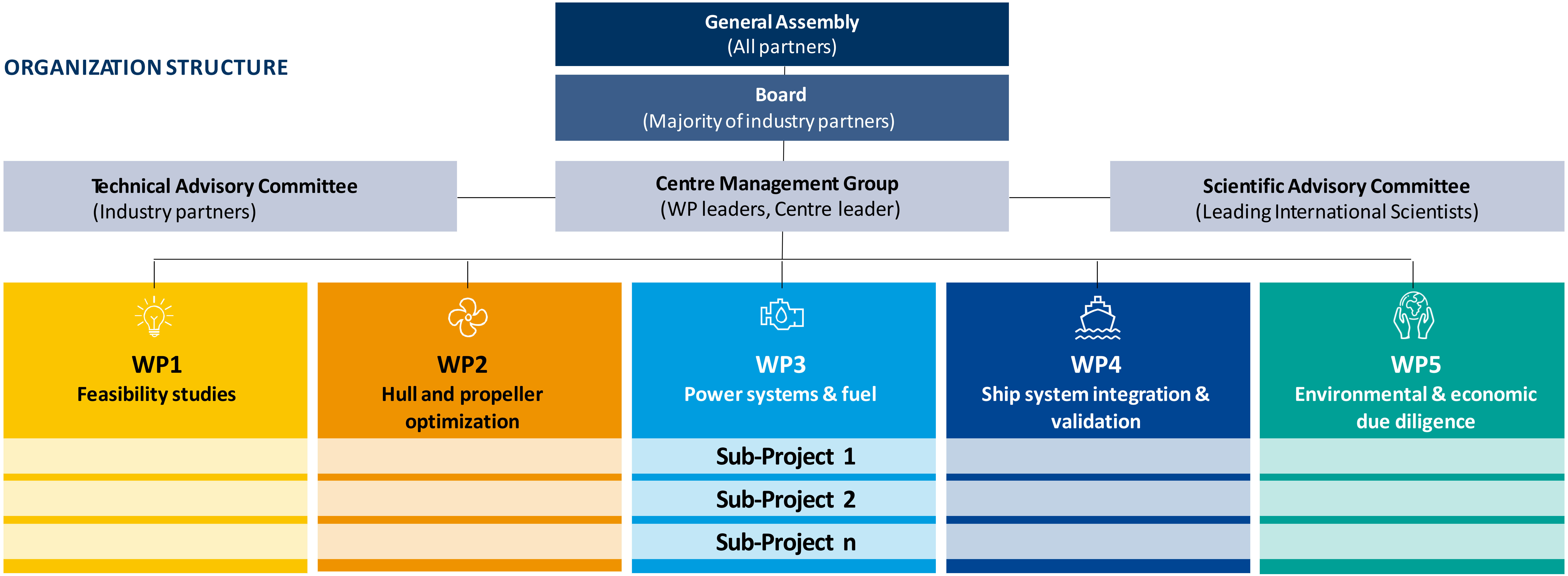
MariTEAM	Spatial-temporal impact	Life cycle assessment	Scenario analysis
Software development Theory-guided big data analytics	Environmental impacts located in time and space	Assess environmental impacts throughout supply chain and service lifetime	Fleet and route development Comparison of technology options

SMART MARITIME

ORGANIZATION

Vard Søviknes_ foto Vard

ORGANIZATION STRUCTURE



SINTEF Ocean hosts the Centre in collaboration with research partner NTNU. The industry partners form the Technical Advisory Committee, covering major parts of the maritime value chain.

The Centre's long-term research activity is organised in five **Work Packages** (WP).

Board: operative decision-making body (7 members)

General assembly: representant from each Consortium partner.

Scientific Advisory Committee (SAC): audit and advice on research progress.

Technical Advisory Committee (TAC): advise the Centre Management on prioritization of R&D activities. Gathered twice a year at the biannual Network Meetings.

SMART MARITIME

Board Members	Affiliation
Jan Øivind Svardal *(Chairman)*	Grieg Star
Jan Fredrik Hansen	ABB
Sverre Torben	Kongsberg Maritime
Ove Bjørneseth	VARD Design
Lars Dessen	Wallenius Wilhelmsen
Beate Kvamstad-Lervold	SINTEF Ocean
Bjørn Egil Asbjørnslett	NTNU
Sigurd Falch (observer)	Norwegian Research Council

Jan Øivind Svardal

Lars Dessen

Sverre Torben

Jan Fredrik Hansen

Beate Kvamstad-Lervold

Ove Bjørneseth

Bjørn Egil Asbjørnslett

Scientific Advisory Committee	Affiliation	Focus area
Professor Karin Andersson	Chalmers University of Technology, Gothenburg	WP 5
Professor Rickard Benzow	Chalmers University of Technology, Gothenburg	WP 2
Professor Harilaos Psaraftis	DTU – Technical University of Denmark	WP 4
Professor Osman Turan	Strathclyde University	WP 1
Professor Friedrich Wirz	TU Hamburg	WP 3

Centre Management Group	Affiliation	Role and responsibility
Trond Johnsen	SINTEF Ocean	Centre Director
Anders Valland	SINTEF Ocean	Deputy Director
Elizabeth Lindstad	SINTEF Ocean	WP1 Feasibility studies
Sverre Steen &	NTNU	WP2 Hull and Propeller
Sverre Anders Alterskjær	SINTEF Ocean	
Mehdi Zadeh	NTNU	WP3 Power systems and Fuel
Jon Dæhlen	SINTEF Ocean	WP4 Ship system Integration
Anders Strømman &	NTNU	WP5 Environment and economy
Helene Muri	NTNU	

Centre administration

Jan Andre Almåsbakk	SINTEF Ocean	Controller
Agathe Rialland	SINTEF Ocean	Administrative Coordinator


Trond Johnsen

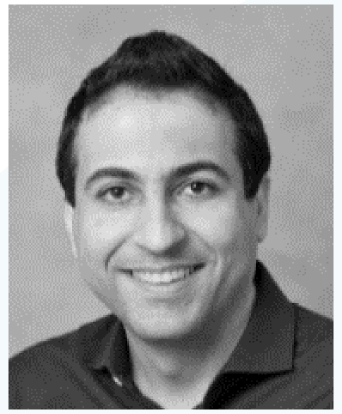

Anders Valland


Elizabeth Lindstad


Stein Ove Erikstad


Sverre Steen


Sverre Anders Alterskjær


Mehdi Zadeh


Jon Dæhlen


Anders Strømman


Helene Muri


Agathe Rialland


Jan Andre Almåsbakk

CENTRE PARTNERS

The Centre collaborates closely with global industry players, national and international research communities and maritime networks. These partners are involved in scientific activity through business cases and subproject activity across the WPs.

Star Lygra. Grieg Star / G2 Ocean Photo: Grieg Star

SMART MARITIME

INDUSTRY PARTNERS

Design, shipbuilding & equipment
ABB
Bergen Engines
HAV Design
Jotun
Kongsberg Maritime
Norwegian Electric Systems
Siemens
Vard Design
Wärtsilä Moss

Ship operators
BW Group
Grieg Star
KG Jebsen Skipsrederi
Höegh Autoliners
Odfjell
Solvang
Torvald Klaveness
Wallenius Wilhelmsen

Other partners
DNV GL
Norwegian Shipowners' Association
Norwegian Maritime Directorate
Kystrederiene

RESULTS

Knowhow Technologies
Concepts Solutions

Problem description
Operational experience
Personnel and resources
Infrastructure

SMART MARITIME

SINTEF

NTNU

Education
Research
Maritime experience
Laboratories

International network and customers

International R&D partners

RESEARCH PARTNERS

SINTEF Ocean (host)

NTNU
Dept. for Maritime Technology
Industrial Ecology Programme

NTNU – Ålesund
Faculty of Maritime Technology and Operations

OCEAN SPACE CENTRE

SFI Scope aligned with Ocean Space Centre strategy.

RESSEARCH & INTEREST ORGANISATIONS

SINTEF Ocean (Host institution)

Department of Marine Technology; Industrial Ecology Programme;
Department of Ocean Operations and Civil Engineering (Ålesund)

DNV GL AS
world's largest ship and offshore classification society and a leading technical advisor to the maritime, energy and oil & gas industries.

Kystrederiene
The Coastal Shipowners Association works for promoting sea transport and marine services with focus on innovation and environmental-friendly solutions.

Norges Rederiforbund
Norwegian Shipowners' Association is a non-government organization serving more than 160 companies.

Sjøfartsdirektoratet
The Norwegian Maritime Authority has jurisdiction over ships registered in Norway and foreign ships arriving Norwegian ports.

SHIP OWNERS

Grieg Star AS
Open Hatch general cargo, conventional Bulk / appr. 40 vessels. All vessels are a part of the G2 Ocean pool, a joint venture between Gearbulk and Grieg Maritime Group.

Wallenius Wilhelmsen ASA
RoRo / 125 vessels
Global supplier of RoRo shipping and vehicle logistics, controlling 125 vessels, servicing 15 trade routes worldwide. Wallenius Wilhelmsen Ocean operates an fleet of 50 RoRo vessels

Höegh Autoliners AS
PCTC / 45 vessels
Global supplier of transportation and logistics services for the RoRo segment, operating a fleet of owned and long-term charter PCTCs with capacity ranging from 2 300 to 8 500 ceu

BW Group
LNG, LPG, Product tankers, Dry bulk, Chemicals, FPSOs / 370 vessels.
BW Group is one of the world's leading maritime groups in the tanker, gas and offshore segments

Torvald Klaveness
Dry bulk, Container / 23 vessels
Operating in the container and bulk segment, Klaveness owns and operates a fleet of 17 combination carriers from 200 to 562 DWT, and 6 Container vessels from 500 to 740 TEU. Klaveness Chartering has a fleet of 140 vessels under management.

Odfjell
Chemical tanker / 120 vessels
World leaders in the global market for seaborne transportation and storage of chemicals and other specialty bulk liquids. The fleet consists of five main categories: Supersegregators with multiple segregations, large stainless steel chemical tankers, medium stainless steel chemical tankers, coated tonnage and regional fleets in Asia and South America.

Solvang ASA
LPG, petrochemical gases / 27 vessels.
One of the world's leading transporters of LPG and petrochemical gases. The fleet consist of 27 vessels – semi-refrigerated/ethylene carriers, LPG ships and VLGC (gas carriers).

Kristian Gerhard Jebsen Skipsrederi AS
Tanker, dry cargo, cement /50 vessels
Integrated shipping company involved in operation of tankers, dry cargo and specialized cement vessels. KGJS owned fleet: 13 Suezmax and LR 2 tankers and 2 OBOs in the SKS pool, 7 pneumatic cement carriers and Kamsarmax bulk carriers in the BTG pool

SHIP DESIGN & SHIP BUILDING

HAV Design

HAV Design AS (previously Havyard Design & Solutions AS) delivers safe, energy-efficient and environmentally friendly ship designs. HAV Design is part of the HAV Group (founded feb. 2021), an international provider of technology and services for maritime and marine industries, with special expertise in digitalisation, energy efficiency and zero-emission solutions in the marine and maritime industry.

Kongsberg Maritime

(replacing former SFI partner Rolls-Royce Marine, fully integrated part of Kongsberg Maritime since April 2019) specialises in the development and delivery of integrated vessel concepts for traditional merchant vessels, ROPAX, fishing vessels, offshore, research vessels and offshore installations.

Vard Design AS

Major global designers and shipbuilders of specialized vessels. VARD operates seven shipyards as well as subsidiary companies in the areas of design, electro, piping, accommodation and handling systems.

EQUIPMENT AND SYSTEM SUPPLIERS

ABB AS
Leading manufacturer of electric power and propulsion systems for ships. The product range also includes advisory systems for monitoring operational parameters.

Bergen Engines AS
A subsidiary of Rolls-Royce Power Systems within the Land & Sea Division of Rolls-Royce. Our medium speed gas and liquid fuel engines are supplied for a broad range of power generation applications.

Jotun AS
World's leading provider of paint systems and marine coatings to ship-owners and managers active in the newbuilding and dry-dock and maintenance markets.

Norwegian Electric Systems AS
Norwegian Electric Systems delivers smart control systems and energy designs that result in safe, efficient and environmentally friendly ships,. HAV Design is part of the HAV Group (founded feb. 2021)

SIEMENS AS
Siemens is among the world's leading suppliers of diesel-electric propulsion systems.

Wärtsilä Moss AS
Manufactures advanced inert gas and nitrogen solutions for marine and offshore oil and gas applications. Wärtsilä Norway delivers solutions for ship machinery, propulsion, automation, ship design, automation systems and liquid cargo solutions.

RESEARCH FACILITIES

The SFI makes use of own research facilities (SINTEF OCEAN and NTNU) as well as on-site laboratories from its industry partners.

SINTEF Ocean / NTNU

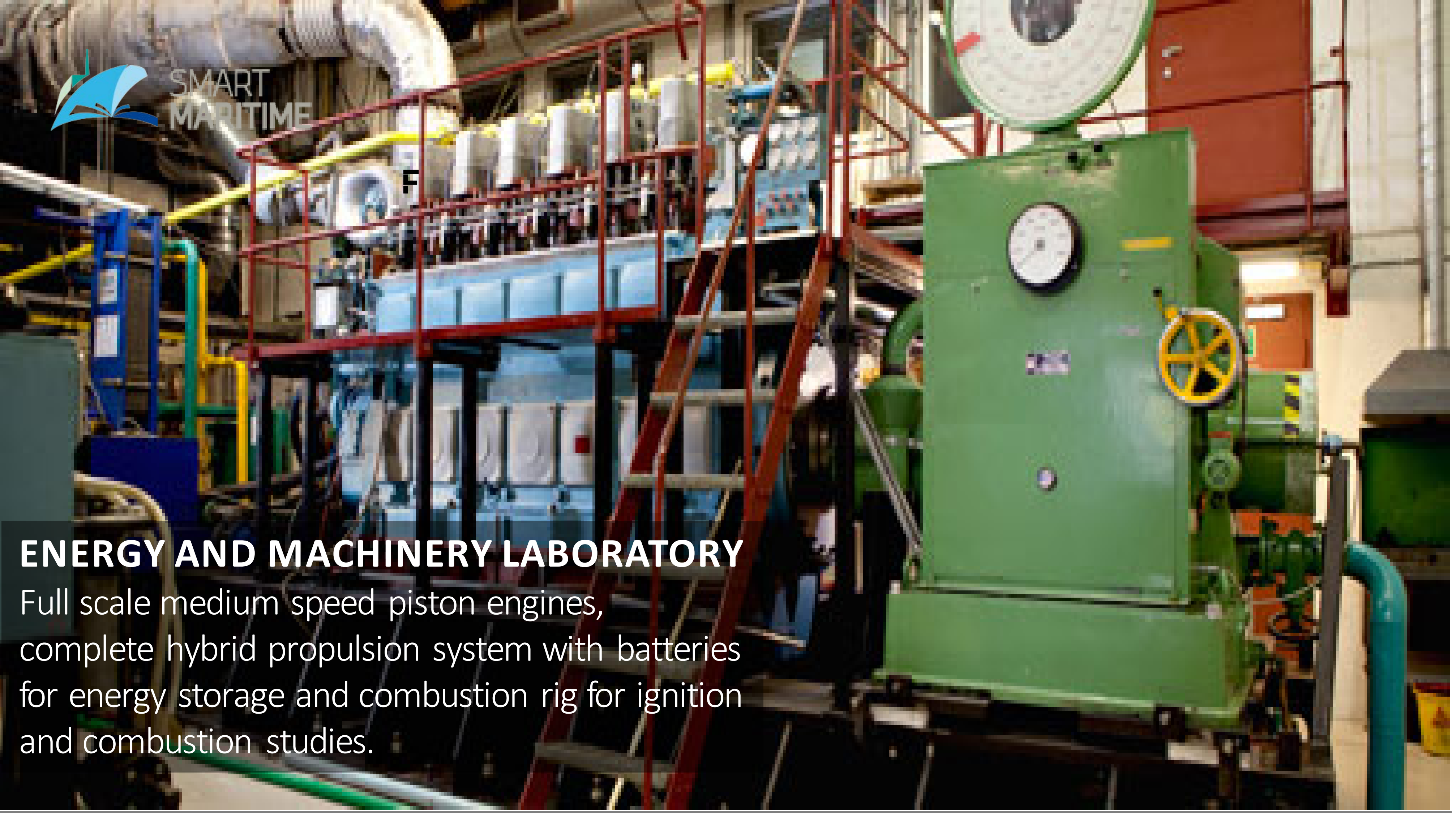
- Energy and machinery laboratory
- Hybrid power laboratory
- Fuel cell and hydrogen laboratory
- Towing tank
- Ocean basin
- Cavitation tunnel
- Circulating water tunnel
- Wave flume
- Marine Cybernetics Laboratory
- High Performance Computing

Industry partners' own laboratories

- Exhaust gas cleaning laboratory (Wärtsilä Moss)
- Power system laboratory (Norwegian Electric Systems)
- Laboratory for gas engine development, equipped with complete exhaust gas emission analysis (Bergen Engines)
- Clipper Harald, LPG tanker equipped with EGR, owner Solvang
- Simulation Centre (Kongsberg Maritime)

ENERGY AND MACHINERY LABORATORY

Full scale medium speed piston engines, complete hybrid propulsion system with batteries for energy storage and combustion rig for ignition and combustion studies.



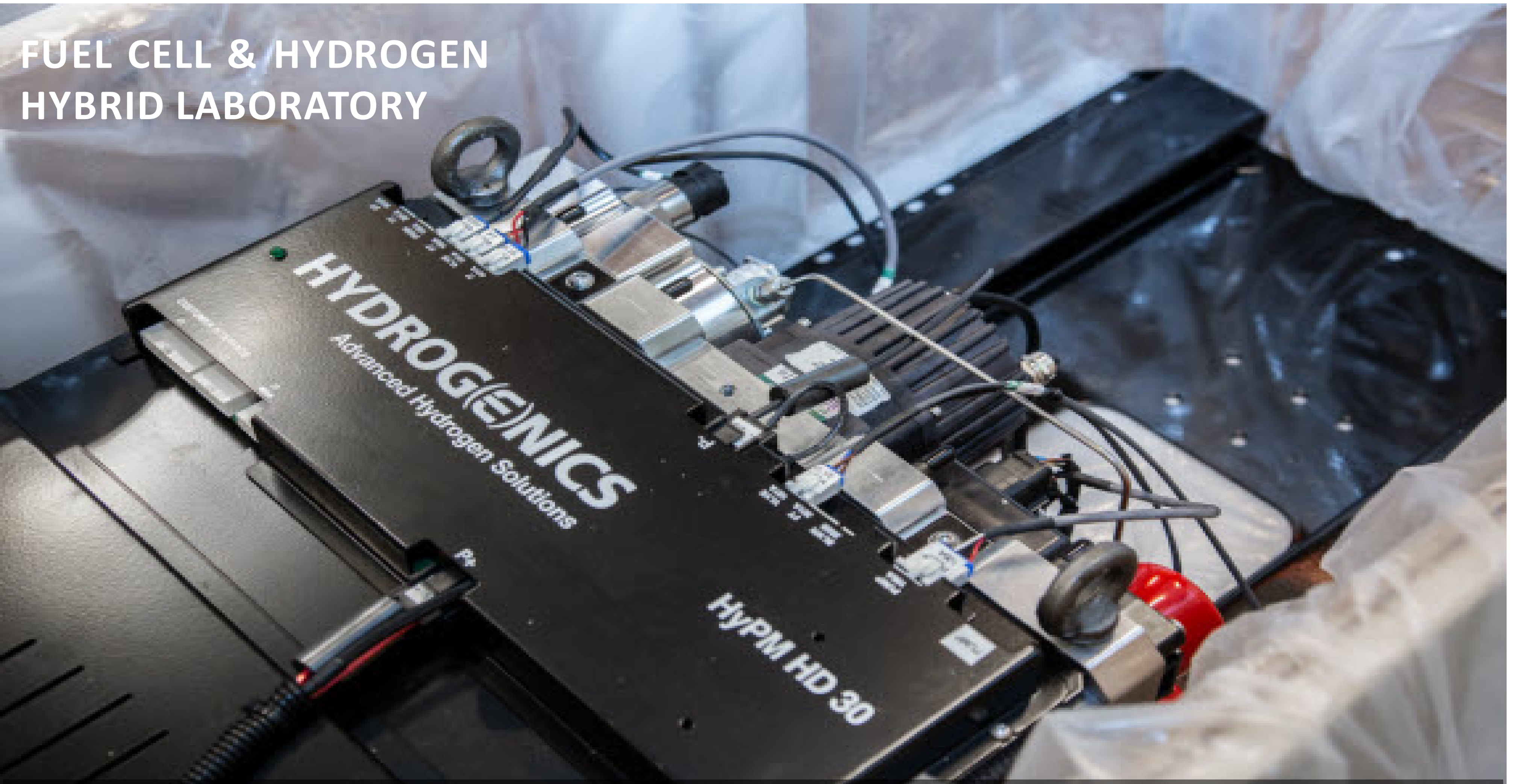
Energy and Machinery Laboratory. Photo: NTNU/Sintef Ocean

COMBUSTION RIG

Combustion rig for ignition and combustion studies.

Energy and Machinery Laboratory. Photo: NTNU/Sintef Ocean

FUEL CELL & HYDROGEN HYBRID LABORATORY

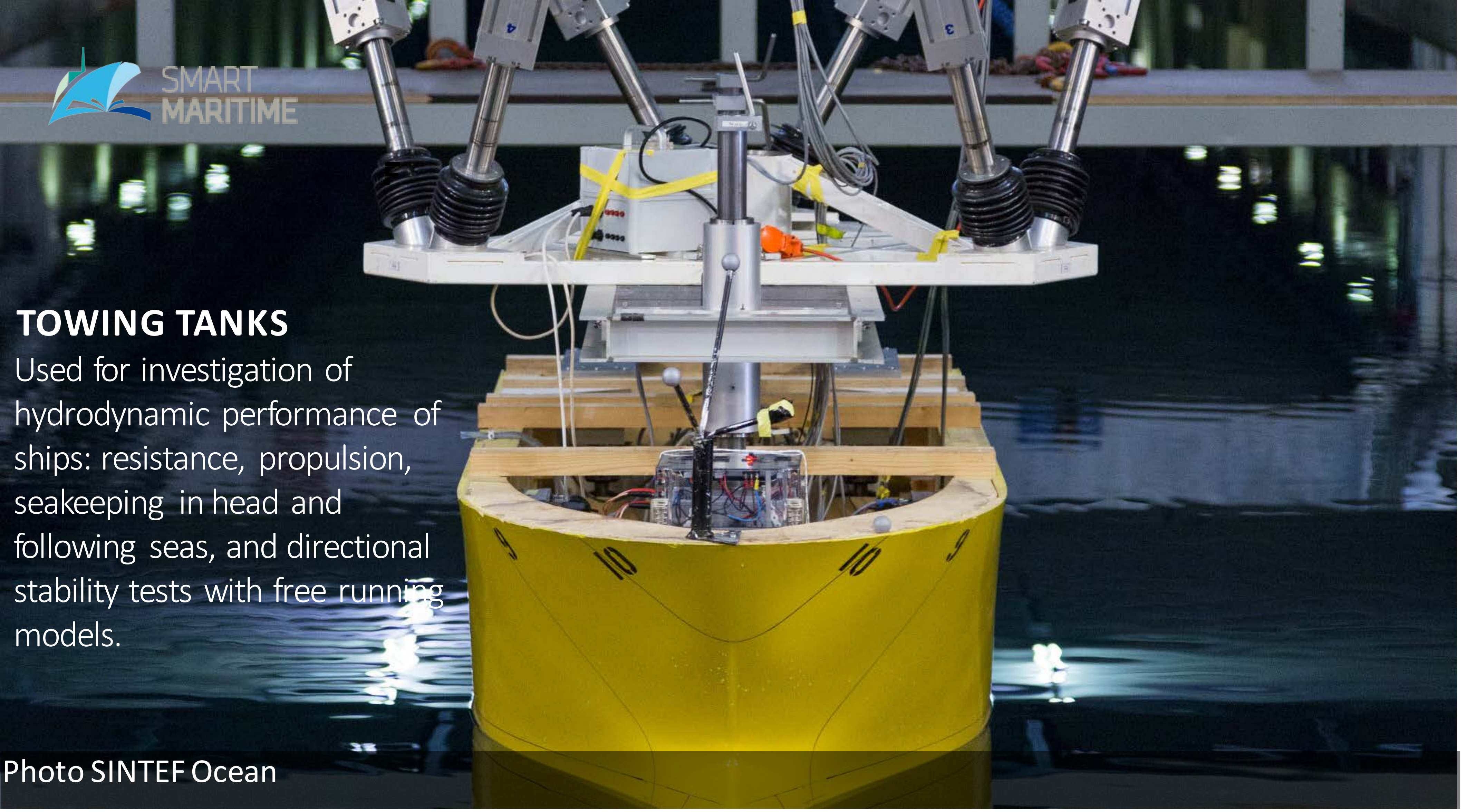


Energy and Machinery Laboratory.

HYBRID POWER LABORATORY

Power and simulation lab for educational and research purposes. It enables the testing of novel marine power plants.

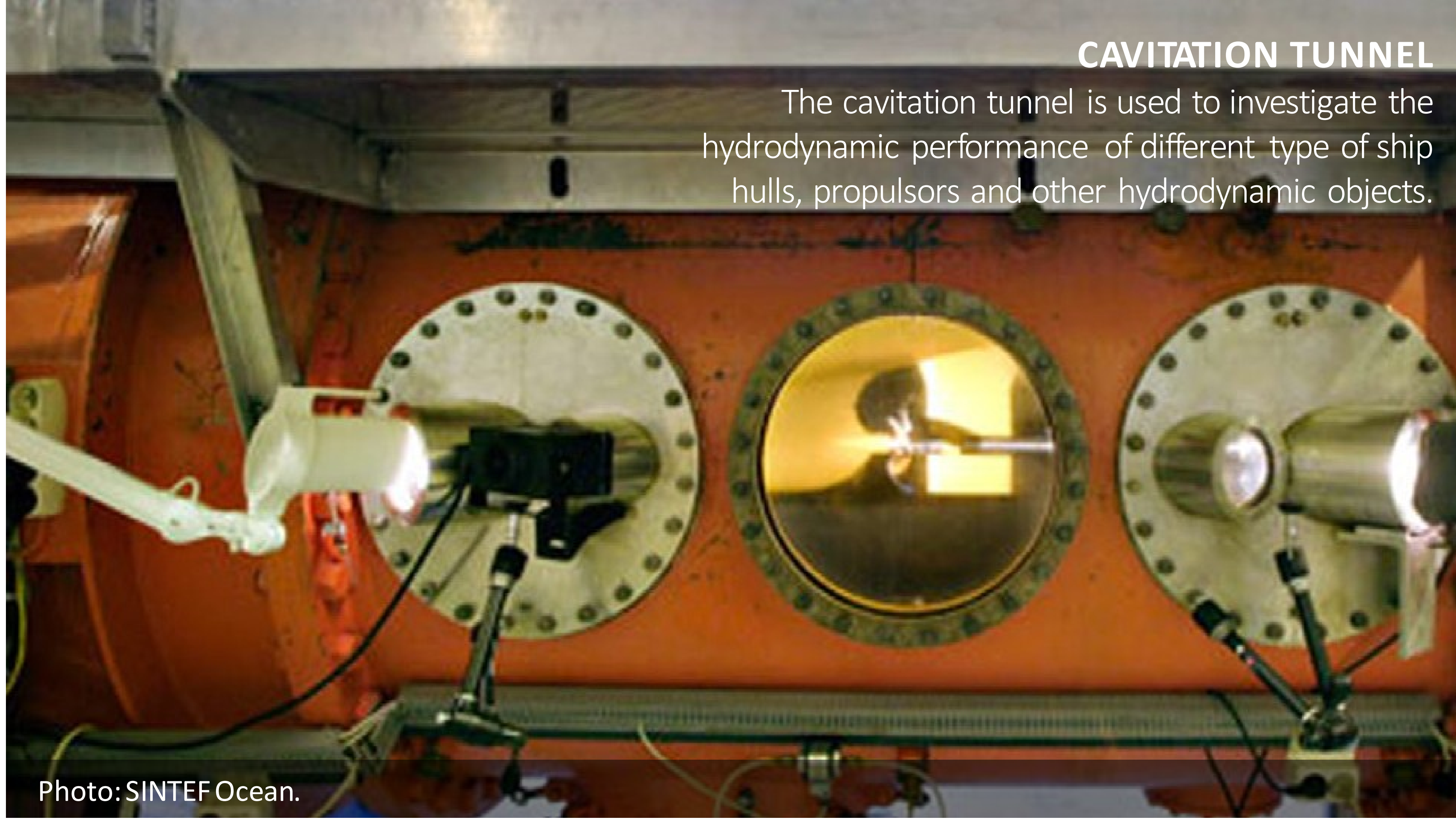
Hybrid Power Laboratory. Photo: NTNU/SINTEF Ocean



TOWING TANKS

Used for investigation of hydrodynamic performance of ships: resistance, propulsion, seakeeping in head and following seas, and directional stability tests with free running models.

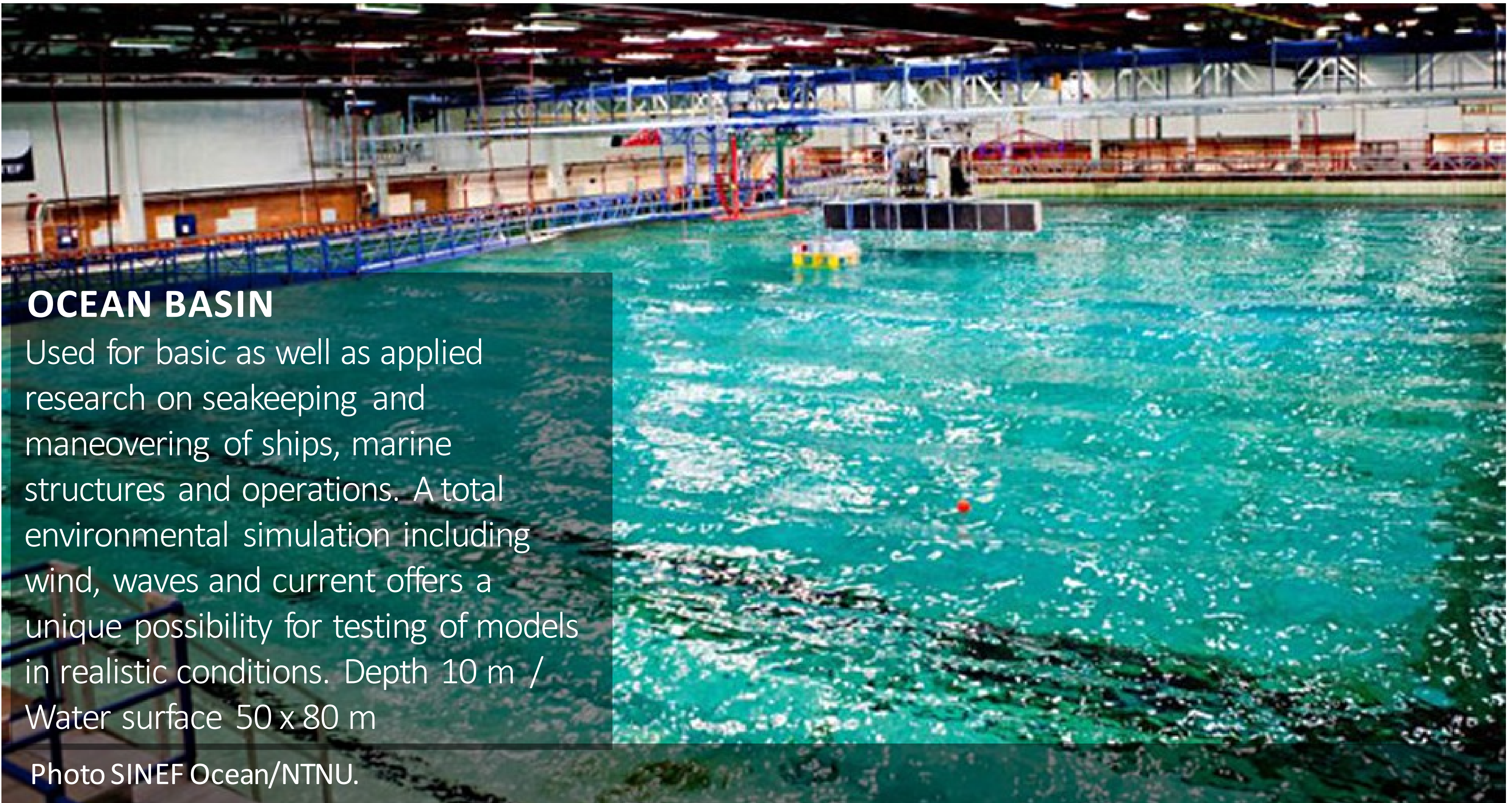
Photo SINTEF Ocean



CAVITATION TUNNEL

The cavitation tunnel is used to investigate the hydrodynamic performance of different type of ship hulls, propulsors and other hydrodynamic objects.

Photo: SINTEF Ocean.



OCEAN BASIN

Used for basic as well as applied research on seakeeping and maneovering of ships, marine structures and operations. A total environmental simulation including wind, waves and current offers a unique possibility for testing of models in realistic conditions. Depth 10 m / Water surface 50 x 80 m

Photo SINEF Ocean/NTNU.

CIRCULATING WATER TUNNEL

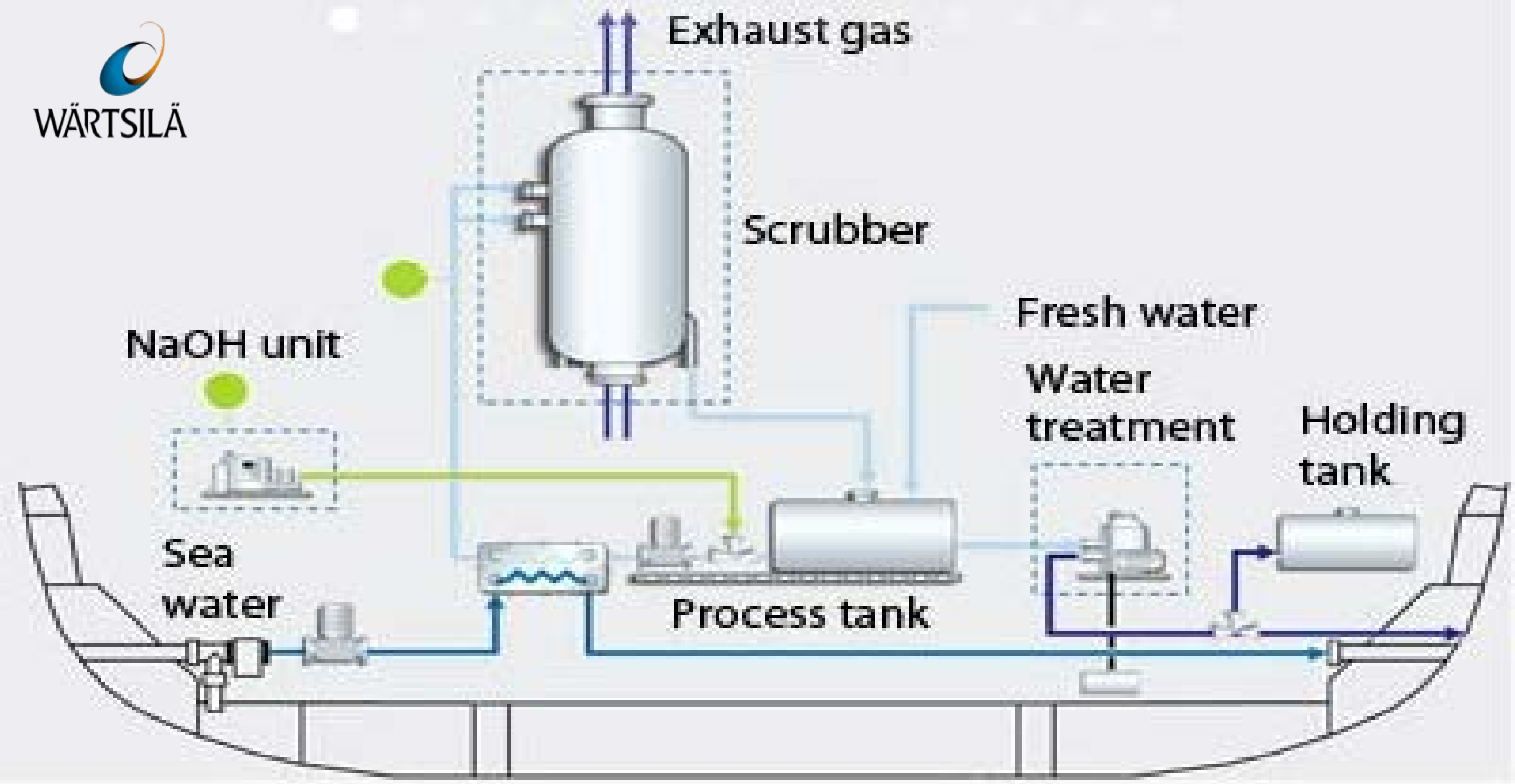
Test facility dedicated to optical measurement techniques and flow visualization.

Photo: SINTEF Ocean.

BERGEN ENGINES LABORATORY

Bergen Engines Laboratory for Gas engine development operating on LNG and equipped with complete exhaust gas emission analysis including PM (Particulate Matter).

Laboratory for gas engine development (Rolls-Royce Bergen Engines)



Exhaust gas cleaning laboratory (Wärtsilä Moss)

LPG tanker operating at coast of Norway on HFO equipped with Exhaust Gas Scrubber with open loop and wash water cleaning system. EGR (Exhaust Gas Recirculation system) for reduction of NOx emissions.

Clipper Harald. Photo: Solvang.

POWER SYSTEM LABORATORY - NORWEGIAN ELECTRIC SYSTEMS

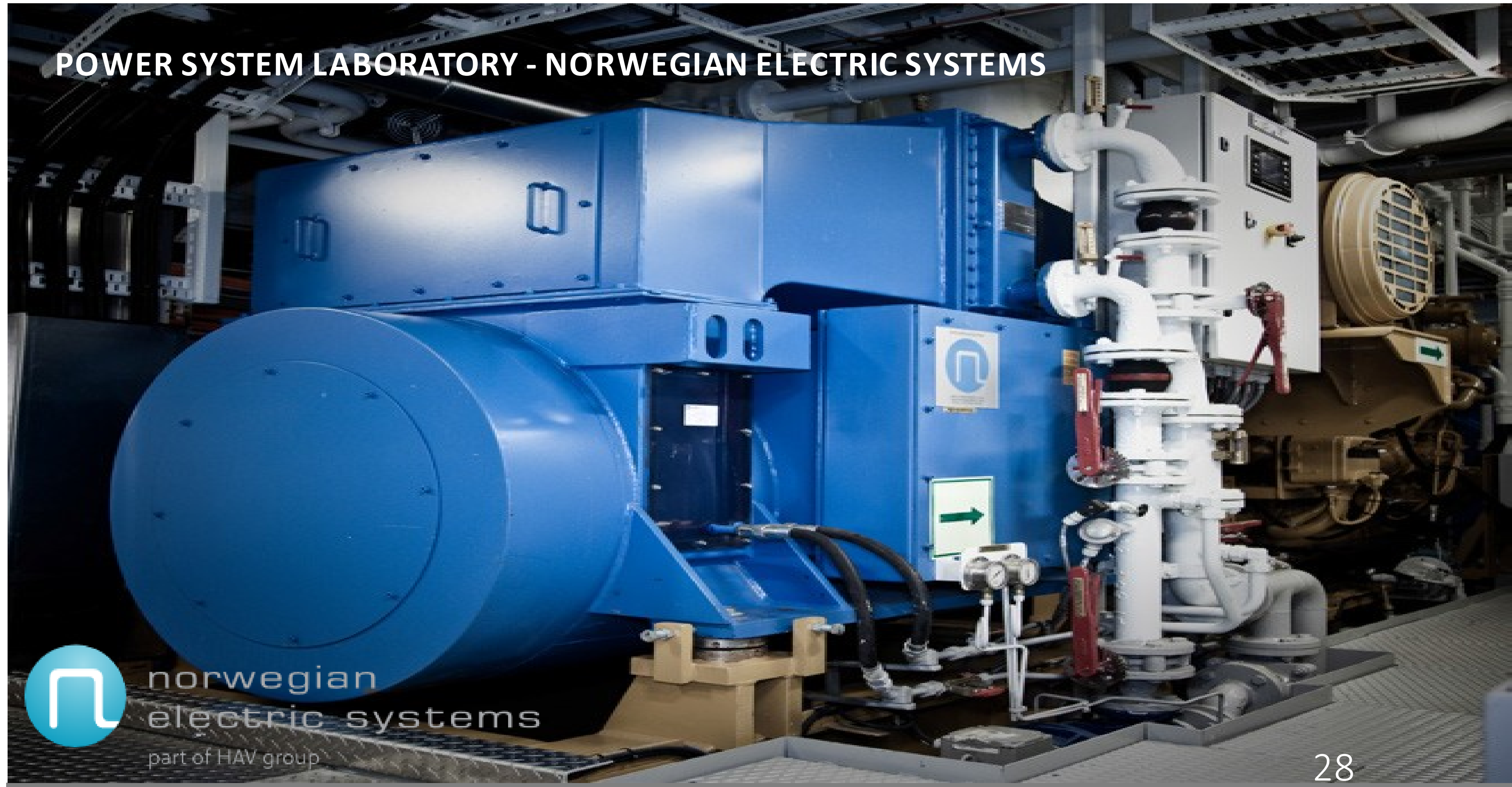
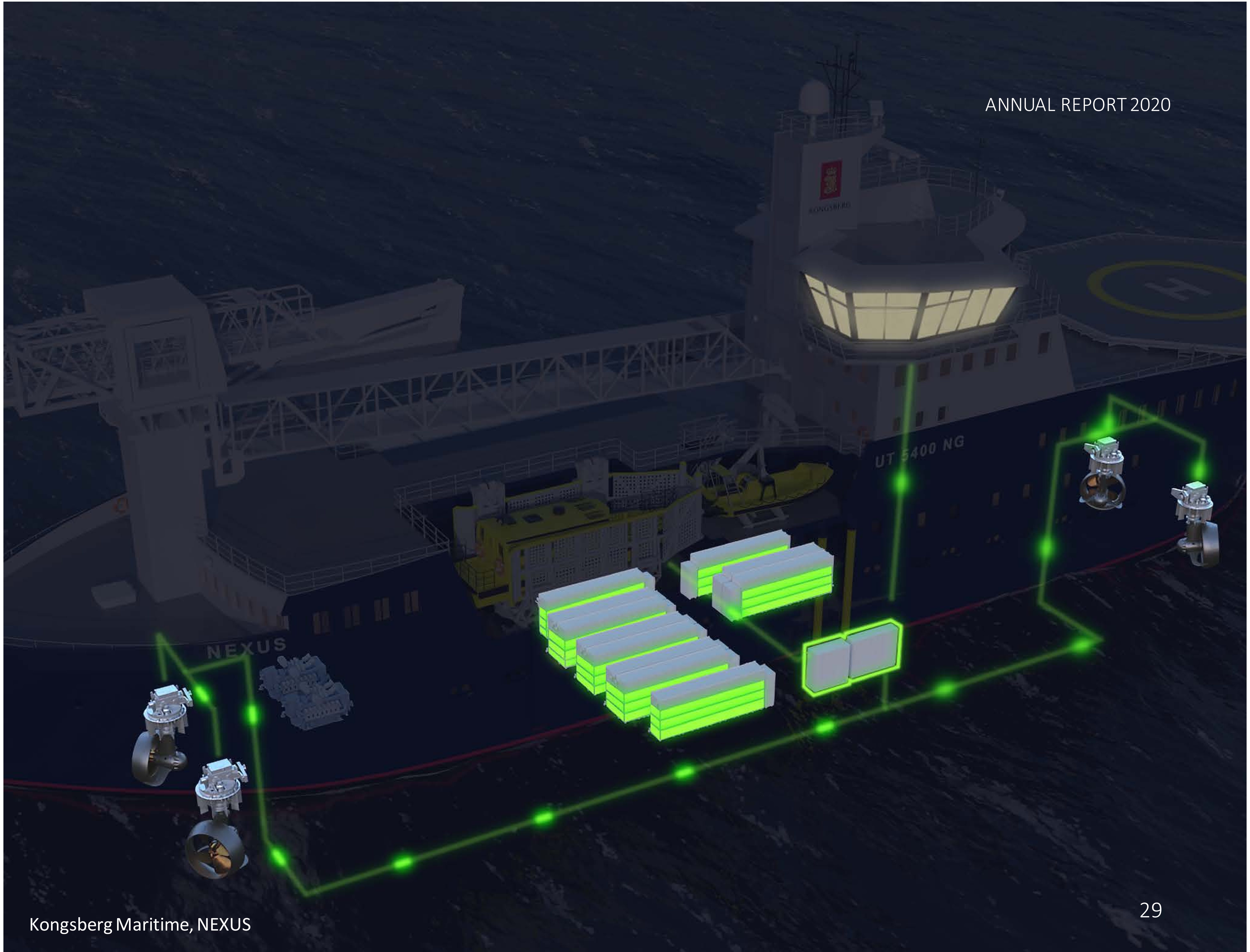


Photo: Norwegian Electric Systems

SMART MARITIME

SCIENTIFIC ACTIVITIES AND RESULTS 2020



Kongsberg Maritime, NEXUS

SMART MARITIME

SCIENTIFIC RESULTS 2020 - HIGHLIGHTS

HYDRODYNAMICS

POWER AND PROPULSION

SIMULATION PLATFORM

SMART MARITIME

HYDRODYNAMICS

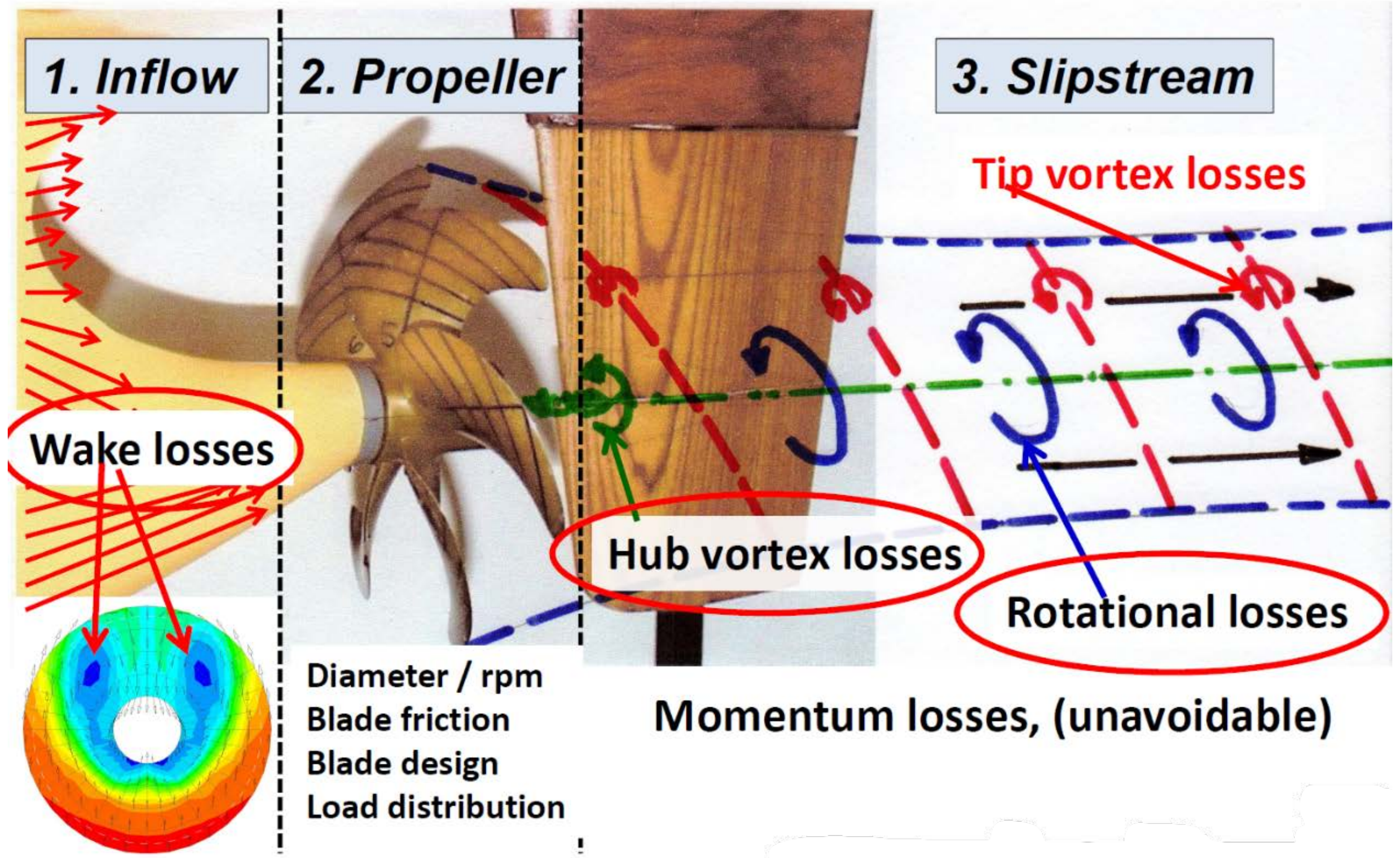
BOW CLIPPER, Photo: Odfjell

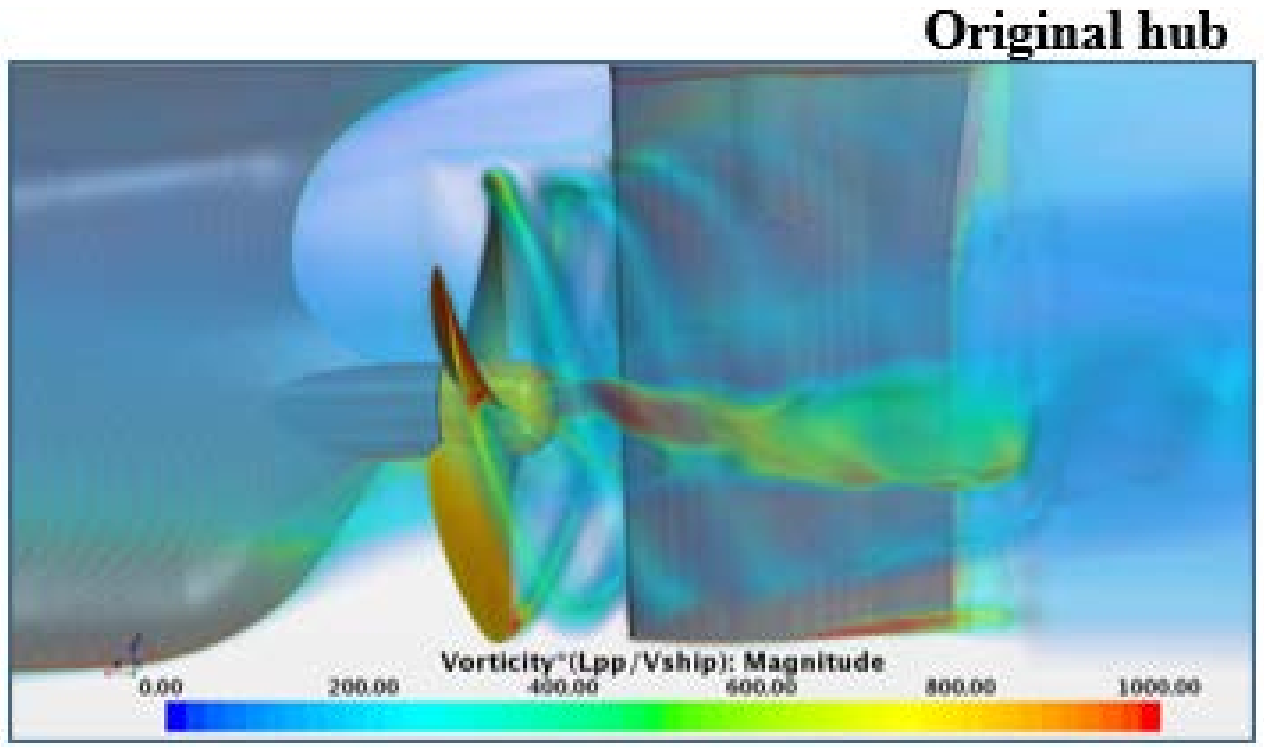
Hydrodynamic Energy Saving Measures

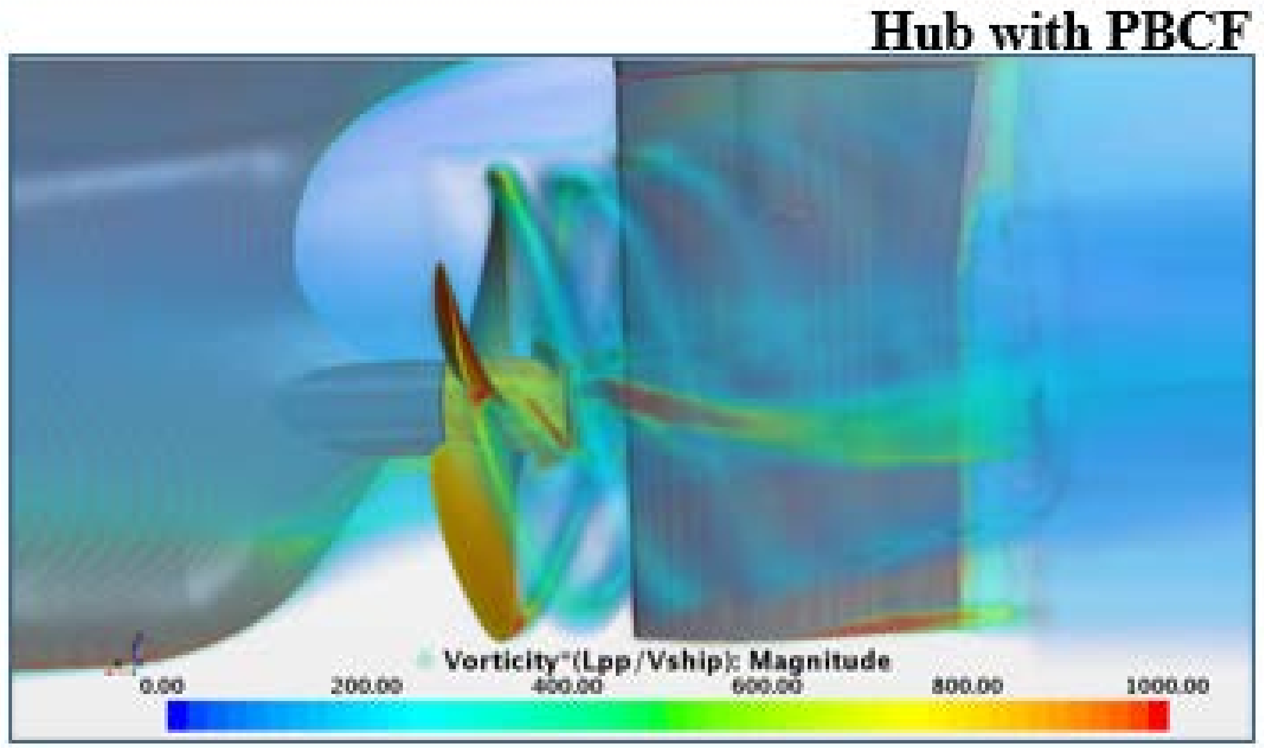
Contact: Kourosh Koushan (SINTEF Ocean)

Different types of energy saving methods within shipping are gaining more interest due to environmental awareness, financial incentives, and, most importantly, new regional and international rules, which limit the acceptable emission from the ships considerably. Some of these measures are based on hydrodynamic principals. Most widely applied are installation of energy saving devices (ESD). There are different types of energy saving devices in the market, and new ones or new versions of existing ones are introduced.

A webinar was presented by Kourosh Koushan in June 2020 to provide basic insight into different main types of hydrodynamic energy saving methods, their working principles, merits and disadvantages, and whether they can be combined.







Reference: Kourosh Koushan, Hydrodynamic Energy Saving Measures. Samrt Maritime WEBINAR 2020-06-17

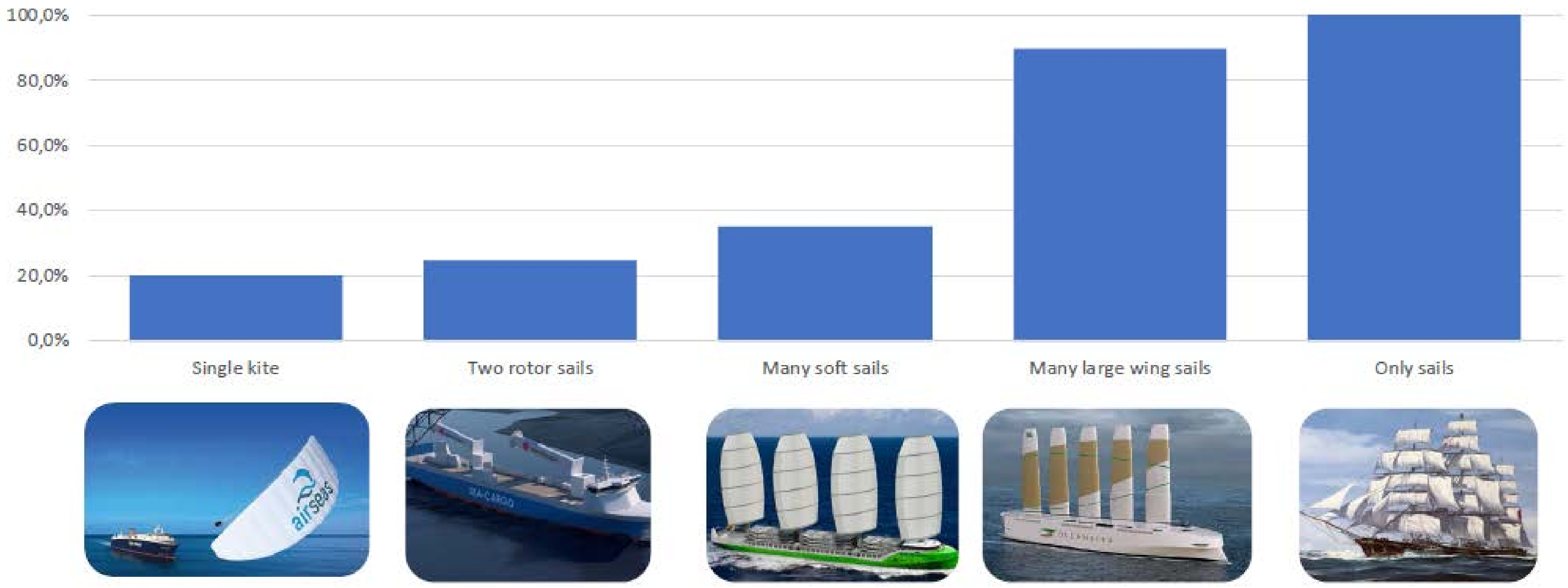
Wind assisted propulsion

Contact: Sverre Anders Alterskjær, Anders Östman (SINTEF Ocean), Jarle Kramer (NTNU)

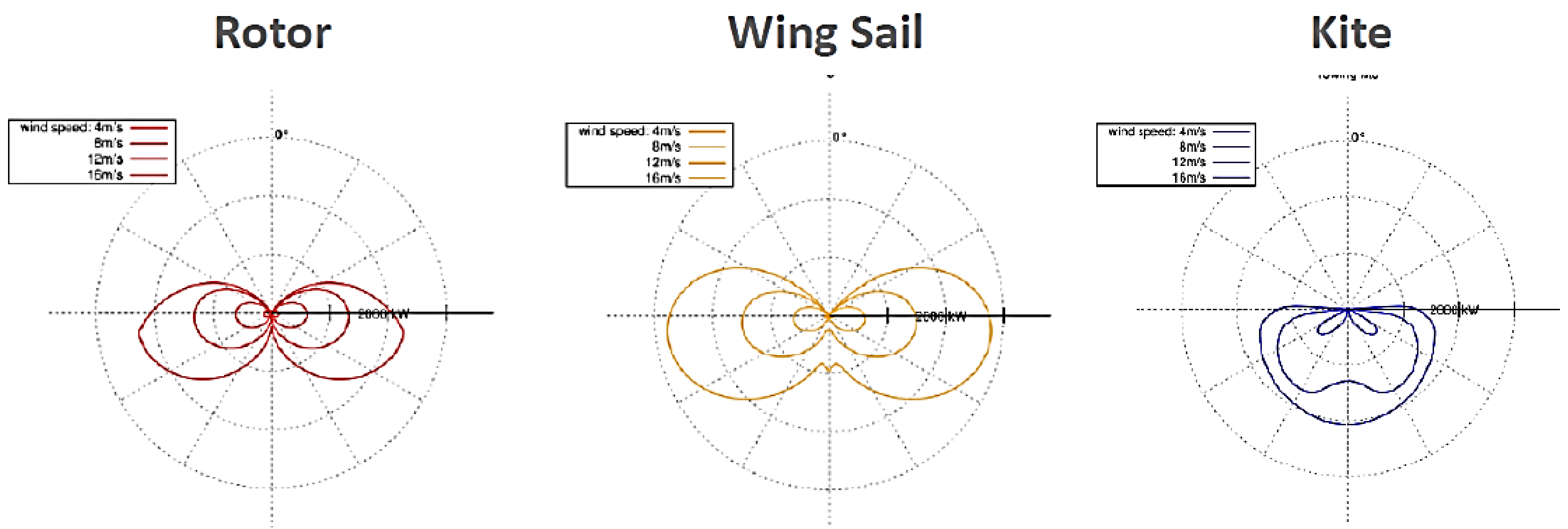
The associated Innovation project CruiZero lead by VARD Design is working on zero-emission expedition cruise ship concept designs and design processes. Model tests for wind assisted vessels include isolated hydrodynamic effect tests and ship system performance tests.

Considered Wind Propulsion Concepts

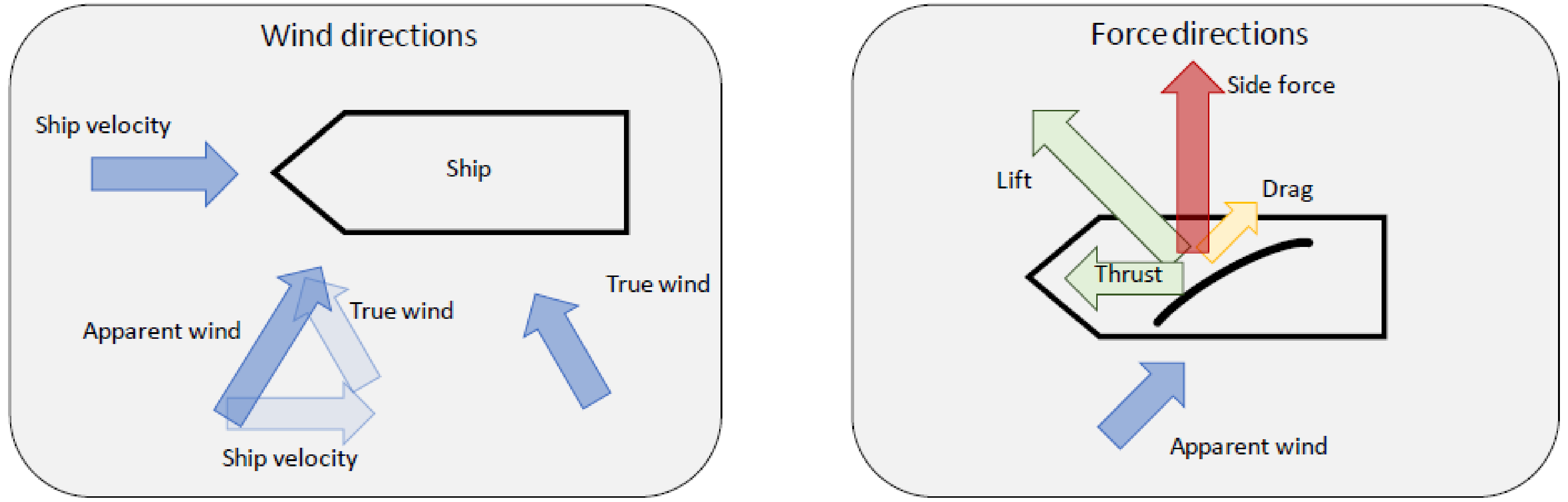
- Flettner rotors/ Rotor sails
- Suction Wing Sails / Ventilated foil systems
- Rigid Wing Sails
- Soft Wing Sails
- Soft Sails
- Kite Sails



Claimed potential of wind-assisted propulsion



Polar graphs (Östman, 2020)



Apparent Wind and Force Direction (Kramer, 2020)

Work in progress:
Development of an efficient software to calculate thrust from wind propulsor. The Software will included in the ShipX workbench and integrated with the Gymir ship power prediction software.

Reference: A.L. Östman, *Wind-assisted propulsion in the CruiZero project*; J. Kramer .*Wind propulsion;* S.A. Alterskjær, Model testing of wind assisted vessels, Smart Maritime WEBINAR Wind-assisted propulsion; 2020-11-10

IPIRiS Improving Performance In Real Seas

Contact: Martin Gutsch (SINTEF Ocean), IPIRiS KSP Project, Duration 2020 – 2024

When a ship is moving forward in waves it will experience an increase in resistance in waves. Traditionally, ship designs are optimized for calm water performance. However, this condition does not reflect the real condition the vessel will experience at sea.

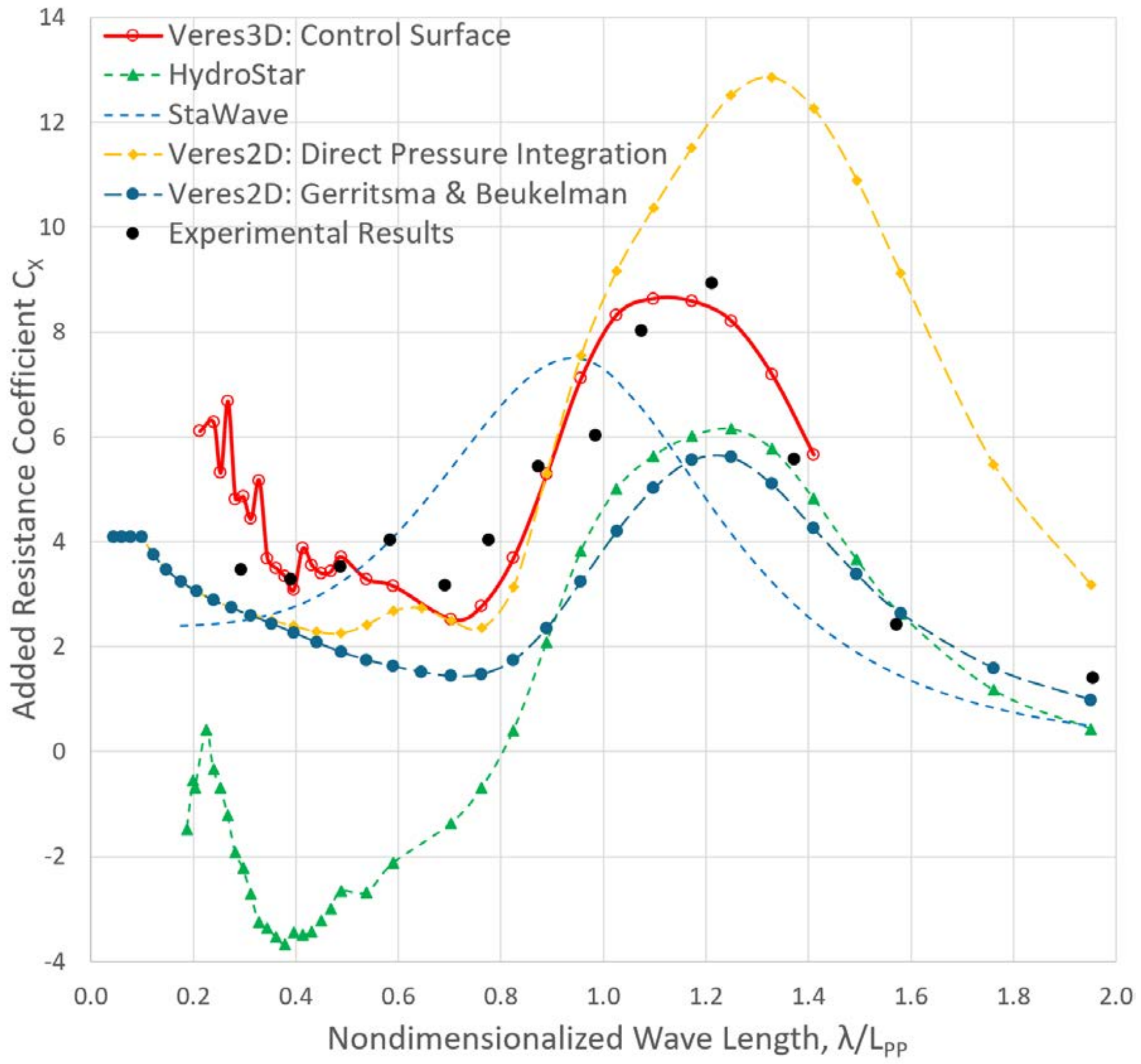
The International Maritime Organization (IMO) has established the Energy Efficiency Design Index (EEDI) as the most important policy measure to reduce greenhouse gas emissions from shipping. The current implementation of the EEDI is based on calm-water conditions. However, when vessels operate under real-sea conditions, the required power exceeds the power requirement in calm water conditions and the emissions are higher than assumed according to the calculations following the EEDI. Hence, calm water optimization, currently applied by the EEDI, does not necessarily produce the ship with the lowest energy consumption over its lifetime, leading to increased fuel consumption and raising a safety concern for the operation of the vessel in extreme weather conditions. To better address the IMO 2050 greenhouse gas reduction target, robust and more accurate analyses of ships in realistic operating conditions are needed with emphasis on the prediction of added resistance in waves.

The overall goal of the current project is the introduction of more accurate numerical tools to study ship seakeeping performance in real-sea conditions. The proposed project will develop high-resolution tools and couple high-resolution modelling with efficient wave modelling to evaluate the added resistance problem in realistic sea states in more detail.

In 2020, the main activity has been the development of a practical, numerical tool for the prediction of the seakeeping qualities of ships with forward speed, accounting for three-dimensional effects. This numerical tool is intended for use by the industry in an early design phase, and efficient computational performance is a main consideration.

A major feature of the seakeeping problem with forward speed is the complicated wave pattern formed by the ship's motions and wave reflection in waves. The calculation of forces on the body requires that the pressure created by the interaction of the moving ship hull with the waves around is obtained correctly. Traditionally, this seakeeping problem is solved by a boundary element method where only the wetted surface of the hull is included in the mathematical description. A fundamental mathematical component of this boundary element method is the Green function. Without forward speed, efficient formulations for this Green function exist and several efficient codes are used within the offshore industry. With forward speed, however, the Green function is much more complex and difficult to calculate, and this inhibits practical use. For the development of a robust industry-standard seakeeping code, a simplified formulation where the forward speed terms in the free-surface condition are dropped, seems favorable. This approach has been chosen for the present development, as it allows for efficient calculations using available formulations for the zero-speed Green function.

The initial work-in-progress release of the numerical tool VERES3D was developed in 2020 and has been made available for the project partners for validation.



Added resistance validation for KVLCC2 in head waves at design speed

Reference: Bruyat, A., Gutsch, M., & Hoff, J. R. (2020). Veres3D User Manual-for Work in Progress Release 0.2. 0-OC2020 A-128.

Power prediction model applied for the ship design problem

Contact: Ehsan Esmailian (NTNU)

Finding a model both accurate and computationally efficient for predicting the ship performance at sea is a big challenge. In this study, different methods were compared to develop a reliable power prediction model applied for the ship design problem. A comparison between the suggested method with experimental data, CFD results, and ship in-service data for two modern post-Panamax container ships, Duisburg Test Case (DTC) and HANJIN-SOOHO, is presented in Figs.1-3. The results show good agreement of the model results with the studied approaches.

The performance prediction method will be applied in two novel methods for optimization of ship design for operation in real sea states and varying operational conditions. Furthermore, an approach will be proposed to improve the prediction of the added resistance in waves, which is an important component in the performance prediction method and therefore in the optimization for operation in real sea states.

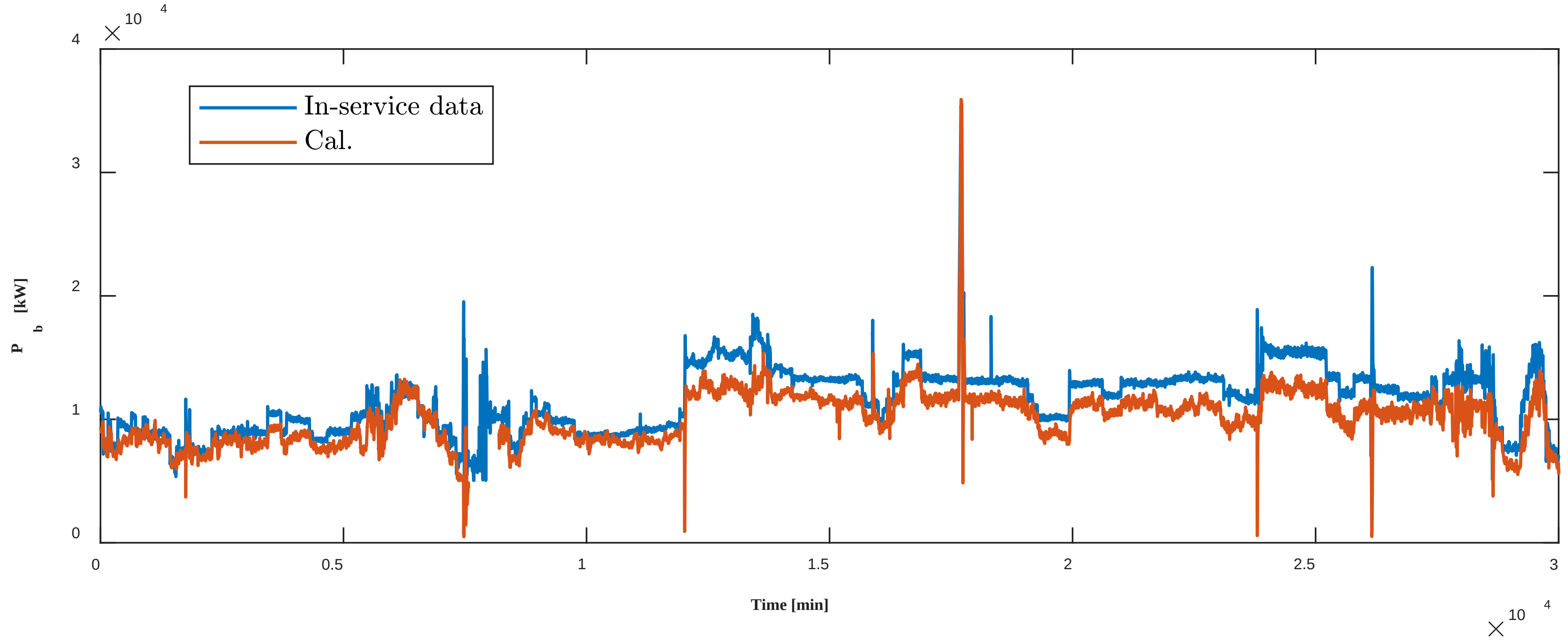


Fig 3. Comparison of the brake power for the HANJIN SOOHO container ship.

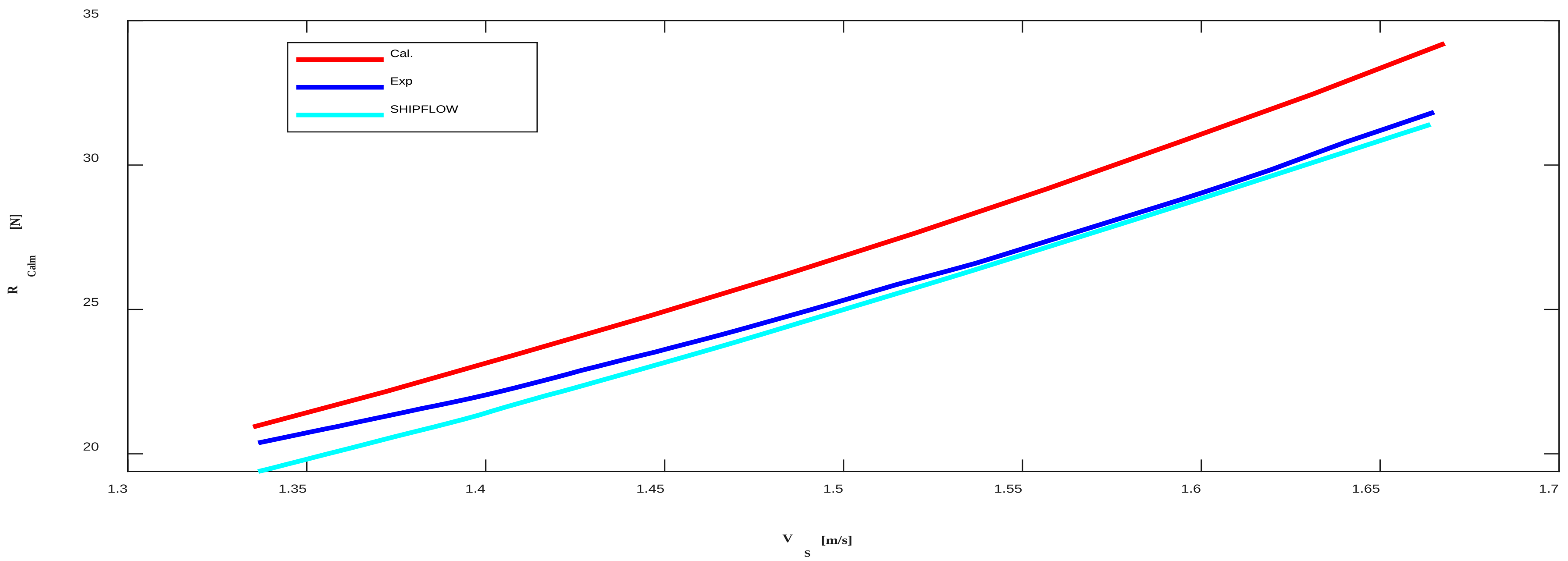


Fig 1. Comparison of the calm water resistance for the DTC container ship in the model scale.

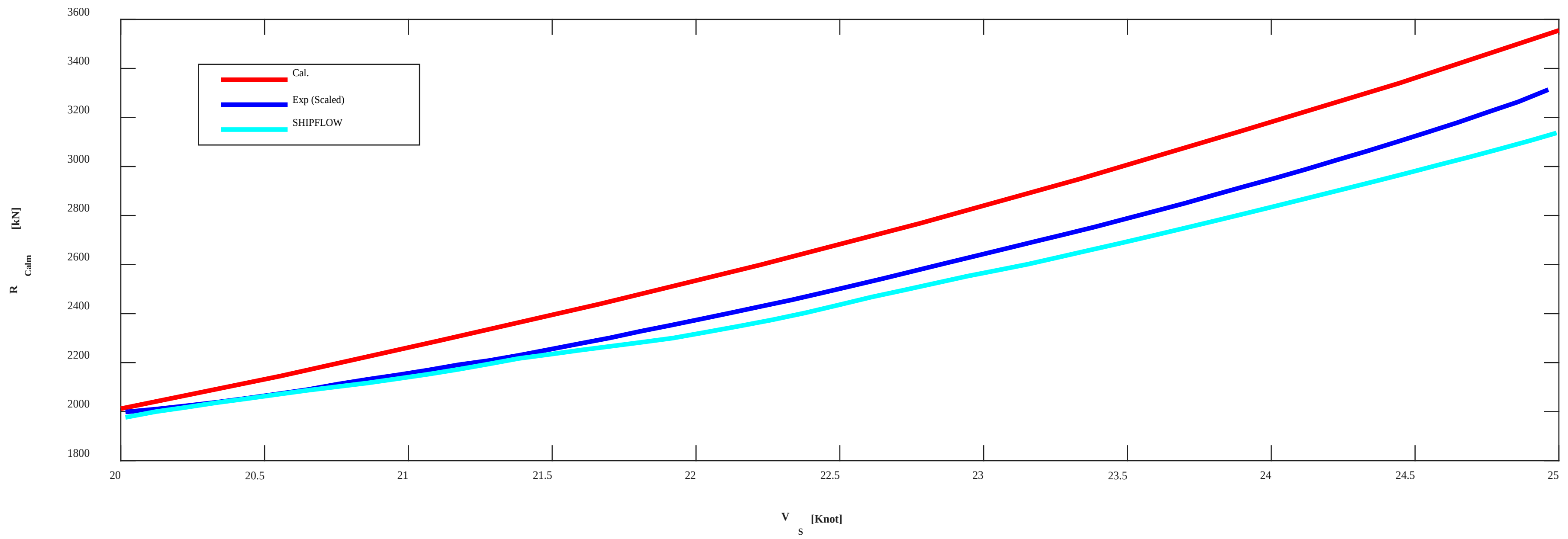


Fig 2. Comparison of the calm water resistance the DTC container ship in the full scale.

Reference: Eshan Esmailian PhD student WP, ongoing work on *Optimization of Ships for Operation in Real Sea States.*

Statistical Modeling of Ship's Hydrodynamic Performance Indicator

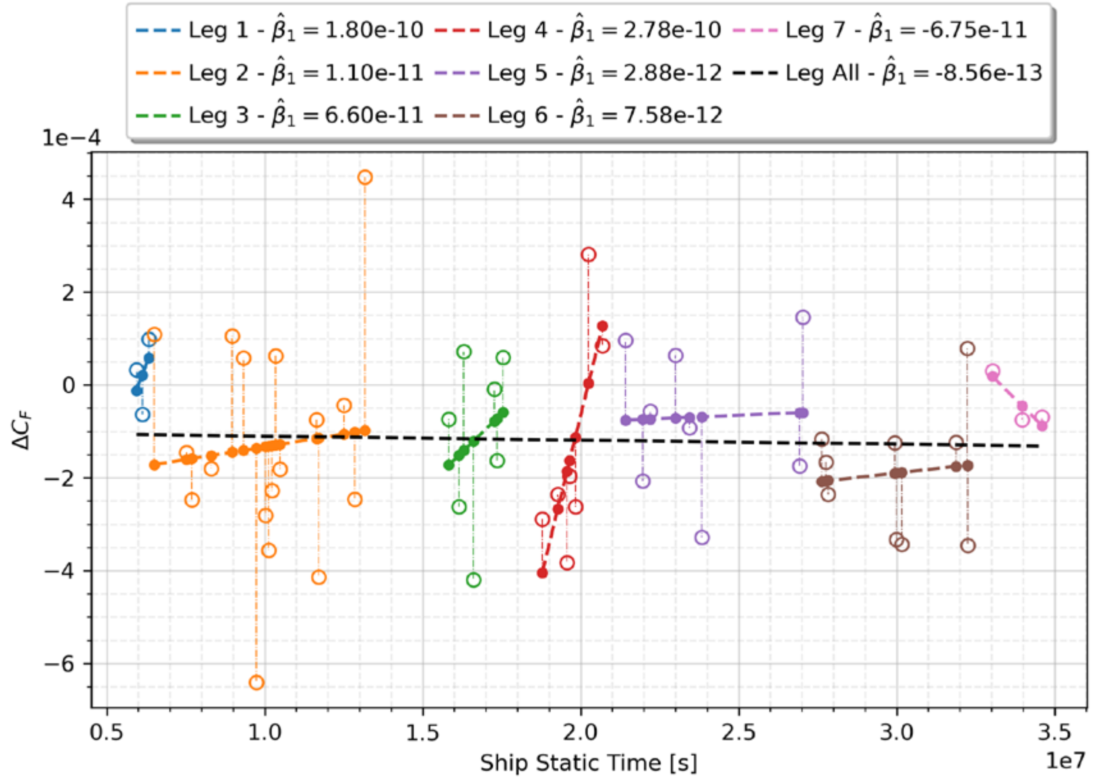
Contact: Prateek Gupta, Sverre Steen (NTNU)

The traditional method to estimate the hydrodynamic performance of a ship uses either model test results or one of many empirical methods to estimate and observe the trend in fouling friction coefficient (ΔC_F) over time. The biggest weakness of this method is that the model test results as well as the empirical methods are sometimes not well-fitted for the full-scale ship due to several reasons like scale effects and, therefore, this method may result in an inaccurate performance prediction. Moreover, in the case of a novel ship design, it would be nearly impossible to find a well-fitting empirical method. The current work establishes a new performance indicator, formulated in the form of generalized admiralty coefficient with displacement and speed exponents statistically estimated using the in-service data recorded onboard the ship itself. The method completely removes the dependence on empirical methods or model test results for the performance prediction of ships. It is observed that the performance predictions using the current method and the traditional method are based on the same underlying logic, and the results obtained from both methods are found to be in good agreement.

Comparing figures 1 and 2, it can be seen that both methods predict an unnatural trend in the performance change of the ship for some legs (leg 1, 6 & 7 for the current method in figure 2, and leg 7 for the traditional method in figure 1). Moreover, both methods predict a drop in performance after the last propeller cleaning event (between leg 6 & 7). Looking at the slopes for each leg, it is quite noticeable that both the methods predict the biggest performance drop in leg 4 and the second biggest drop in leg 3, and the predicted performance drop in leg 2 is quite comparable. Thus, the results obtained from the traditional method (fig 1) are in good agreement with results obtained from the current method (fig2).

As the results from the current method are well-validated, it provides the ship operators with a simplistic and easily implementable method to monitor the hydrodynamic performance of a ship directly using the in-service data, thereby, removing the dependence on empirical methods or model test results. The reference speed-power-displacement surface for calm-water conditions (represented by the generalized admiralty coefficient) can be easily estimated using the in-service data without carrying-out any environmental load corrections and marine fouling corrections. The environmental load corrections can be avoided by using a near-calm-water filtering limit for the in-service data, and the data recorded onboard a new-built ship may not need fouling corrections, as indicated by the results in the current work. Thus, the performance of a ship can be simply monitored by observing the trend in the generalized admiralty coefficient using the filtered near-calm-water in-service data.

Reference: Gupta, Prateek; Taskar, Bhushan; Steen, Sverre; Rasheed, Adil. Statistical Modeling of Ship's Hydrodynamic Performance Indicator. Journal of Applied Ocean Research. 2021. Preprint: http://dx.doi.org/10.13140/RG.2.2.10492.56964



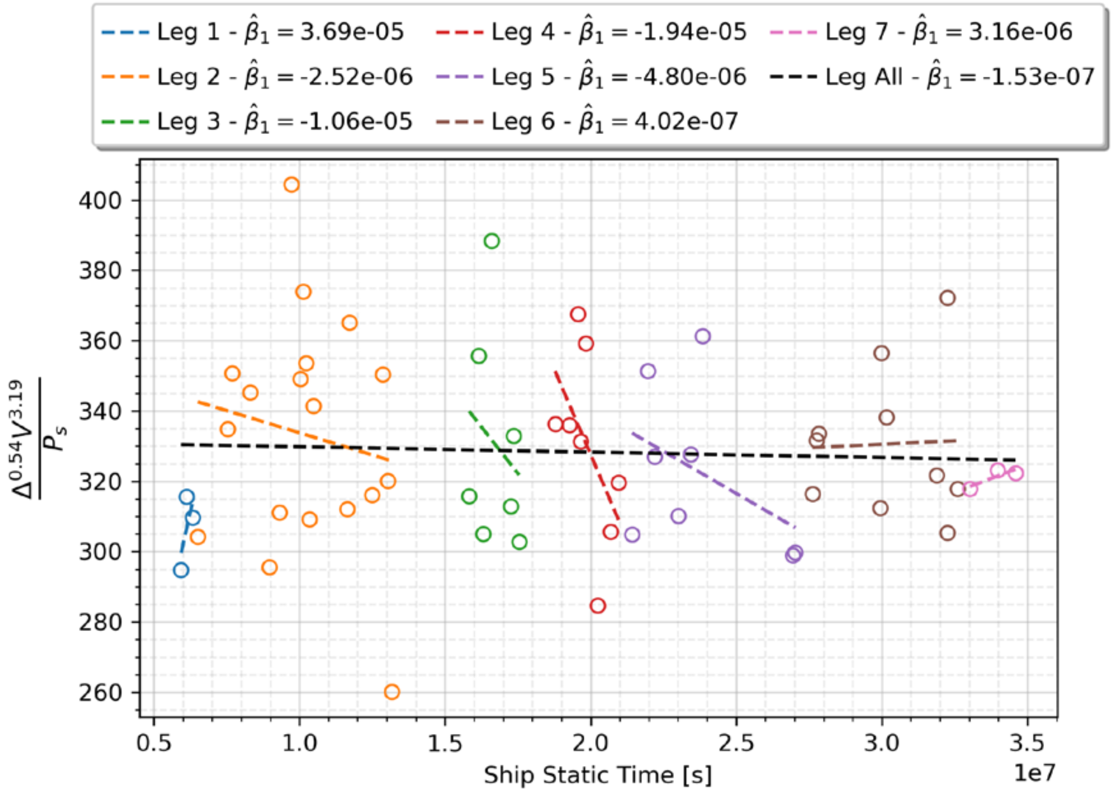


Figure 1 (upper) & 2 (lower): ***Fouling friction coefficient*** *(ΔCF) (Fig.1) and* ***Generalized admiralty coefficient*** *(Fig.2) with respect to ship static time showing the trend in the hydrodynamic performance of the ship.*

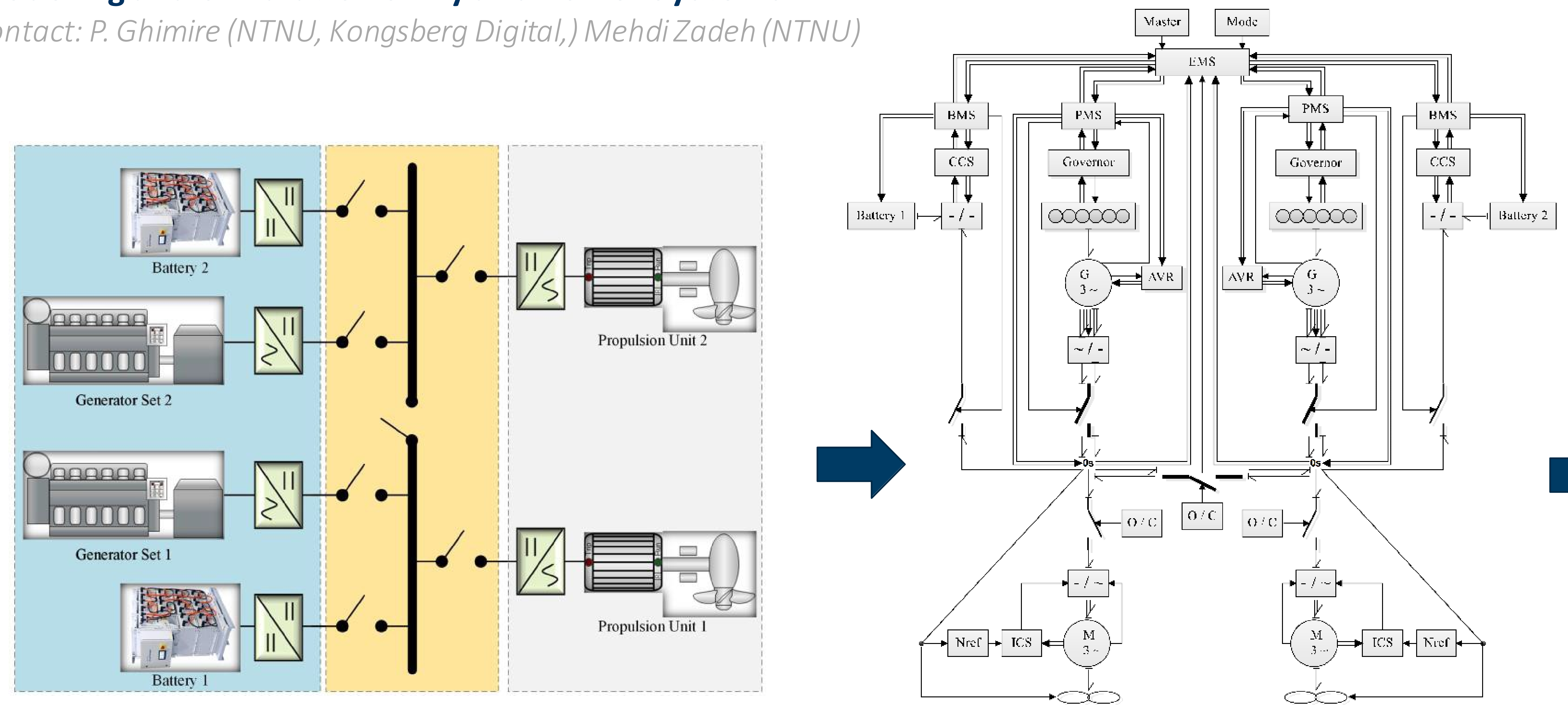
SMART MARITIME

POWER AND PROPULSION

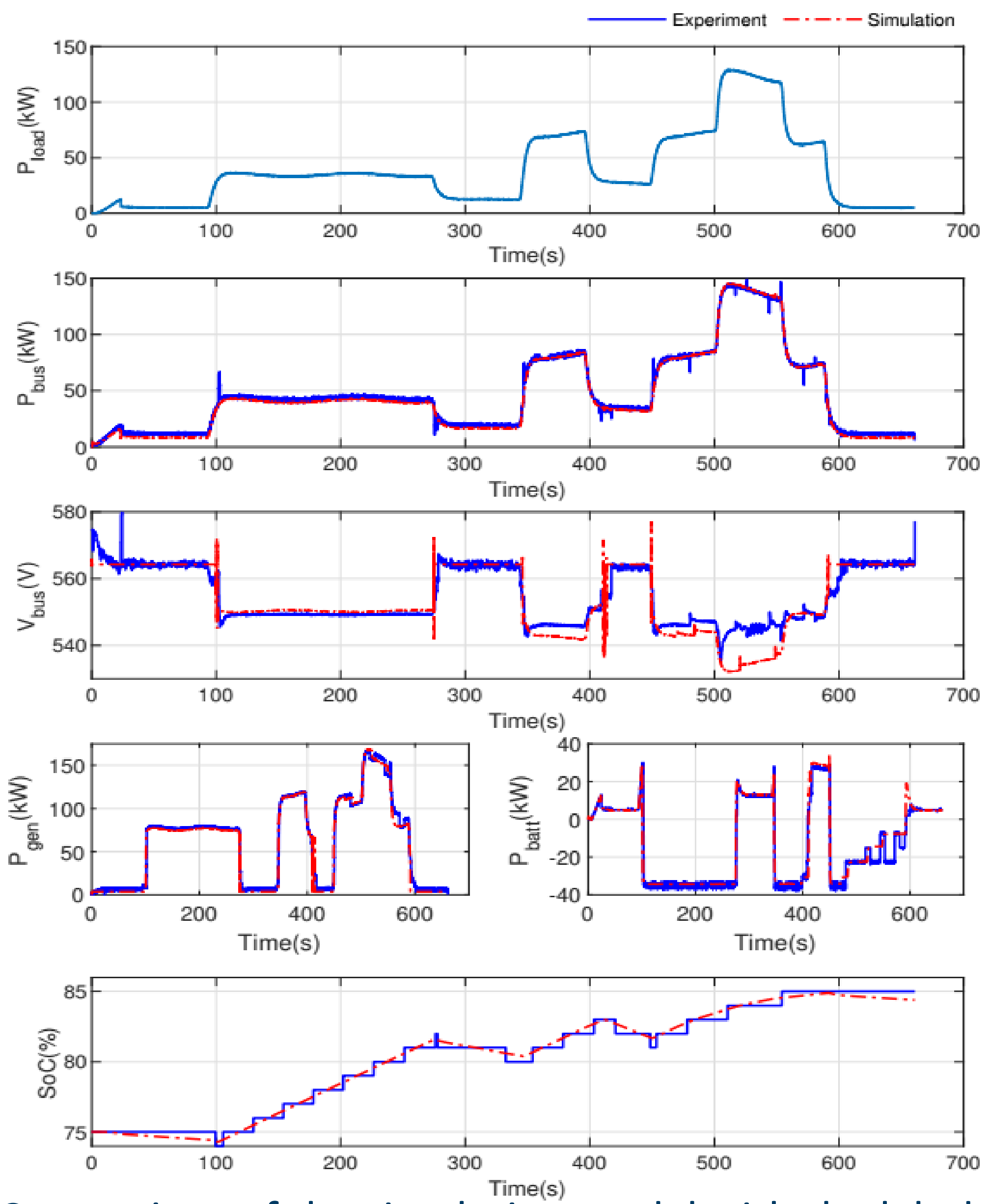
BW Pavilion Leeara, Photo: BW Group

Modeling and Simulation of Hybrid Power Systems

Contact: P. Ghimire (NTNU, Kongsberg Digital,) Mehdi Zadeh (NTNU)



From analytical model to simulation and experiment



Comparison of the simulation model with the lab data

Modelling fidelity: Design, analysis, control, and optimization of sophisticated hybrid power systems require reliable and efficient modelling tools. In this work, a typical DC hybrid power system model is developed using a bond graph modelling approach.

The developed system model, along with the rule-based energy management system, is used to simulate the entire system and investigate the load-sharing strategies and the system stability in various operating scenarios.

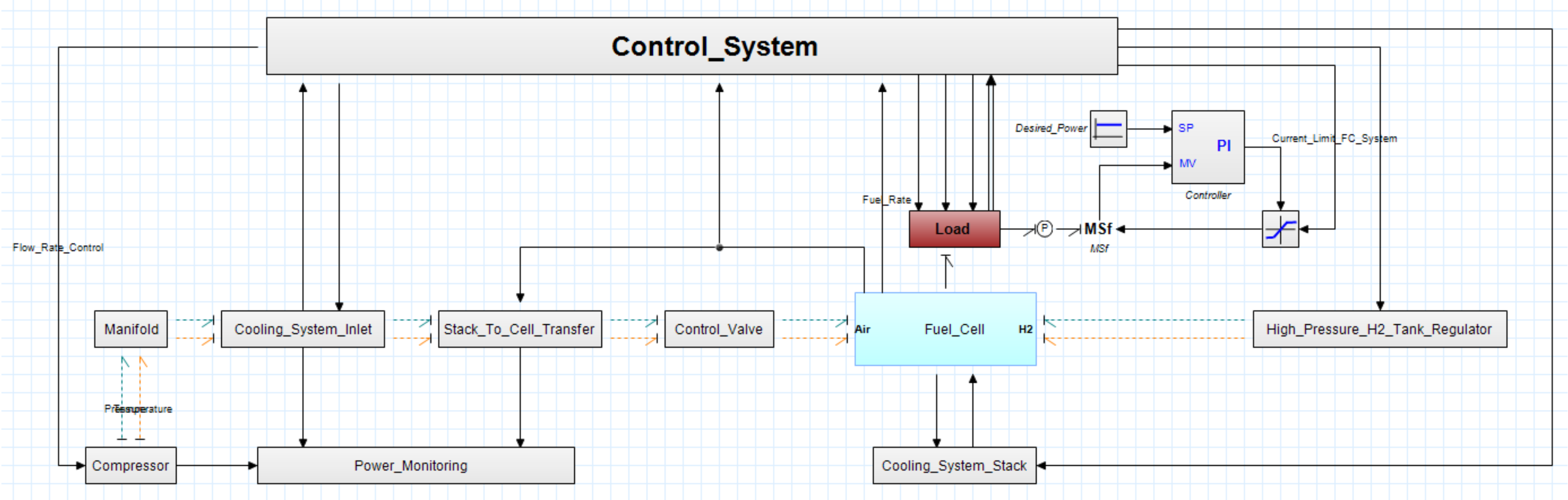
The simulation results are validated with experimental results conducted on a full-scale laboratory setup of DC hybrid power system and with a ship load profile. The results show that the system model is capable of capturing the fundamental dynamics of the real system.

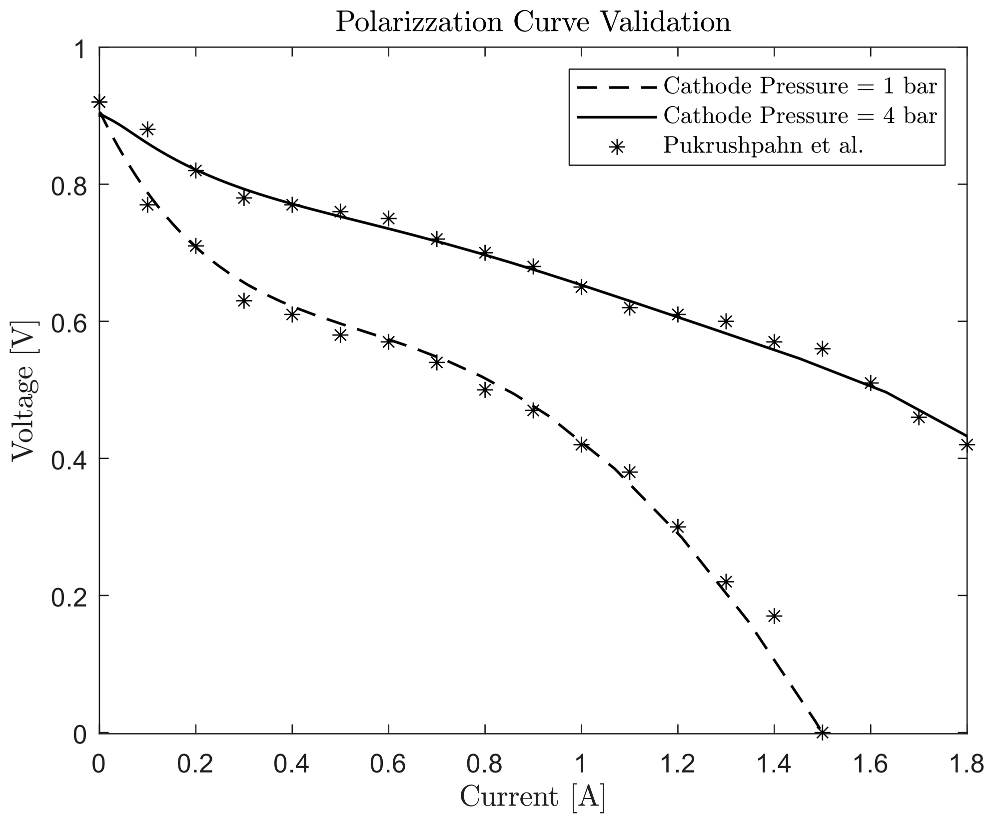
Reference: P. Ghimire, M. Zadeh, E. Pedersen and J. Thorstensen, "Dynamic Modeling, Simulation, and Testing of a Marine DC Hybrid Power System," in IEEE Transactions on Transportation Electrification, doi: 10.1109/TTE.2020.3023896.

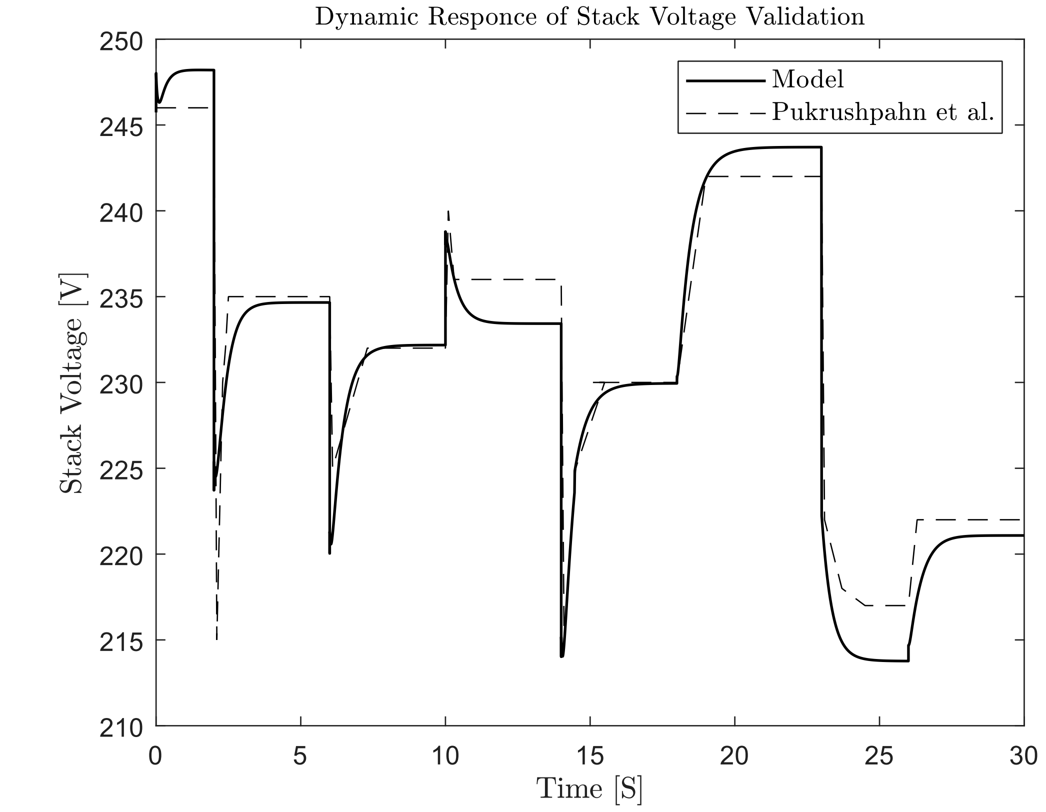
CFD modelling of fuel cell

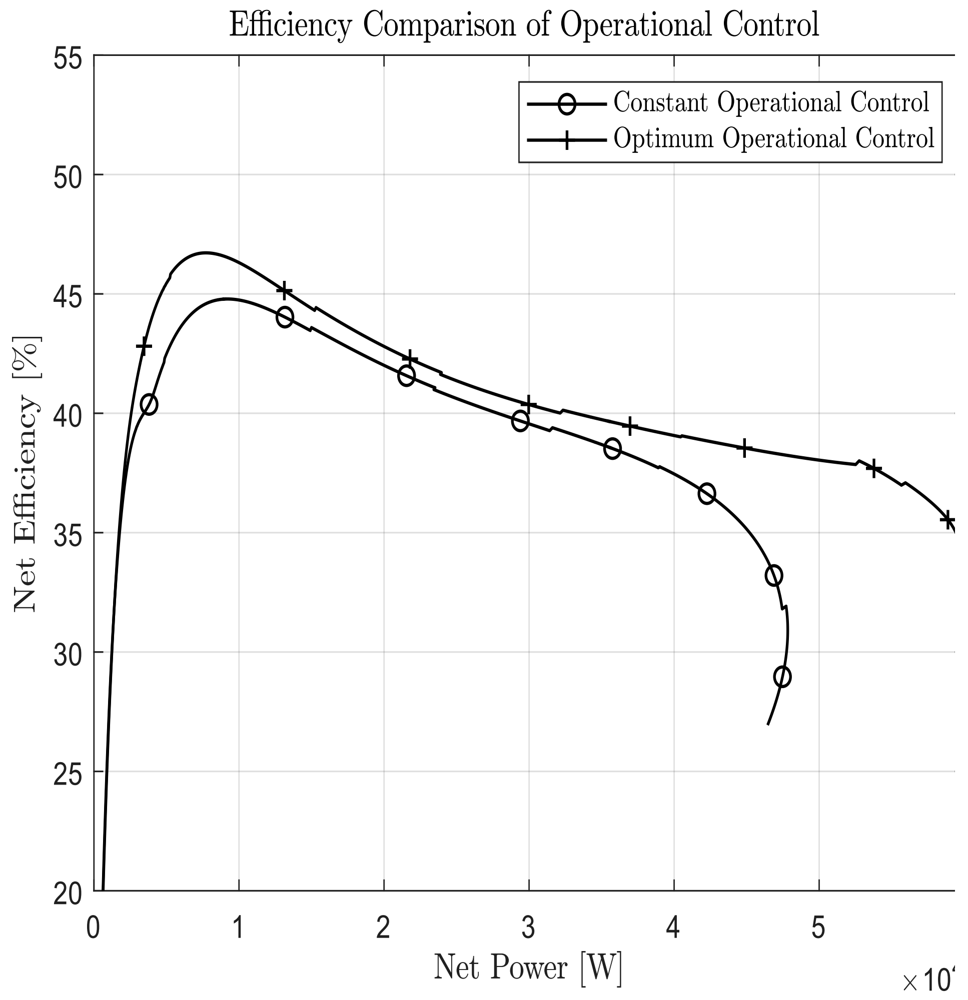
Contact: Kamyar Maleki (NTNU)

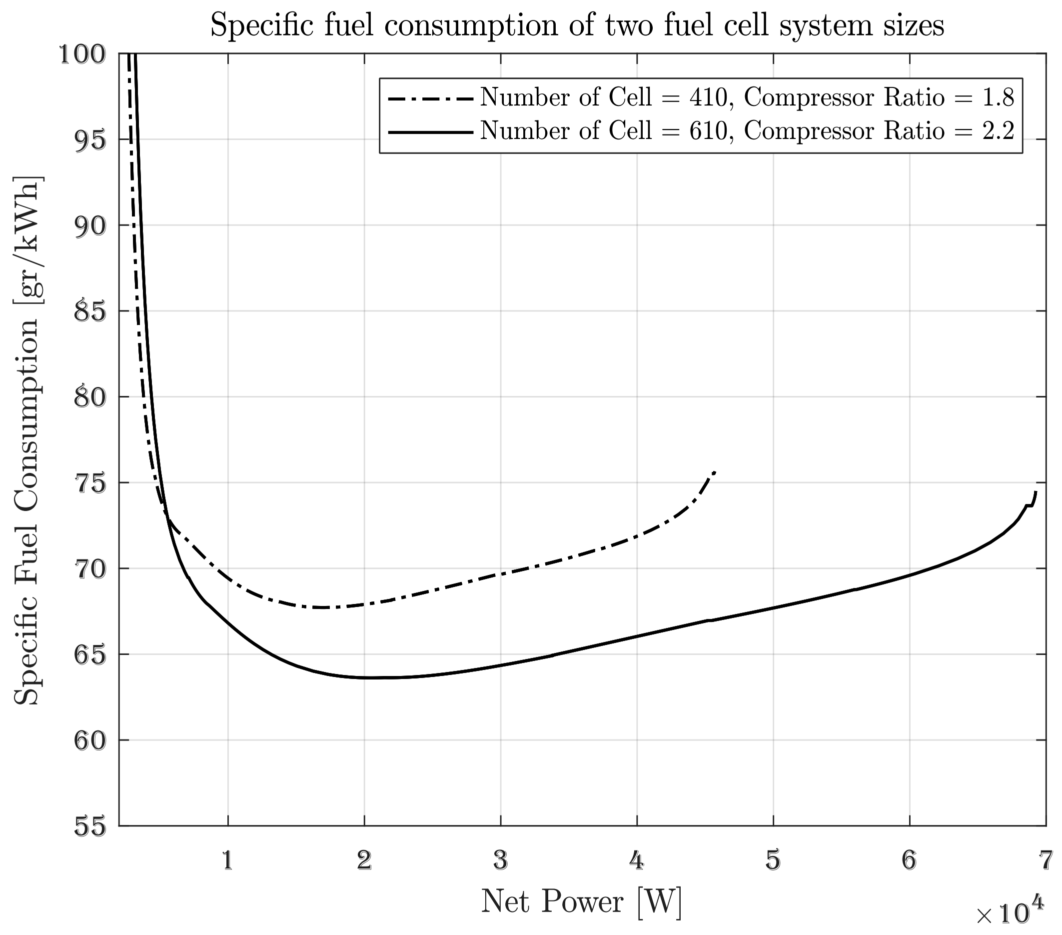
- Modular and flexible modeling of PEM fuel cell system based on physics
- Optimization of PEM fuel cell system components and operational parameters
- Modeling of simple DC hybrid power system with PEM fuel cell and battery
- Optimal sizing of fuel cell and battery based on efficiency curve









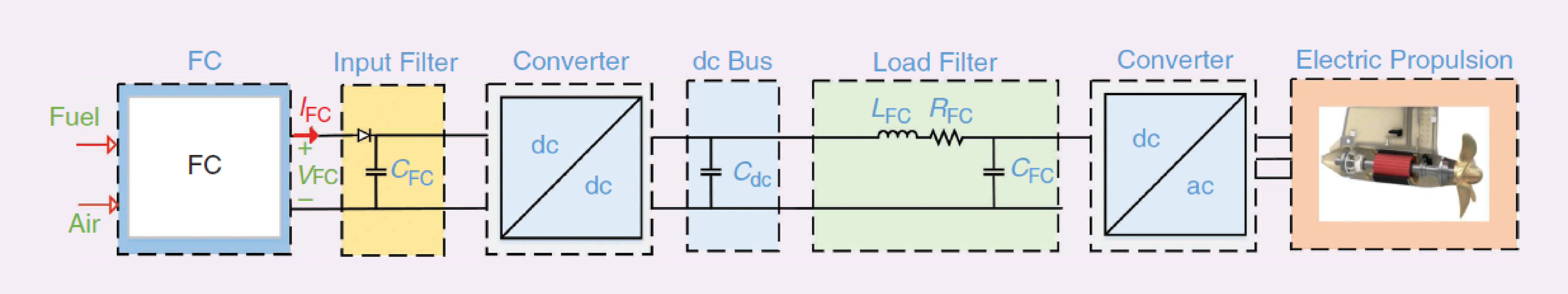


Reference: work under publication, WP3, Kamyar Maleki - Simulator Approach to Concept Analysis and Optimization of Marine Power Plants

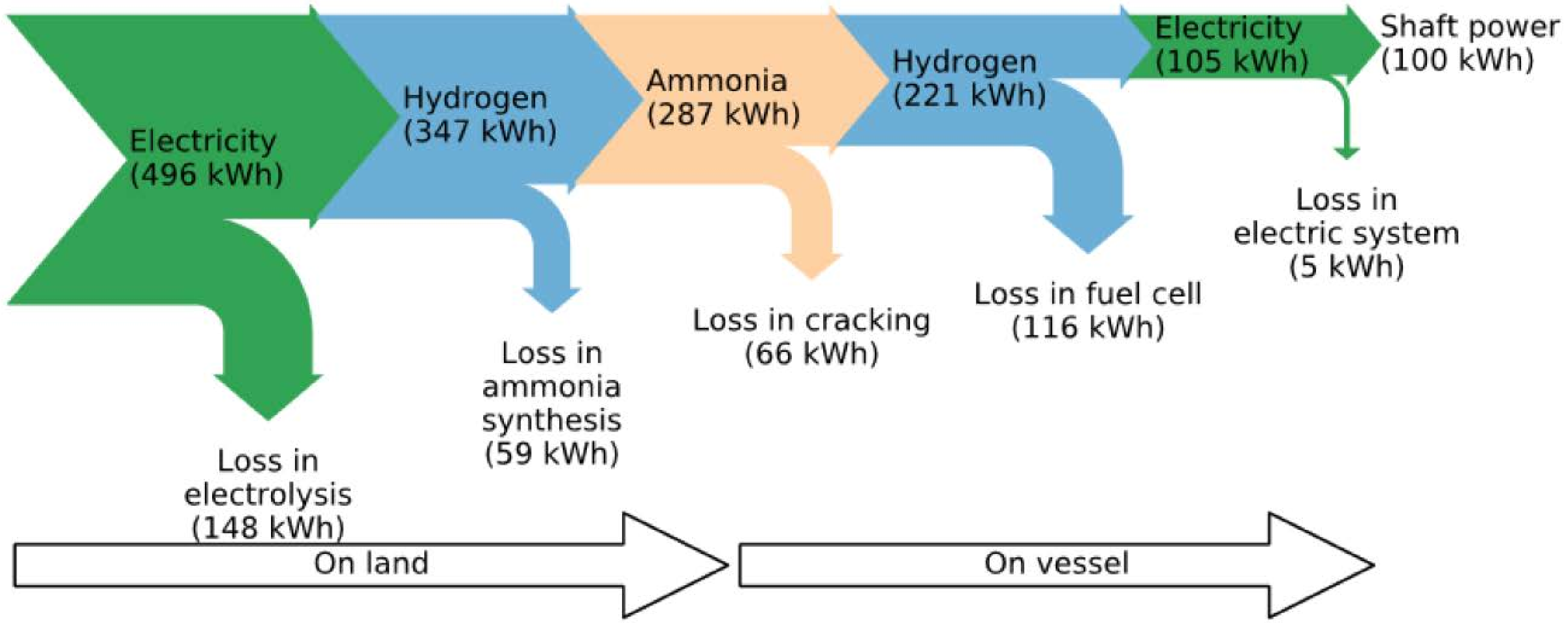
Hydrogen propulsion

Contact: Mehdi Zadeh (NTNU), Jørgen B. Nielsen (SINTEF Ocean)

The study of Hydrogen Fuel Cells for Ship Electric Propulsion by Shakeri et al. (2020) addresses several challenges related to the development of zero-emission ship propulsion through hydrogen fuel cells (FCs) as the main source of energy. One main barrier to the development of FC propulsion is the production and transportation of hydrogen. However, in this article, it is assumed that hydrogen is available in the form of pure hydrogen or hydrocarbons. Still, many challenges related to the installation and operation of the FC remain; we discuss some of the main issues, such as the technical requirements for FC installation onboard, power system integration, control, and safety and related regulations. The factors addressed in this article are limited to the tools, requirements, and components that are physically located onboard ships.



Electrical diagram of a typical Fuel Cell powertrain (Shakeri et al., 2020)



Energy loss, from hydrogen production to power train (Bremnes Nielsen, 2020)

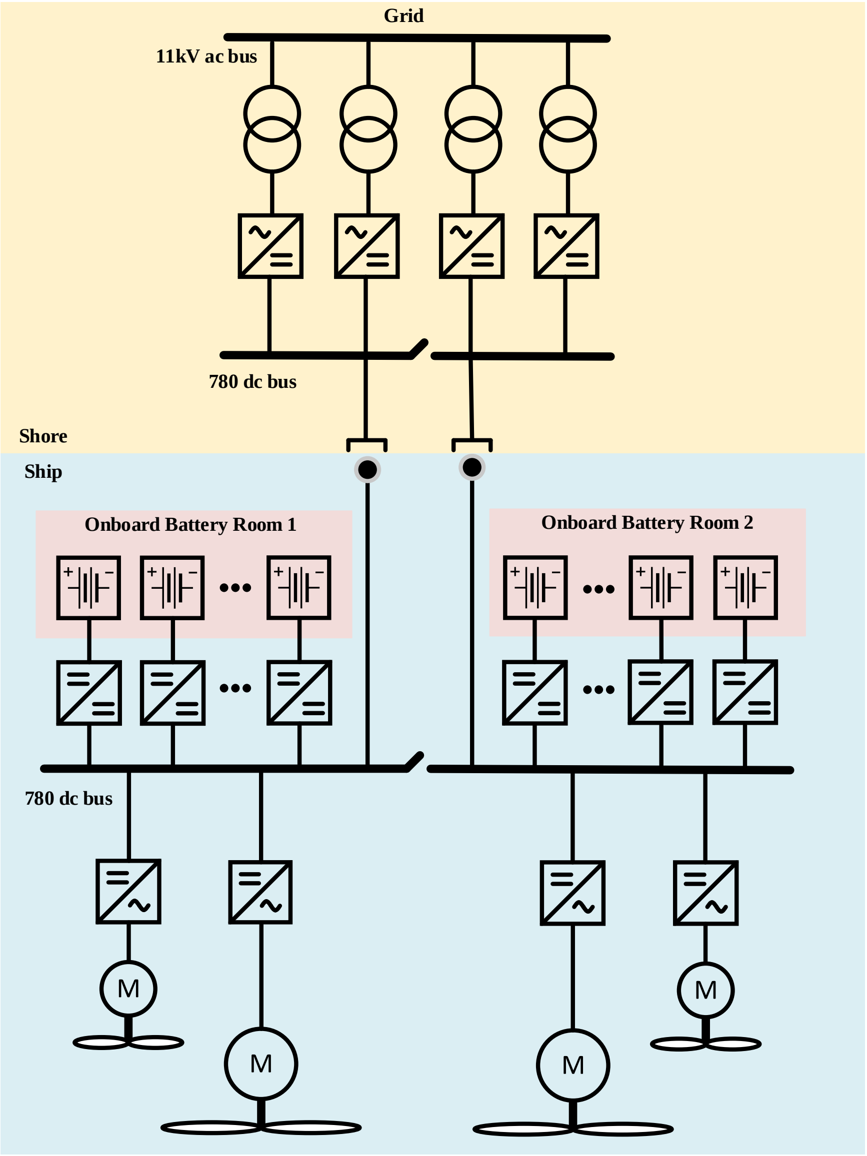
Reference:
N. Shakeri, M. Zadeh and J. Bremnes Nielsen, "Hydrogen Fuel Cells for Ship Electric Propulsion: Moving Toward Greener Ships," in IEEE Electrification Magazine, vol. 8, no. 2, pp. 27-43, June 2020, doi: 10.1109/MELE.2020.2985484.
J. B. Nielsen et al (2020); Alternative Fuels and Flexible Technology Solutions, WEBINAR Smart Maritime 2020-03-11

Shore to ship charging

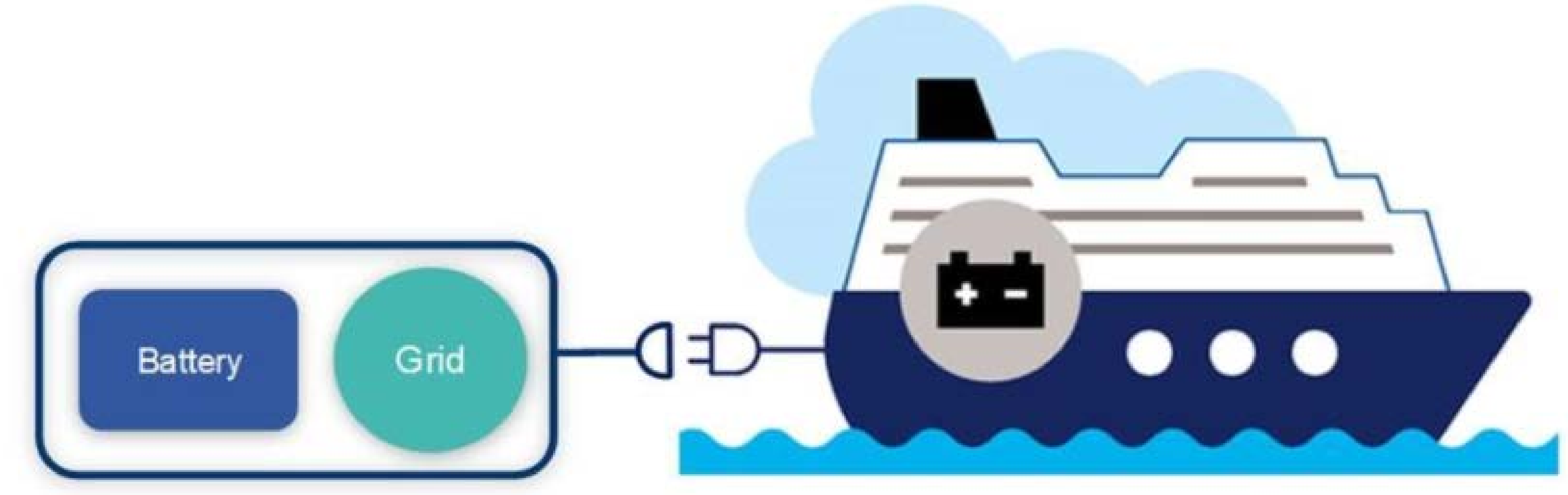
Contact: Siamak Karimi, Mehdi Zadeh (NTNU)

Shore-to-ship charging systems are usually designed based on various operational and design parameters including the onboard power and propulsion requirements, available charging times, and the capability of local power grids. In rural areas with weak grids, onshore energy storages are utilized to enable the high-power charging necessary for vessels with short charging times. However, on-shore energy storage increases the system complexity, and the choice of system configuration can have significant impact on the energy transfer efficiency from the grid to the vessel. This paper presents an energy efficiency comparison between AC, DC and Inductive shore-to-ship charging solutions for short-distanced ferries with AC- and DC-based propulsion. The results demonstrate how an increased share of energy contribution from the onshore battery leads to reduced overall energy efficiency of the charging process.

Hence, the energy efficiency should be considered when sharing the load between the grid and the onshore battery. The results show that DC charging is advantageous over other solutions for AC-based propulsion systems in terms of energy efficiency. However, for a DC-based propulsion system, the most efficient solution could be either DC or the AC charging, depending on the load sharing between the grid and onshore battery. Moreover, it is concluded that the inductive charging solution energy efficiency is not far less than the wired schemes, even though it adds more conversion stages and complexity to the system. Considering other advantages of contactless charging, namely, reliability, safety and robustness, these results promote the inductive charging as a promising solution.



Single line diagram of an all-electric ship with shore-to-ship charging.



Shore-to-ship charging for all-electric or hybrid ships

References:

S. Karimi, M. Zadeh and J. A. Suul, "Evaluation of Energy Transfer Efficiency for Shore-to-Ship Fast Charging Systems," 2020 IEEE 29th International Symposium on Industrial Electronics (ISIE), Delft, Netherlands, 2020, pp. 1271-1277.

S. Karimi, M. Zadeh and J. A. Suul, "Shore Charging for Plug-In Battery-Powered Ships: Power System Architecture, infrastructure, and Control," in IEEE Electrification Magazine, vol. 8, no. 3, pp. 47-61, Sept. 2020.

SMART MARITIME

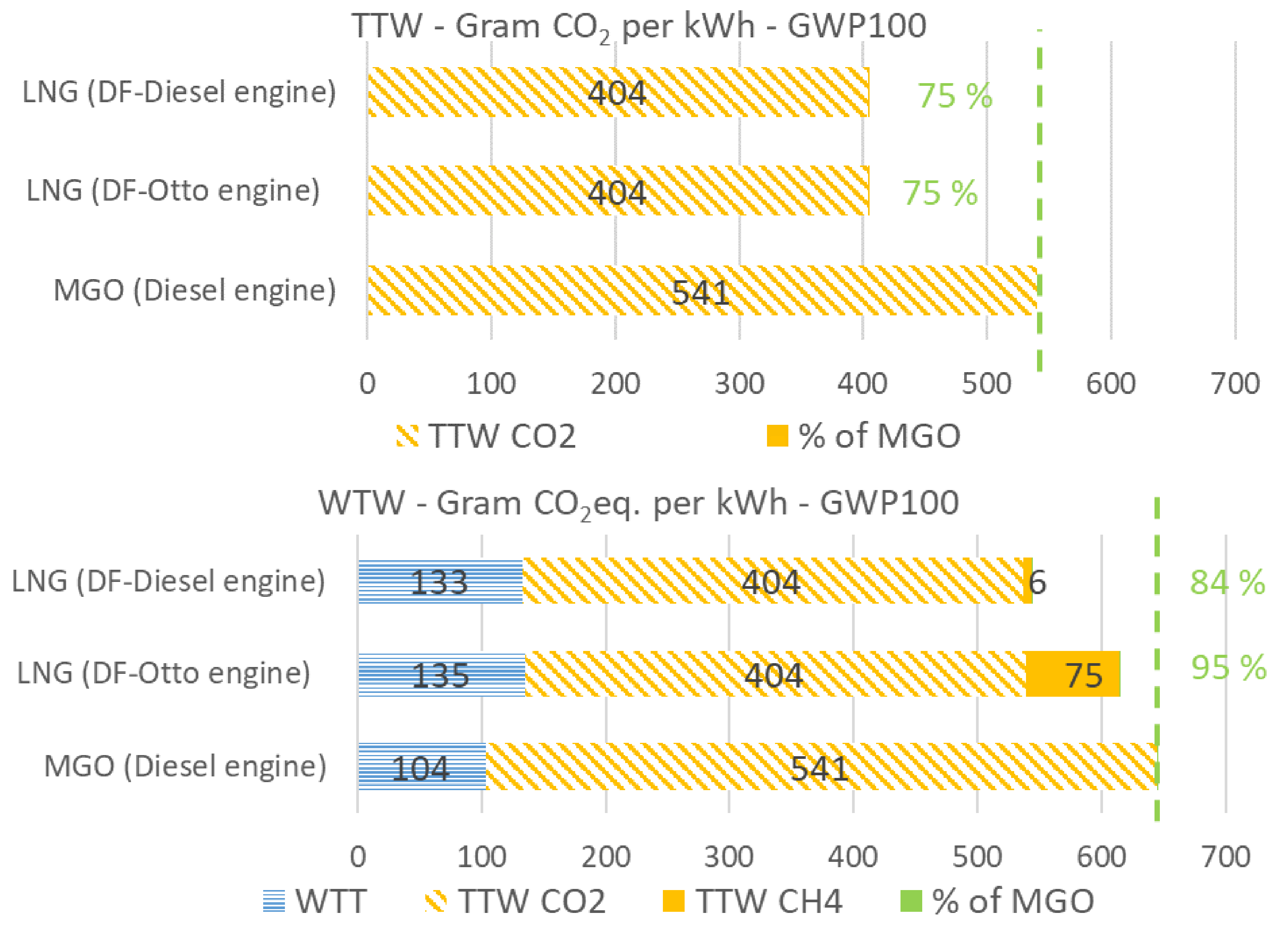
LNG as a transition fuel

Contact: Elizabeth Lindstad (SINTEF Ocean)

Liquefied natural gas (LNG) is by many seen as a potential transition fuel for decarbonizing shipping. Its favourable hydrogen to carbon ratio compared to diesel or bunker fuel translates directly into lower carbon emissions per kilowatt produced. However, these gains may be nullified once one includes the higher Well-to-Tank emissions (WTT) of the LNG supply chain and the vessel's un-combusted methane slip (CH4) from its combustion engine.
This study investigates under what conditions LNG can serve as a transition fuel in the decarbonization of maritime transport. We establish a robust and transparent estimation of well-to-wake GHG emissions for distinct LNG dual fuel engines compared to conventional fuels. We conduct an economic analysis of alternative engine technologies based applied to a Supramax dry bulker 63000 dwt, highlighting the potential of dual fuel engines. The results show the importance of applying appropriate engine technologies to maximize GHG reductions, and indicate that only a high-pressure dual fuel diesel type engine gives real GHG reductions on a WTW perspective (15% compared to MGO). While the GHG reduction of LNG even with best engine technology (i.e. dual fuel diesel engines) are small, ships with these engines can with modest modification switch to ammonia produced with renewable energy when it becomes available in sufficient amounts. This study illustrates the necessity of adopting policies targeting broad GHG emissions from shipping instead of CO2 only, as well as including the well-to-tank emissions of marine fuels instead of operational emissions only.

References:
SFI Smart Maritime Report: Fuels and engine technologies – SFI Smart Maritime – version 3.0, 14th of April 2020
E. Lindstad, Eskeland, G., Rialland, A., Valland, A. Decarbonizing Maritime Transport: The Importance of Engine Technology and Regulations for LNG to serve as a Transition Fuel. Sustainability 2020 ;Volume 12.(21)

Example of a 2-stroke engine, comparing MGO with LNG in dual-fuel engines on a Tank-to-wake (upper figure) vs. Well-to-wake (bottom figure) basis.



On a Tank-to-Wake basis, including only CO2 emissions, both LNG engine options reduces emissions with 25% reductions compared to MGO.
With Well-to-Wake, and including CH4 emissions, the advantage of LNG DF-diesel is reduced to 16% compared to MGO, while the advantage of the LNG DF-Otto option is reduced to only 5%.

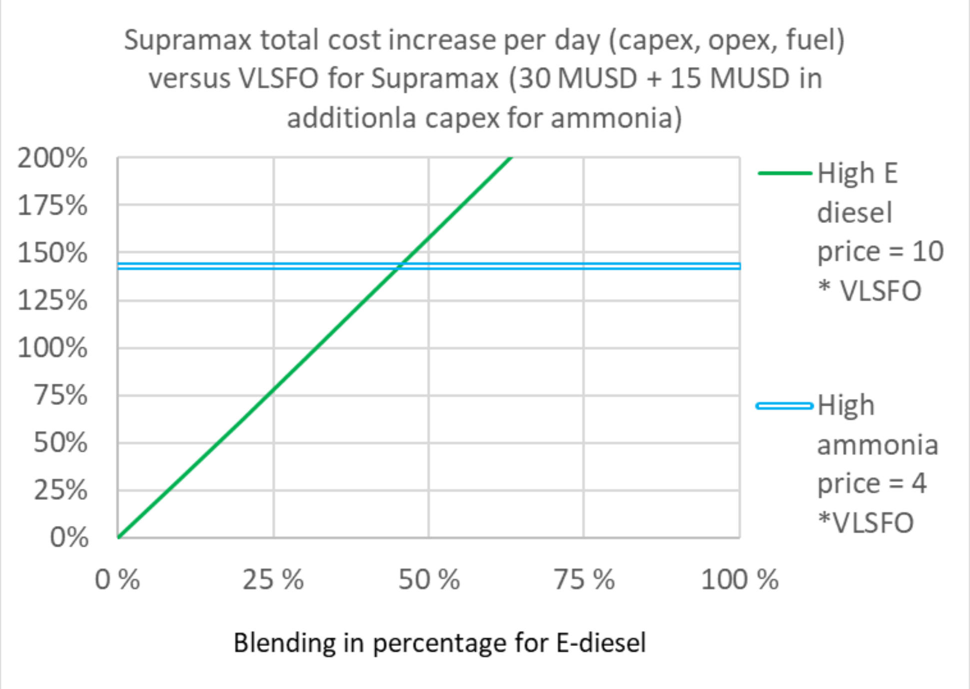
Fuel Study: Comparing synthetic e-fuels with hydrogen and ammonia solutions

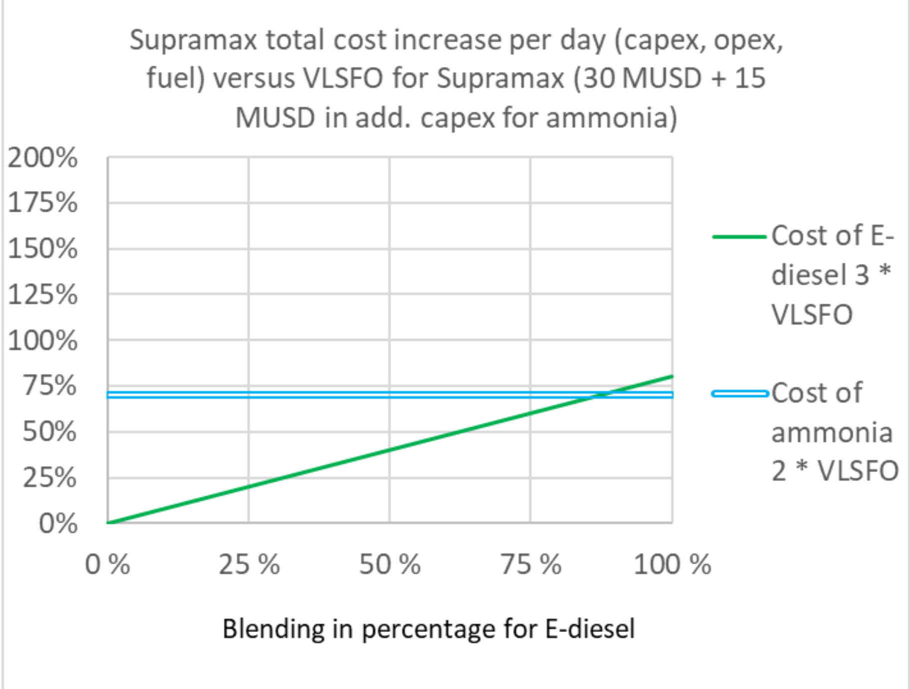
Contact: Elizabeth Lindstad (SINTEF Ocean)

Hydrogen and Ammonia's WTW emissions are determined by the combination of their production pattern and their energy source:

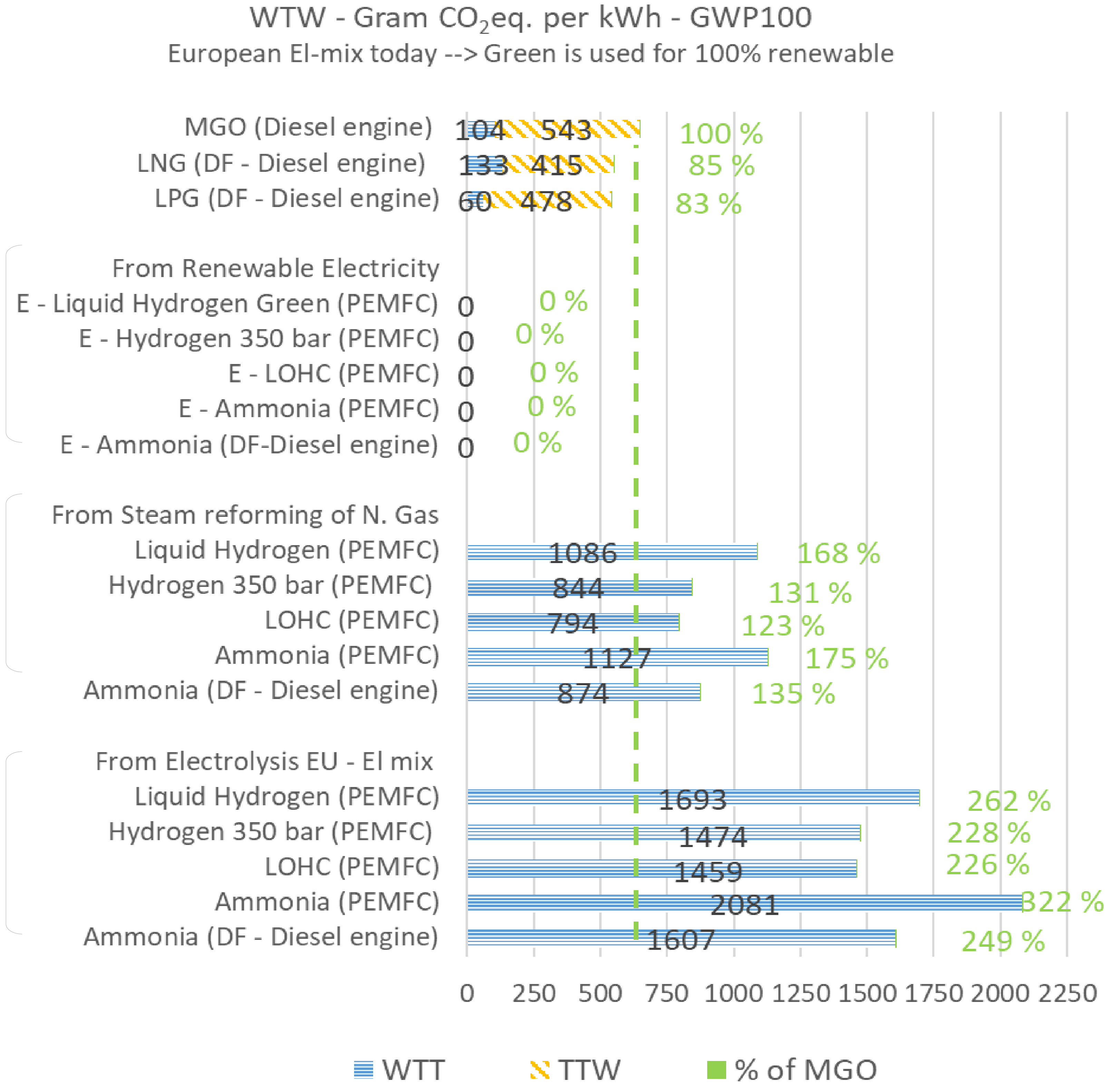
- From electrolysis with renewable energy
- From steam reforming of natural gas
- From electrolysis: example with EU-el-mix nearly doubling the WTT emissions compare to steam reforming

Synthetic electro-fuels or e-fuels are gaseous or liquid fuels from hydrogen and captured carbon using renewable electricity, with high energy efficiency and enables blends such as MGO & e-diesel or LNG & e-LNG.





Reference: E. Lindstad. Sustainable Alternative Marine Fuels, Smart Maritime WEBINAR 2020-10-06



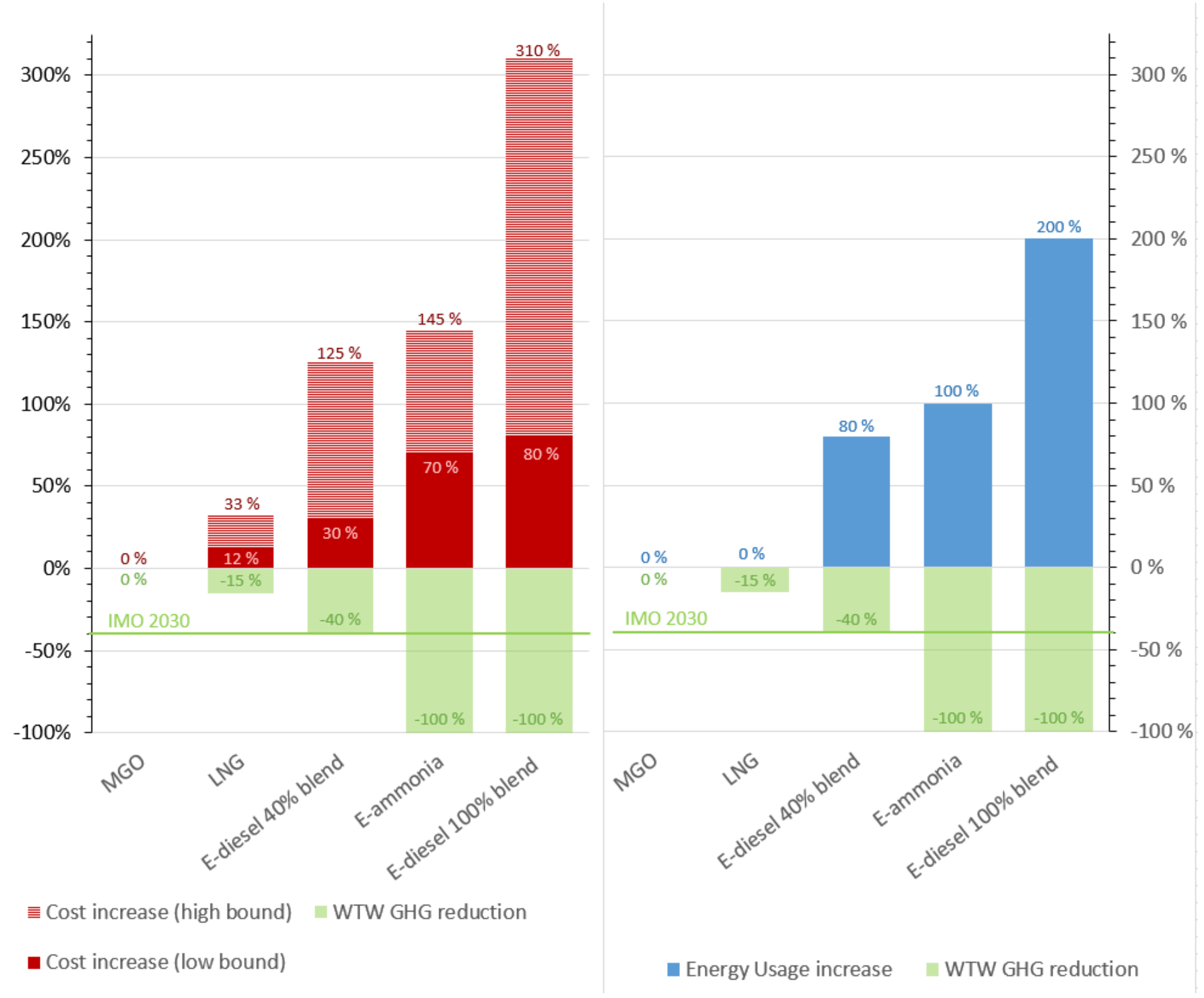
Impact of e-fuel prices:

- With low E-fuel prices, E-diesel seams much more attractive than ammonia.
- With high E-fuels prices (LR & UMAS, 2020) even a 25% GHG reduction comes at a 75% increase of total vessel cost (capex+opex+fuel) and a 100% reduction at a 140% cost increase

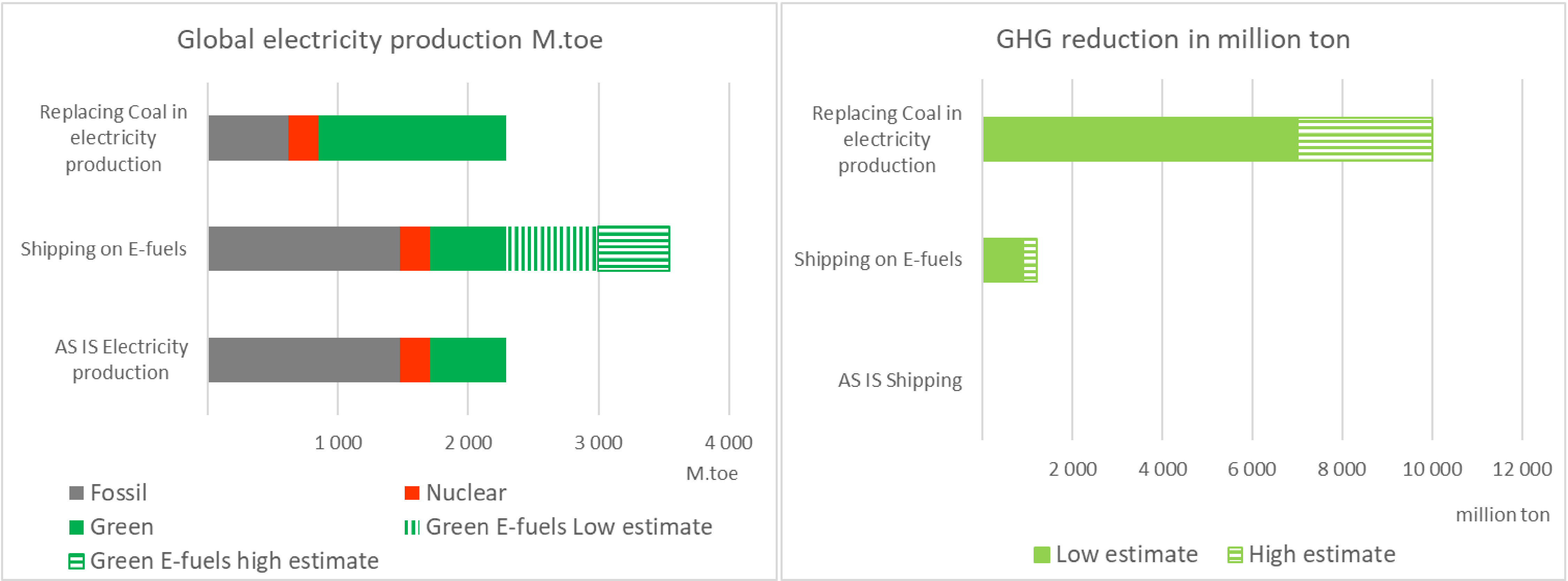
Assessing Alternative Fuel pathways considering GHG emissions, Energy usage and Cost, in a Well-to-Wake perspective

Contact: Elizabeth Lindstad (SINTEF Ocean)

To fairly compare alternative fuels and fuel pathways, comprehensive view of the economic, environmental and sustainability aspects of fuel selection and pathways.



Comparing alternative fuel pathways' impacts of costs, GHG emissions and energy usage (Baseline: MGO)



Global GHG emissions can be reduced 5–10 more times per kWh by exploiting renewable energy to replace coal fired power plants in stead of for producing e-fuels.

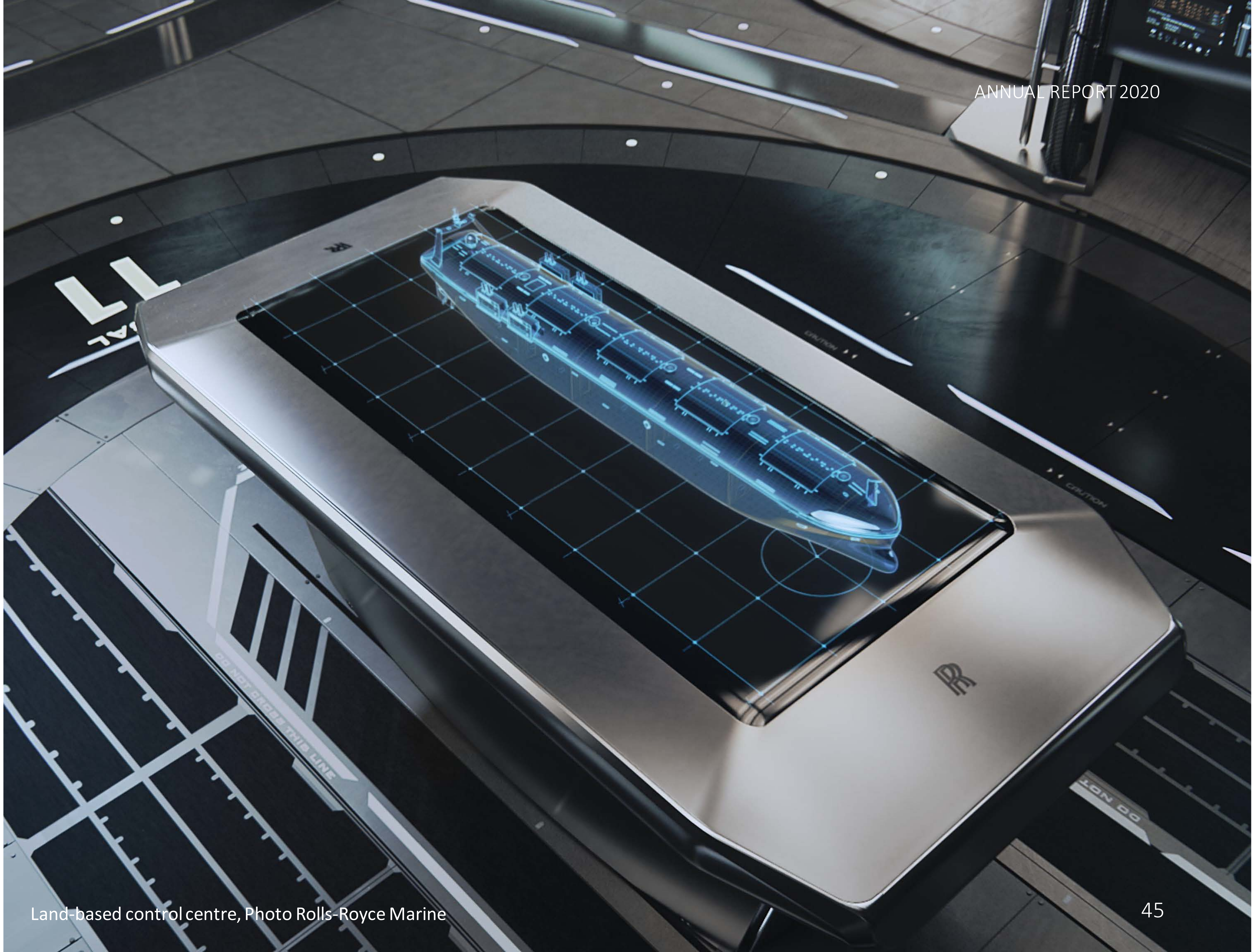
Reference:

E. Lindstad, Pathways and investment strategies to reach IMO 2030 and IMO 2050 GHG targets. Smart Maritime WEBINAR 2020-12-01

Lindstad, Valland, Rialland. Assessment of Alternative Fuels and Engine technologies to reduce GHG, SNAME 2021. Under publication

SMART MARITIME

SIMULATION PLATFORM

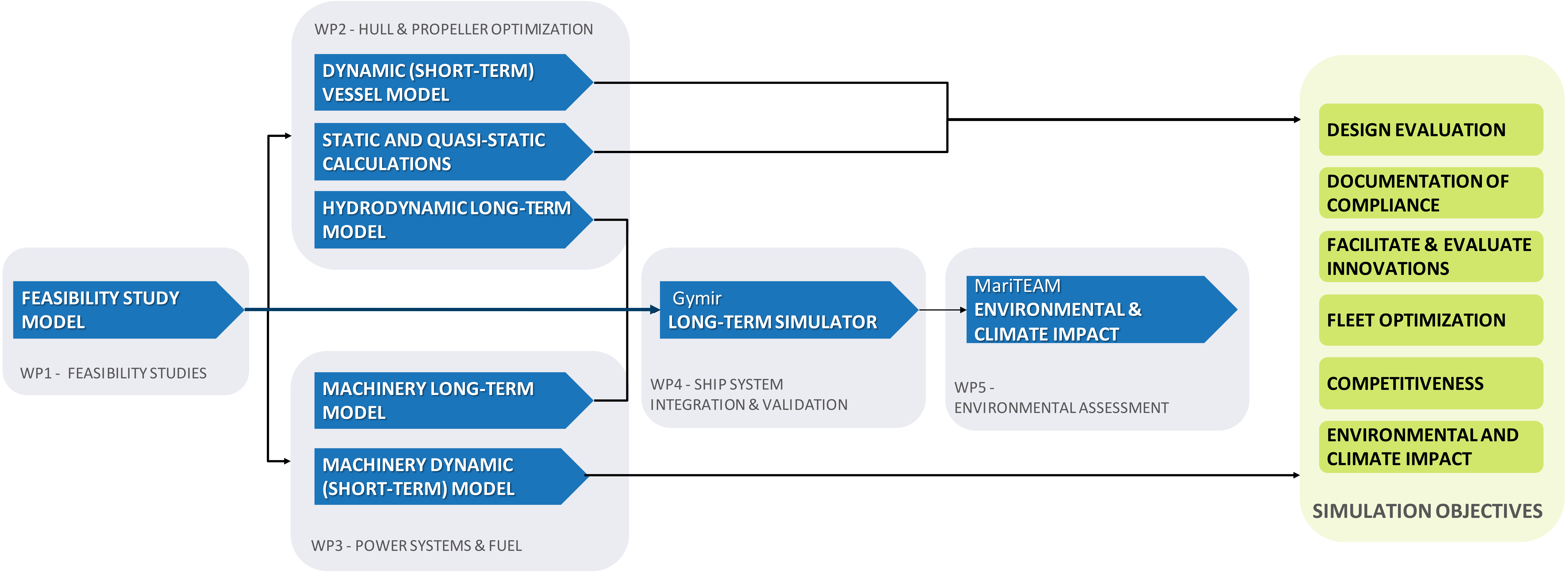


Land-based control centre, Photo Rolls-Royce Marine

System-oriented analysis platform

Smart Maritime's system-oriented analysis platform aims at assessing the effect of energy savings solutions under realistic operation- and weather conditions. The purpose of the platform is to support the efficient and effective simulation and optimization of a ship, virtually and in an early design phase.

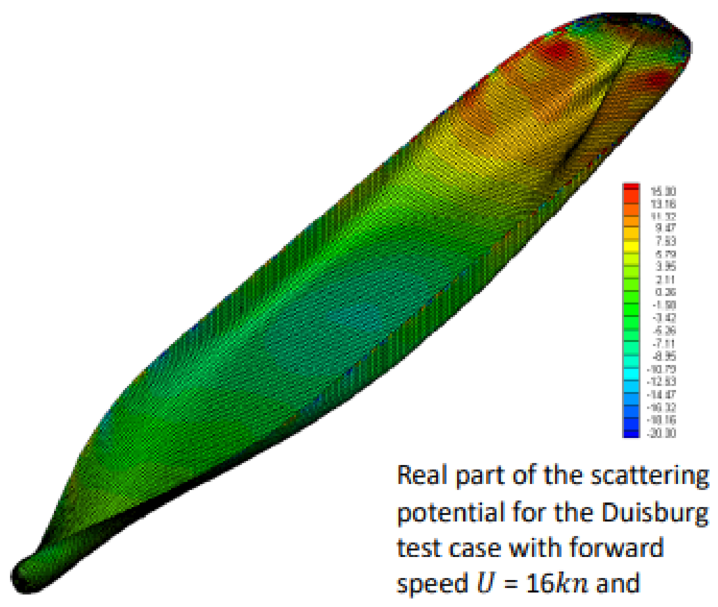
Simulations tools for hull and propeller optimization and power systems are available as stand-alone tools, as well as integrated through the Long-Term Ship Performance Simulation tool Gymir.



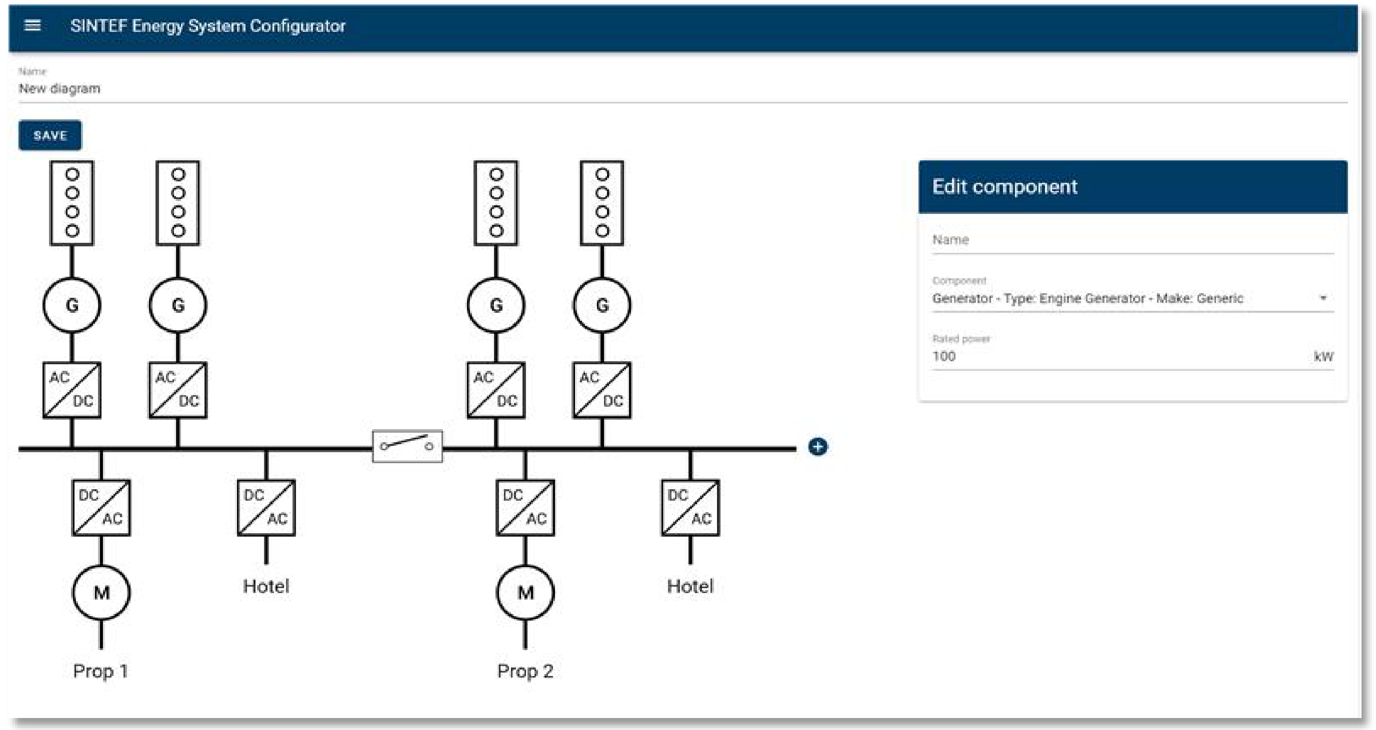
Smart Maritime Analysis and Simulation Tools

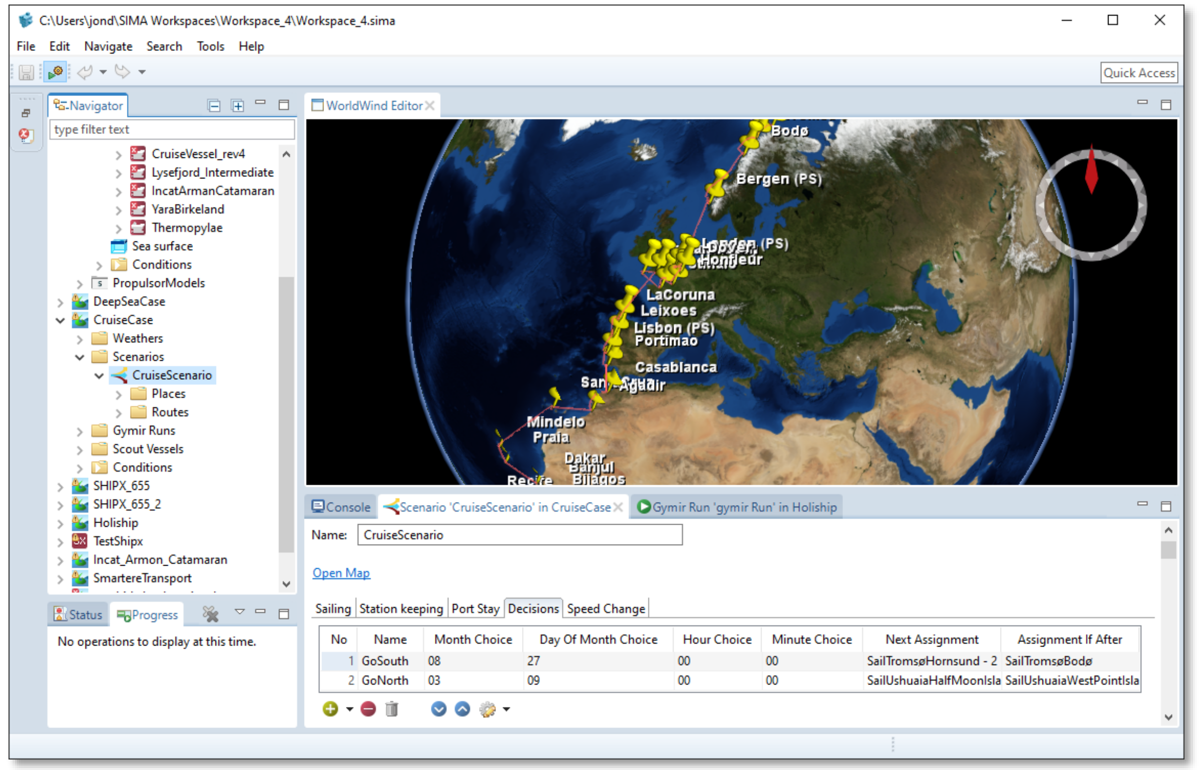
2020 achievements:

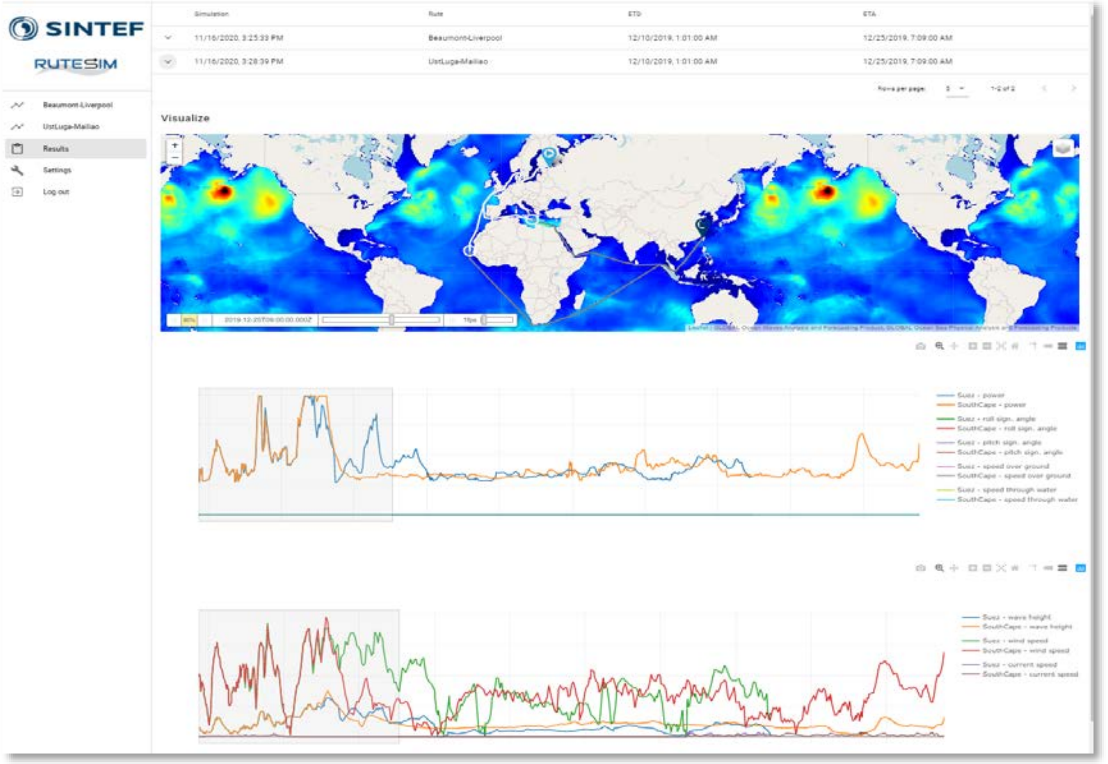
- VERES3D for added resistance in waves
- Hybrid power system simulator
- Wind-assisted propulsion
- GYMIR for RuteSim
- MariTEAM for fleet emission calculations



Real part of the scattering potential for the Duisburg test case with forward speed U = 16kn and wave period T = 14.0 sec







SMART MARITIME

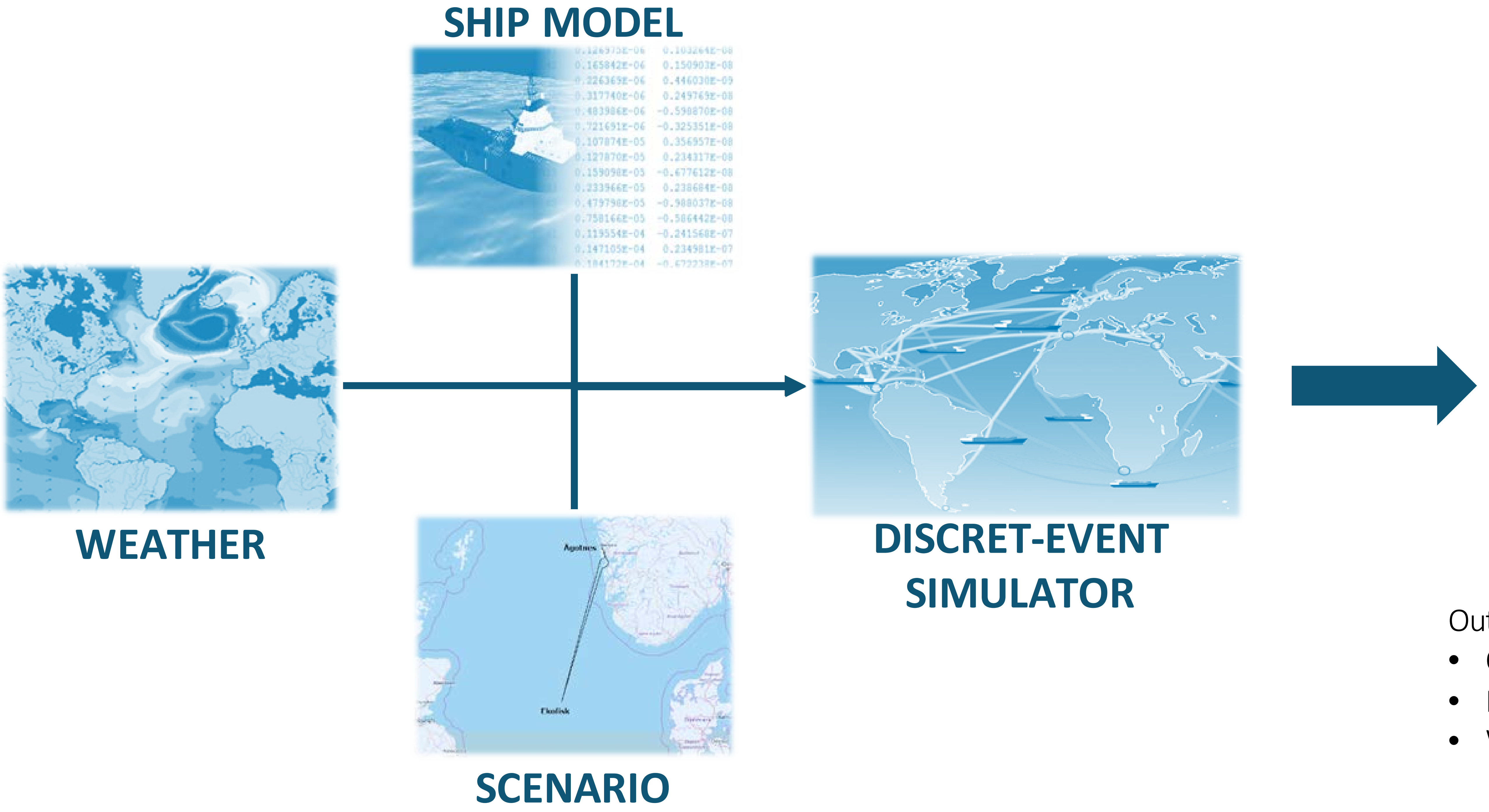
Gymir – ship performance simulation

Contact: Jon Schonhovd Dæhlen (SINTEF Ocean)

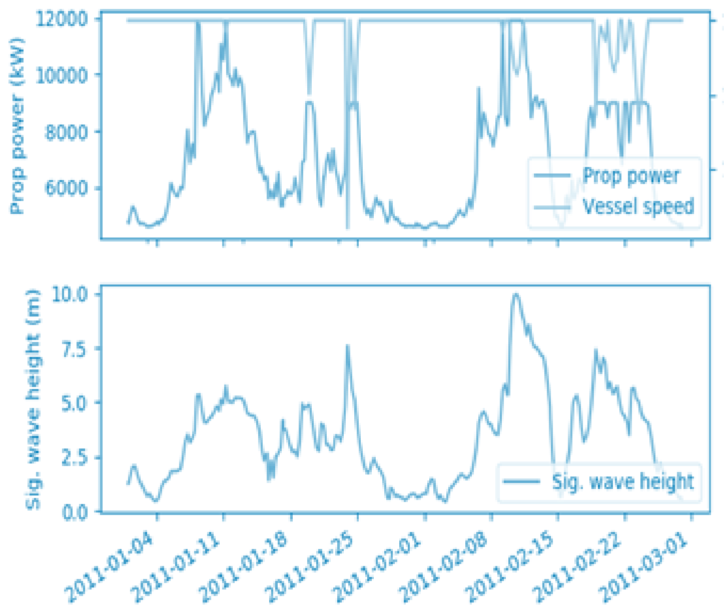
GYMIR is developed as a tool for virtual testing of ship design solutions, providing insight that improve early stage design decisions. It builds on validated advanced ship model, and enables simulation in realistic operational pattern and weather conditions.

Achievement 2020:

- Integration of new machinery model from WP3 into simulation package
- Integration of updated hydrodynamics model (constant RPM) from WP2
- "Virtual captain" stage 1 in simulation package: Voluntary speed loss; Automatic route speed suggestion dependent on weather
- Introduce sea current calculations in ship model



SHIP PERFORMANCE



Output

- Operation profile & predicted sea margin.
- Machinery working point & power demand
- Weather statistics

RouteSimulation

Contact: Jon Schonhovd Dæhlen, Endre Sandvik, Agathe Rialland (SINTEF Ocean)

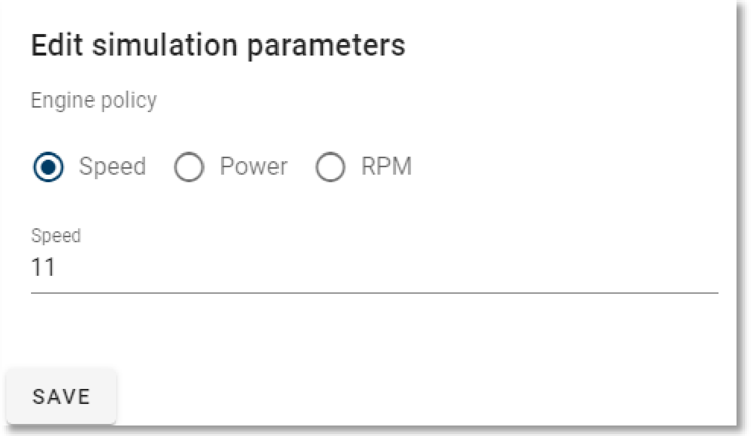
In cooperation with the associated innovation project RuteSim, the following developments to the simualtion platform, hydrrodynamic and ship model, have been carried out:

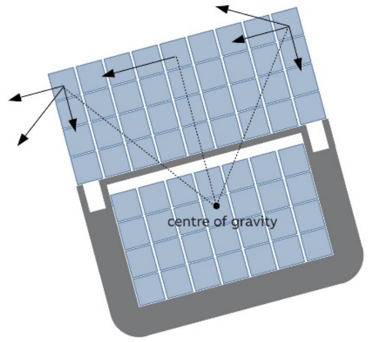
1. Constant RPM implemented in hydrodynamic model: Accommodation of engine settings for simulation: Constant RPM; Constant Power; Constant Speed.

2. Motion response characteristics implemented in ship model : computing the short-term statistical response in irregular waves, and reporting roll and pitch significant response in front-end.

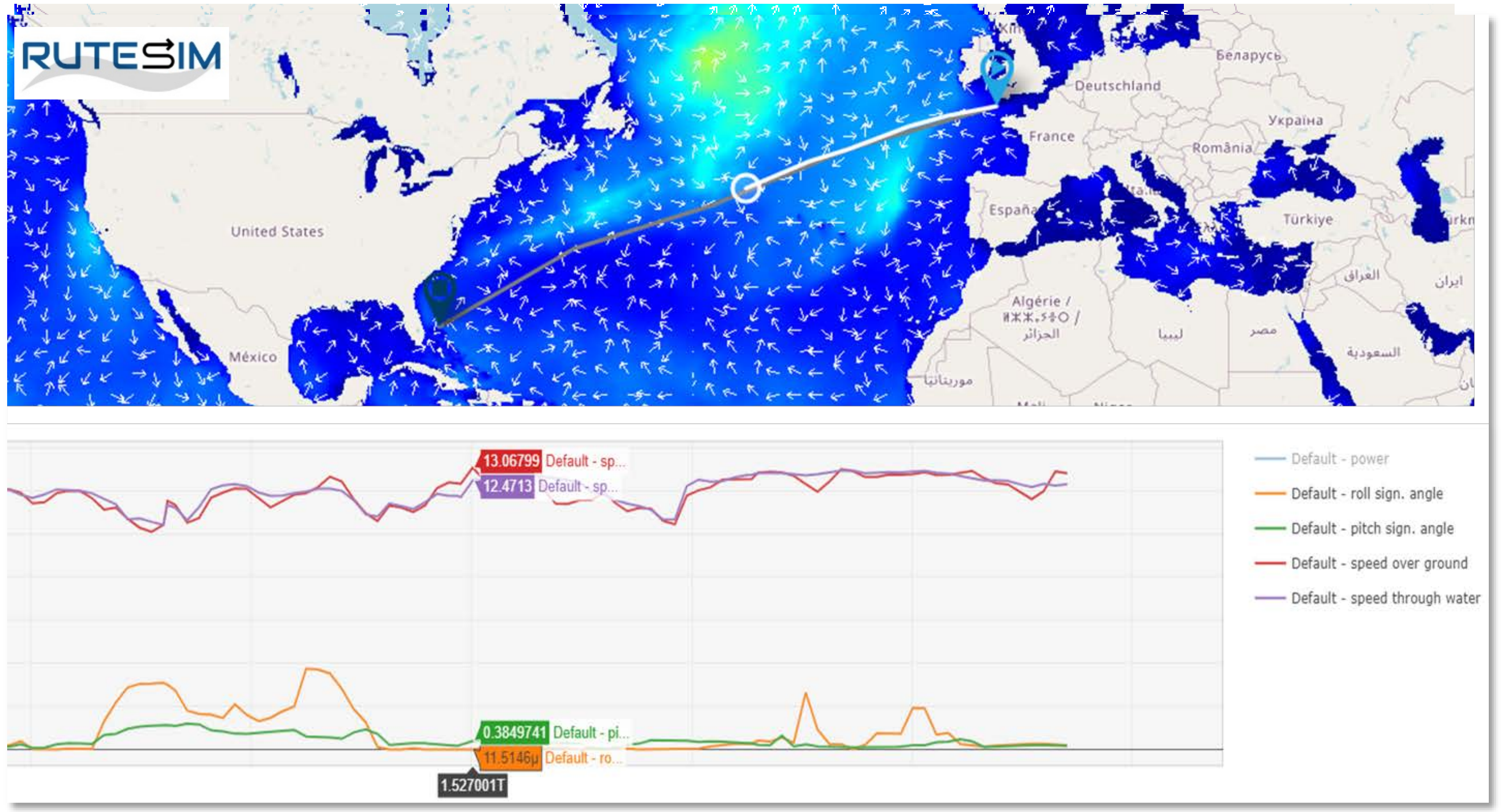
3. Voluntary speed loss limits with motion limits

4. Introduce sea current calculations





Reference: J. S. Dæhlen, A. Rialland. Smart Maritime Simulation Platform updates, WEBINAR 2020-10-09



About Rutesim:

The project RuteSim has developed a route simulation tool combining validated ship simulators with detailed weather forecasts and ocean current models. The tool aims at increasing the precision of the calculation of key parameters as fuel consumption, ship motion, sailing time, and by that give ship operators a better foundation for route assessment and planning. The project was lead by Grieg Star, and involved Smart Maritime Partners K.G. Jebsen Skipsrederi and Wallenius Wilhelmsen Ocean, as well as research partner Nansen Environmental and Remote Sensing Center.

GRIEG STAR

KRISTIAN GERHARD JEBSEN SKIPSREDERI
PART OF THE KRISTIAN GERHARD JEBSEN GROUP

Wallenius Wilhelmsen

Modular Conceptual Synthesis of Low-Emission Ships.

Contact: Benjamin Lagemann, Stein Ove Erikstad (NTNU)

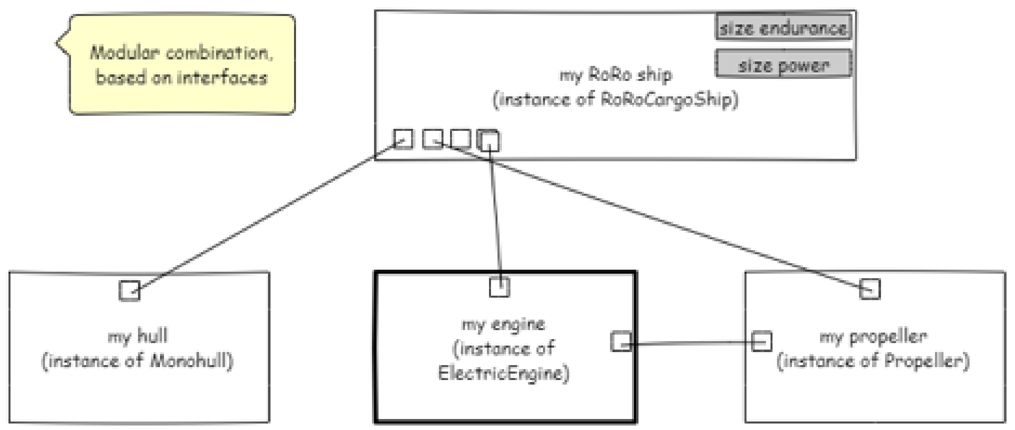
With the ambition of lowering emission from shipping, ship designers face both the freedom and challenge to select from a large set of different ship system concepts during the conceptual design stage.

In order to design competitive vessels, these options need to be assessed in an efficient and systematic way. Building upon established ship design methodologies (system-based ship design and design building block approach), this paper presents **a combined synthesis model adapted to low-emission ship design**. By making extended use of modularity, namely component swapping and combinatorial modularity, the model enables flexibly synthesizing diverse ship configurations.

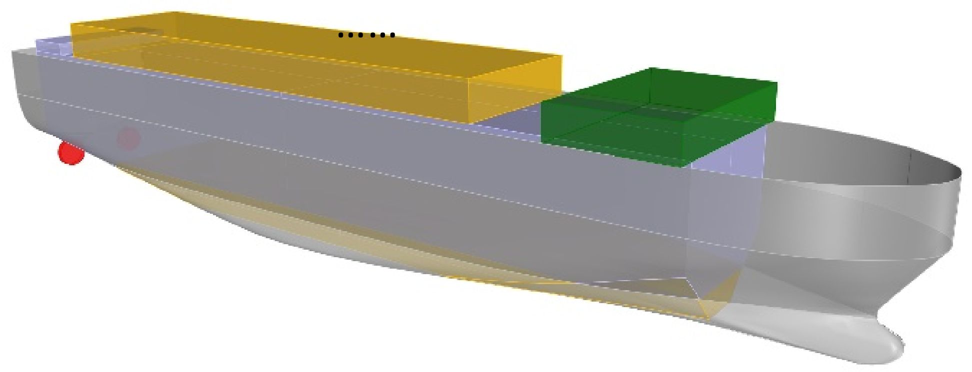
To illustrate how the model can be used, we show how it can be implemented computationally and apply it to a RoRo transport case for the route Rotterdam - Halifax. An efficient discrete event simulation enables immediate performance evaluation. The ship designer can thus directly foresee the consequences of decisions and elucidate requirements on an informed basis.

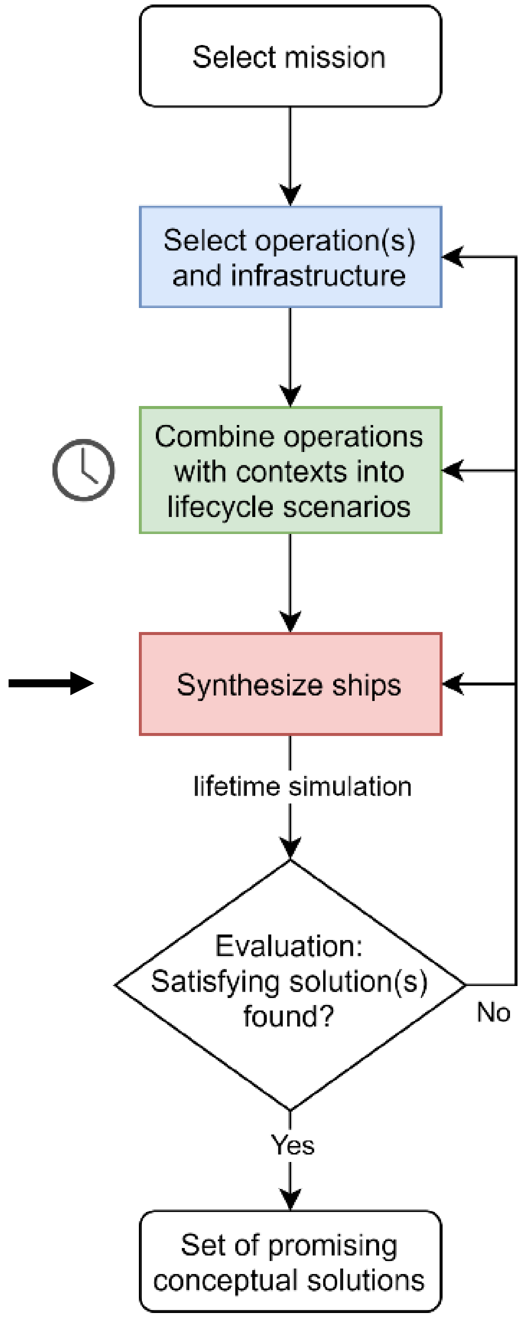
Ship Synthesis Workflow enabling efficient ship configuration:

1. Select modules from library based on different working principles (Pahl & Beitz)
2. Connect modules in system topology



3. Place modules spatially





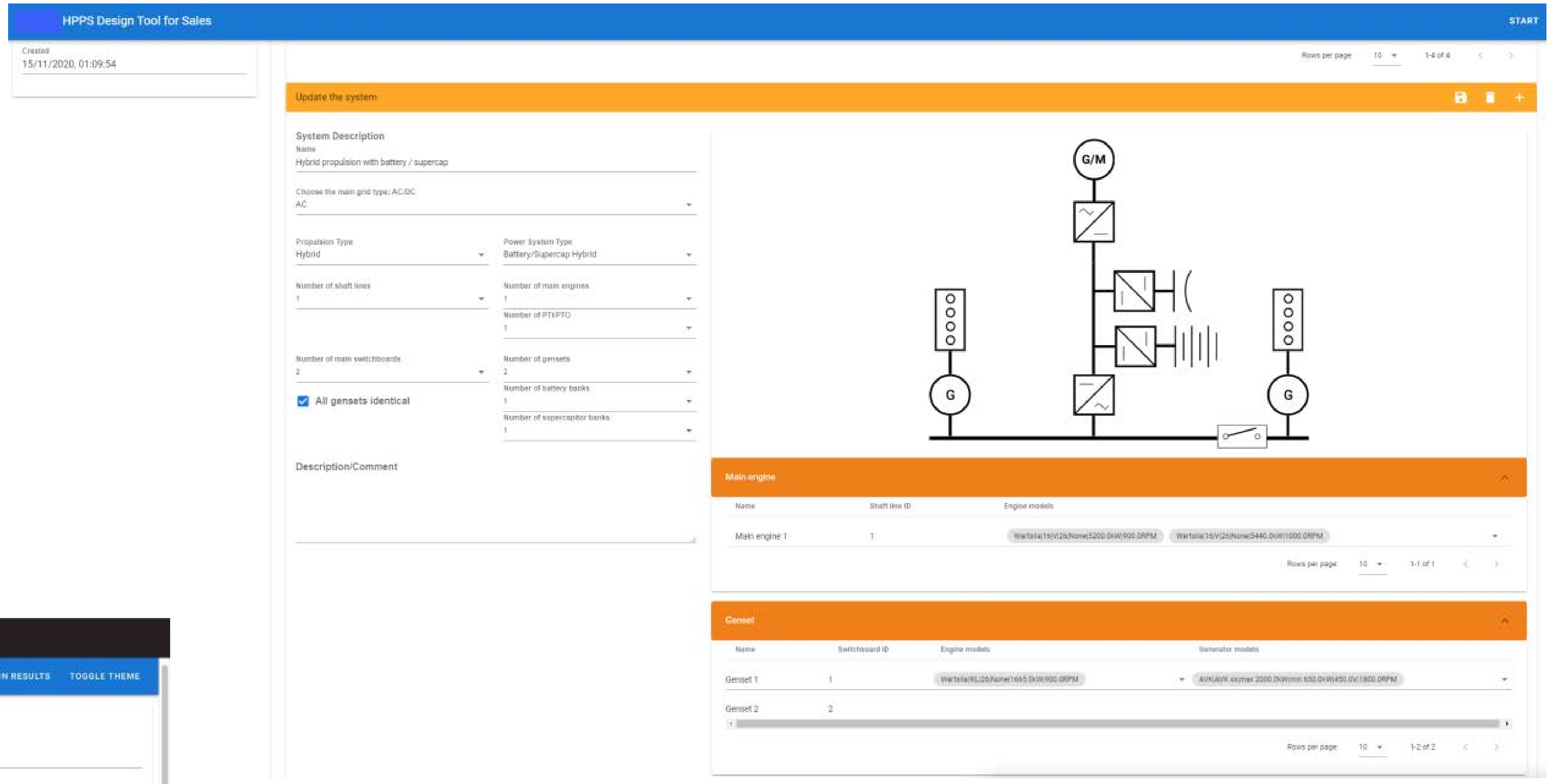
Synthesis Model as part of a Design Methodology

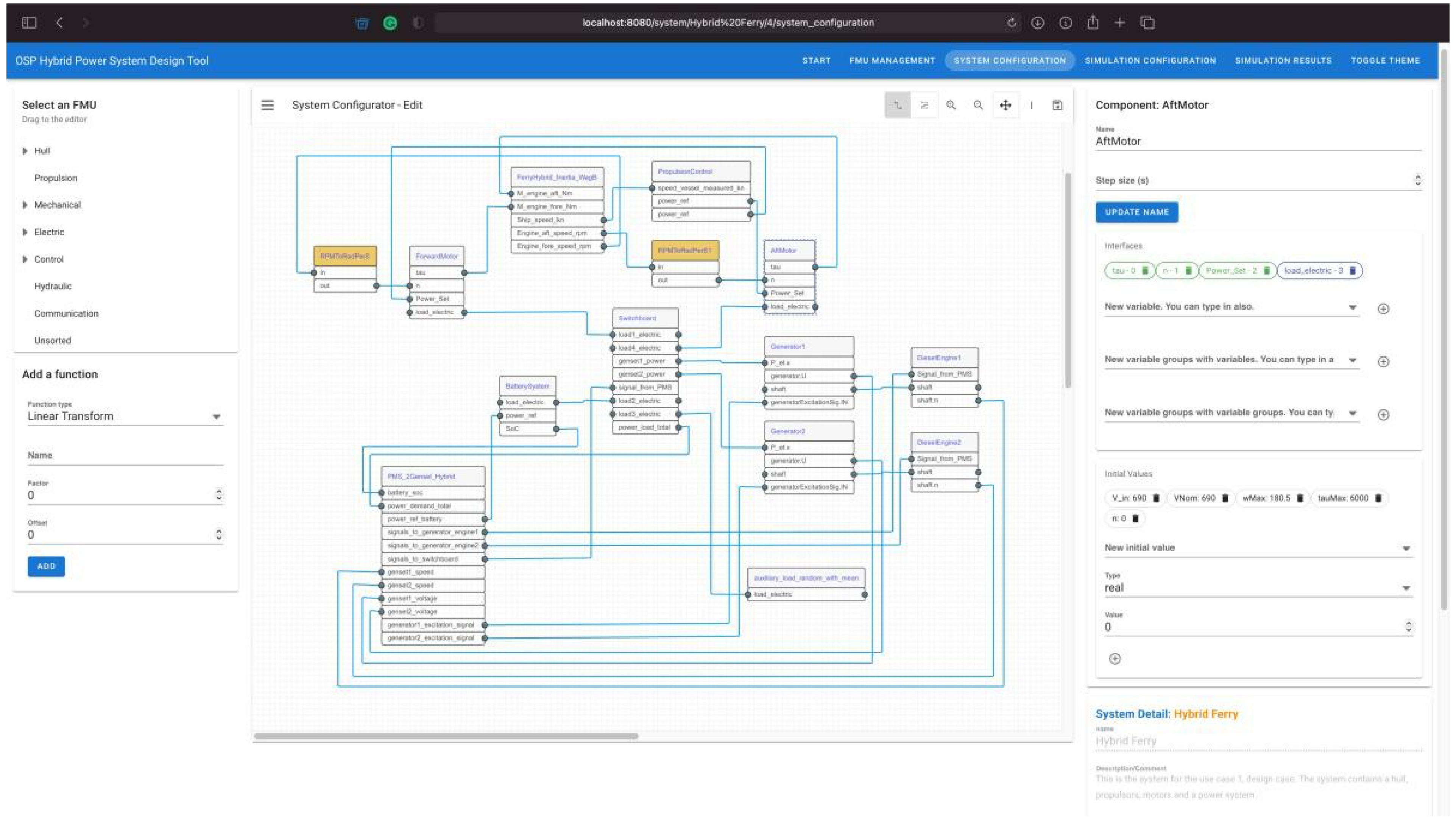
Reference:
Lagemann, Benjamin; Erikstad, Stein Ove. Modular Conceptual Synthesis of Low-Emission Ships. I: 12th Symposium on High-Performance Marine Vehicles. Technische Universität Hamburg-Harburg 2020 ISBN 978-3-89220-718-4. s. 134-151.
Lagemann, Benjamin. Methodology for low-emission concept ship design. SFI Smart Maritime WEBINAR Simulation Platforms; 2020-10-09

Machinery configurator for evaluation of low-emission propulsion.

Contact: Kevin Koosup Yum (SINTEF Ocean)

- Hybrid Power and Propulsion Design Tool With PMS
- Machinery Configurator
- Digital platform for testing control logic / configuration
- OSP Hybrid Ferry Design Tool





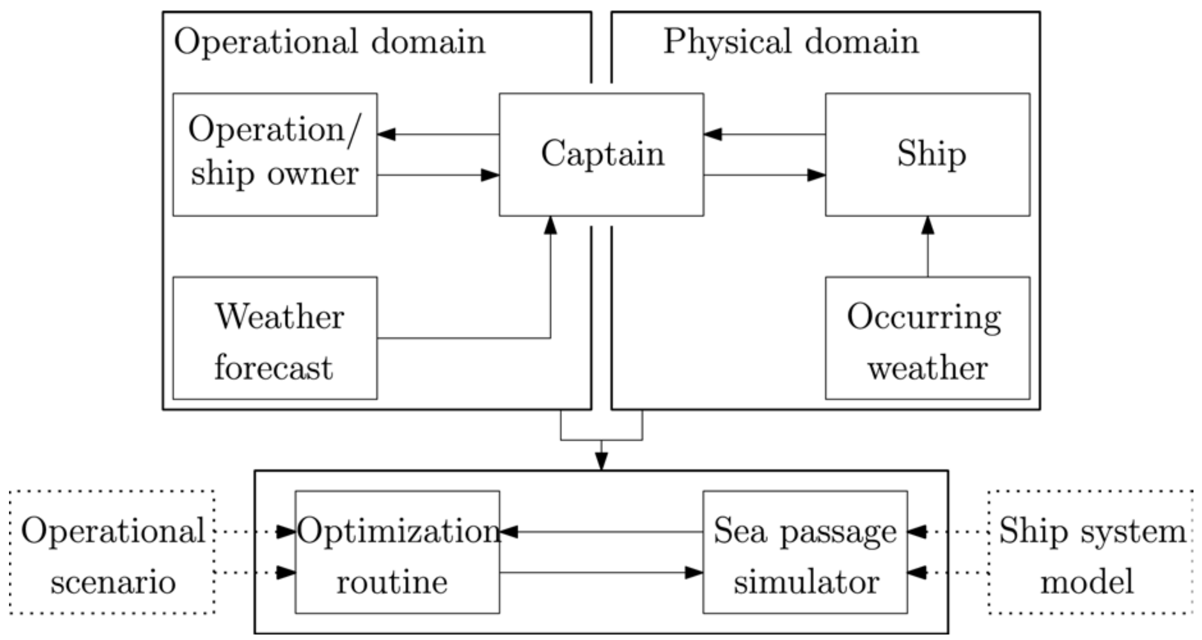
Operational sea passage scenario generation for virtual testing of ships using an optimization for simulation approach

Contact: Endre Sandvik (SINTEF Ocean)

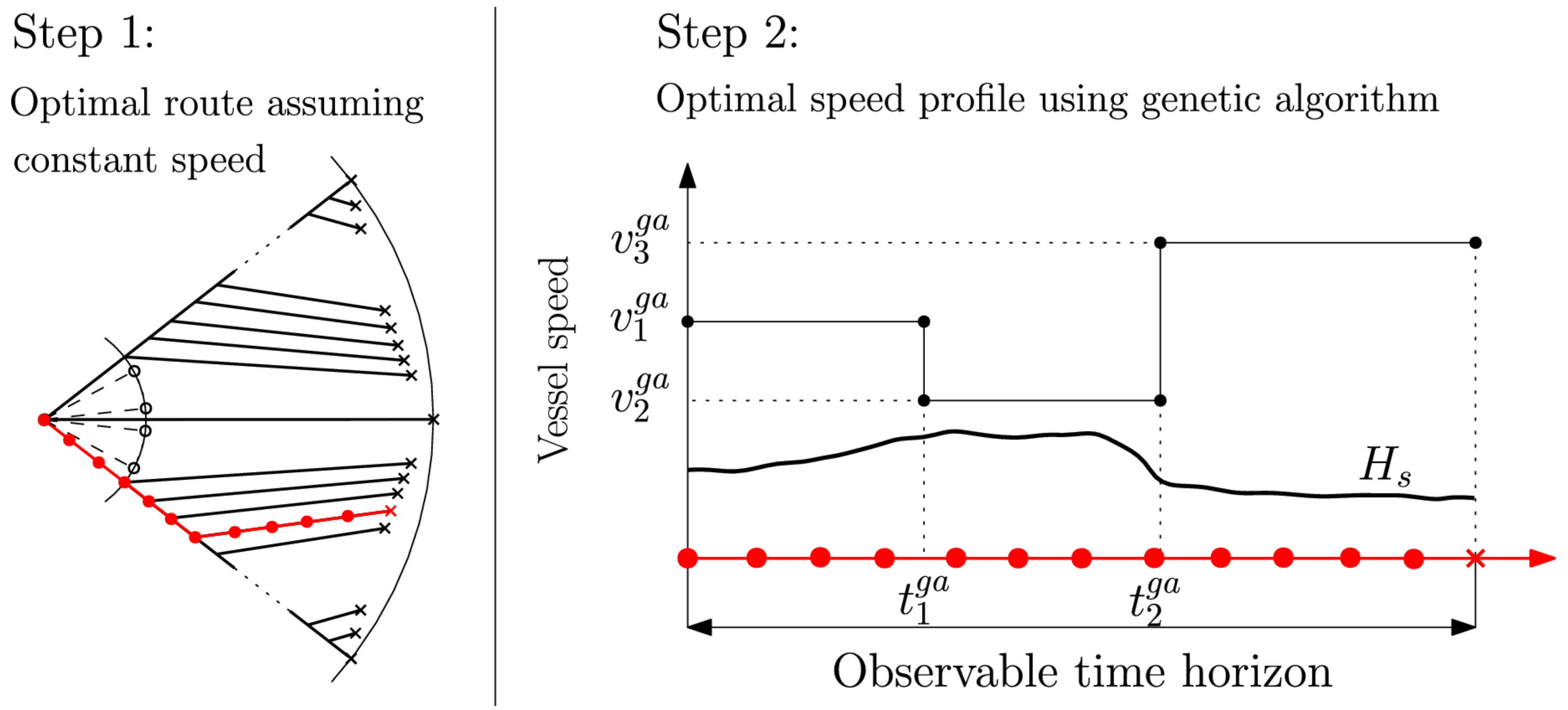
In this paper, a model for implementation of sea passage operational scenarios in the context of simulation-based design of ships is presented. To facilitate the transition towards more energy-efficient shipping, the ability to evaluate and understand ship and ship system behaviour in operational conditions is central.

By introducing an optimization model in virtual testing frameworks, operational scenarios can be generated that enhances scenario relevance and testing abilities. The optimization for simulation approach provides speed and course commands based on an optimization framework which factors in the operational considerations and sea state conditions in the area of operation. Impact on the understanding of ship system performance using simulation is assessed in a case study where a sea passage over the North Pacific is replicated for varying operational scenarios and seasons.

It is found that the variation of operational scenario, affecting the sea state and speed relation, causes significant differences in required power and fuel consumption estimates. Sea passage control is found to be an important dimension in virtual testing approaches.



Vessel captain as the interface between the operational and physical domain and application of optimization for simulation to generate operational scenarios



Optimization procedure divided in two steps for providing heading and speed input for the simulator

Reference: Sandvik, E., Nielsen, J.B., Asbjørnslett, B.E. et al. Operational sea passage scenario generation for virtual testing of ships using an optimization for simulation approach. J Mar Sci Technol (2020). https://doi.org/10.1007/s00773-020-00771-0

MARITIME TRANSPORT ENVIRONMENTAL ASSESSMENT MODEL (MariTEAM)

Contact: Helene Muri (NTNU)

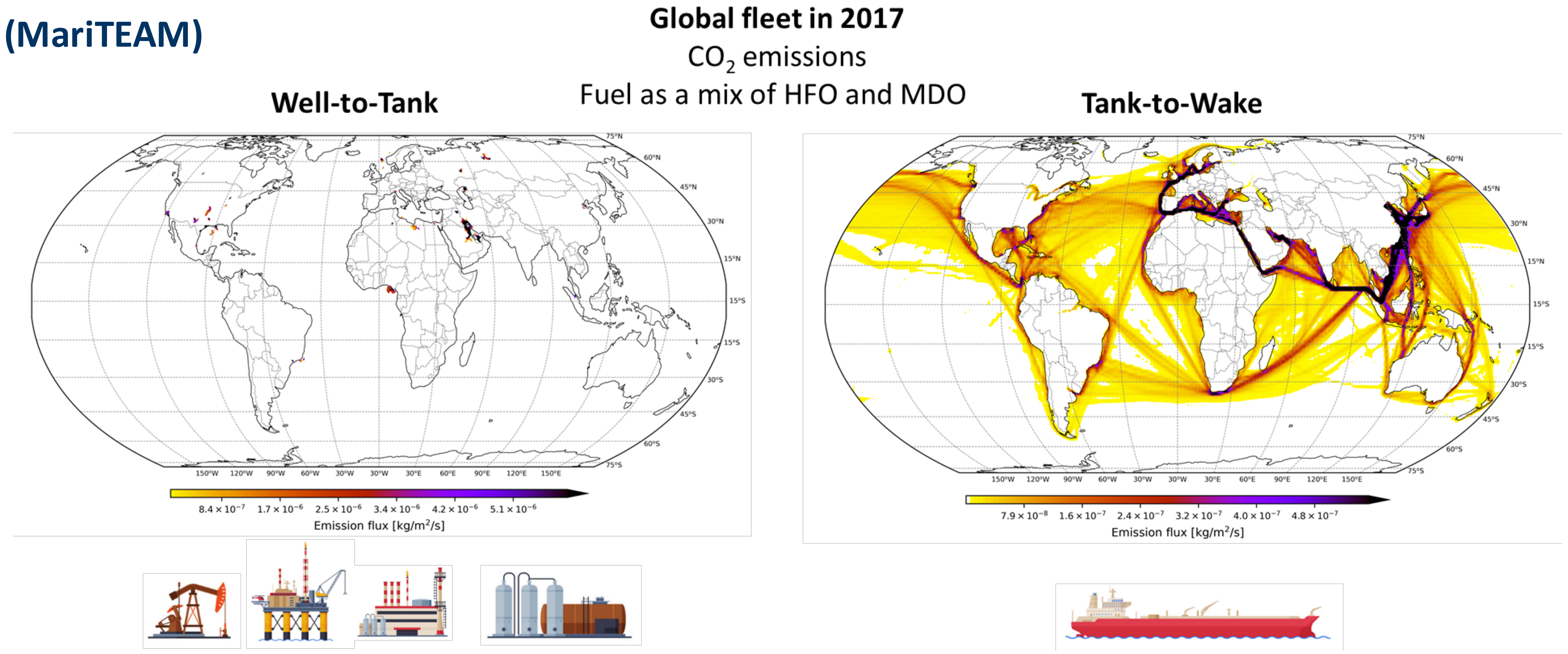
MariTEAM model development

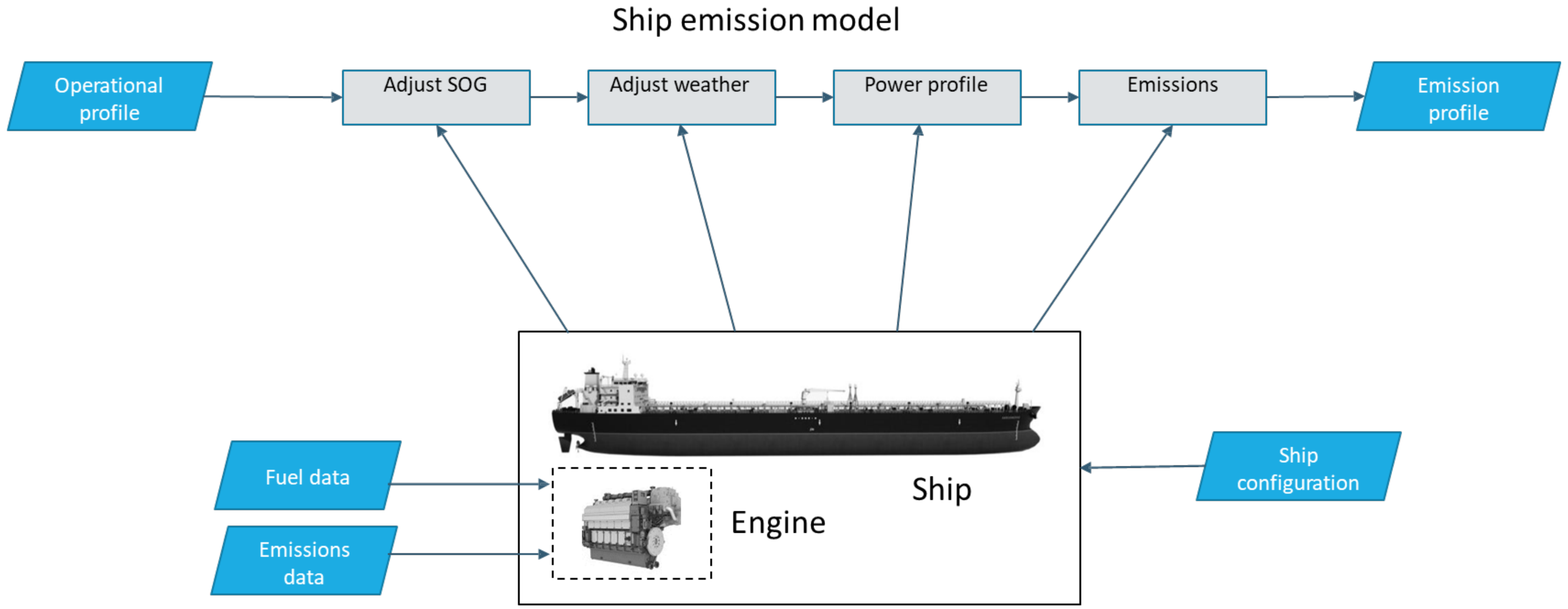
Fleet level emission assessment

- Fleet stock scenario model
- Geospatial LCA and climate footprint of fuels

Fleet emission inventory

- Ship level assessment
- Battery electric ferry case.
- Evaluation of power prediction models

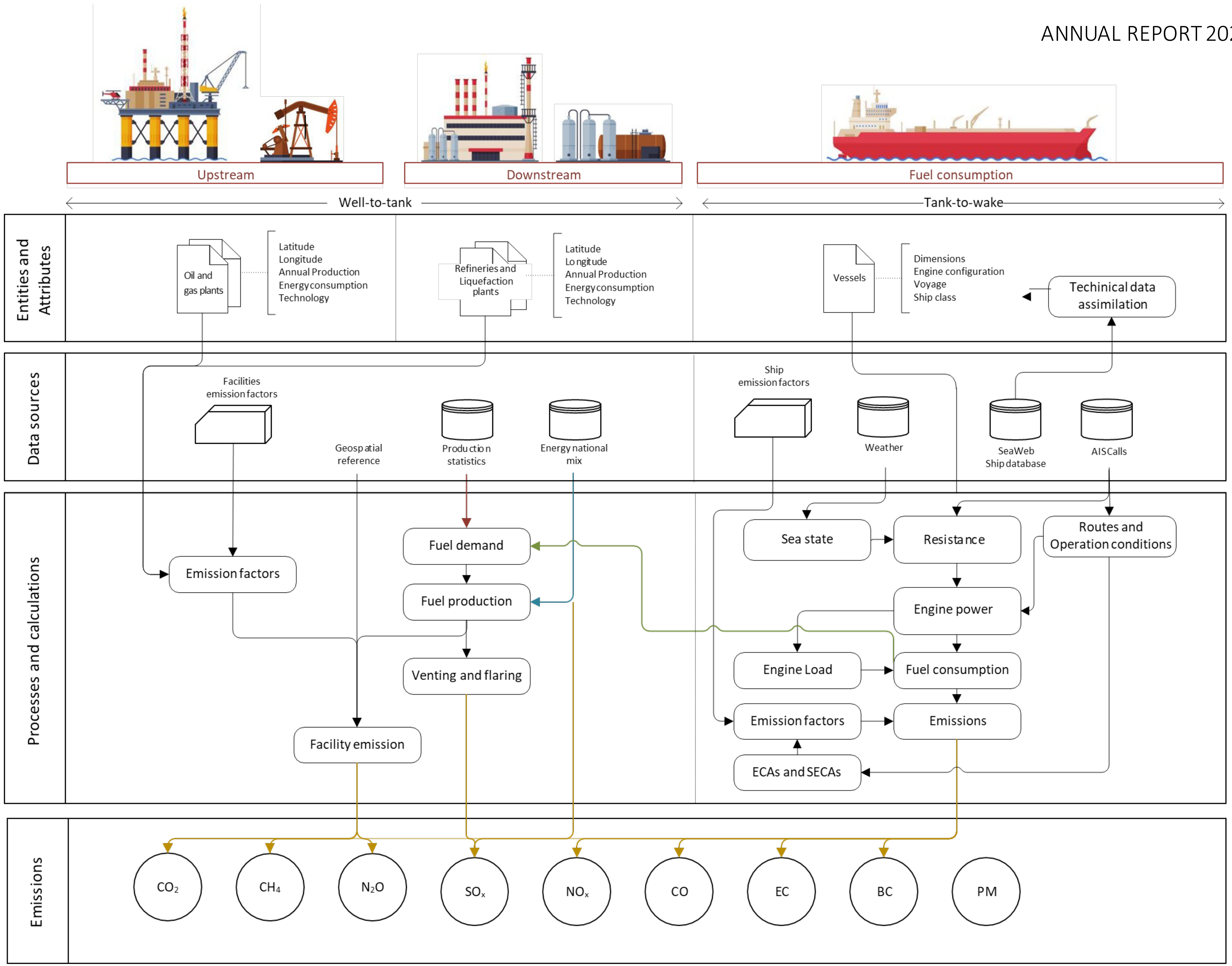




GEOSPATIAL LCA FRAMEWORK FOR THE MARITEAM MODEL

Contact: Diogo Kramel, CLIMMS project (NTNU)

The figure represents the structure of the LCA framework, consisting of the spatial and technical datasets for each entity included in the model, obtained through the combination of several databases, which are used to calculate emissions at a facility- and ship-level, and finally are compiled numerically and spatially.



Battery electric ferry case study with the MariTEAM model

Contact: Helene Muri (NTNU)

A comparative Life Cycle Assessment of a Diesel electric and a battery electry ferry was conducted based on data from the ferry Lagatun. The ferry operates in Norway Trøndelag. And is equipped with battery system from Siemens.

The study shows that building electric ferry generates more GHG emissions than from diesel ferry, but this gap closes after 7 months of operations.

Lagatun, Foto: Geir Magne Sætre

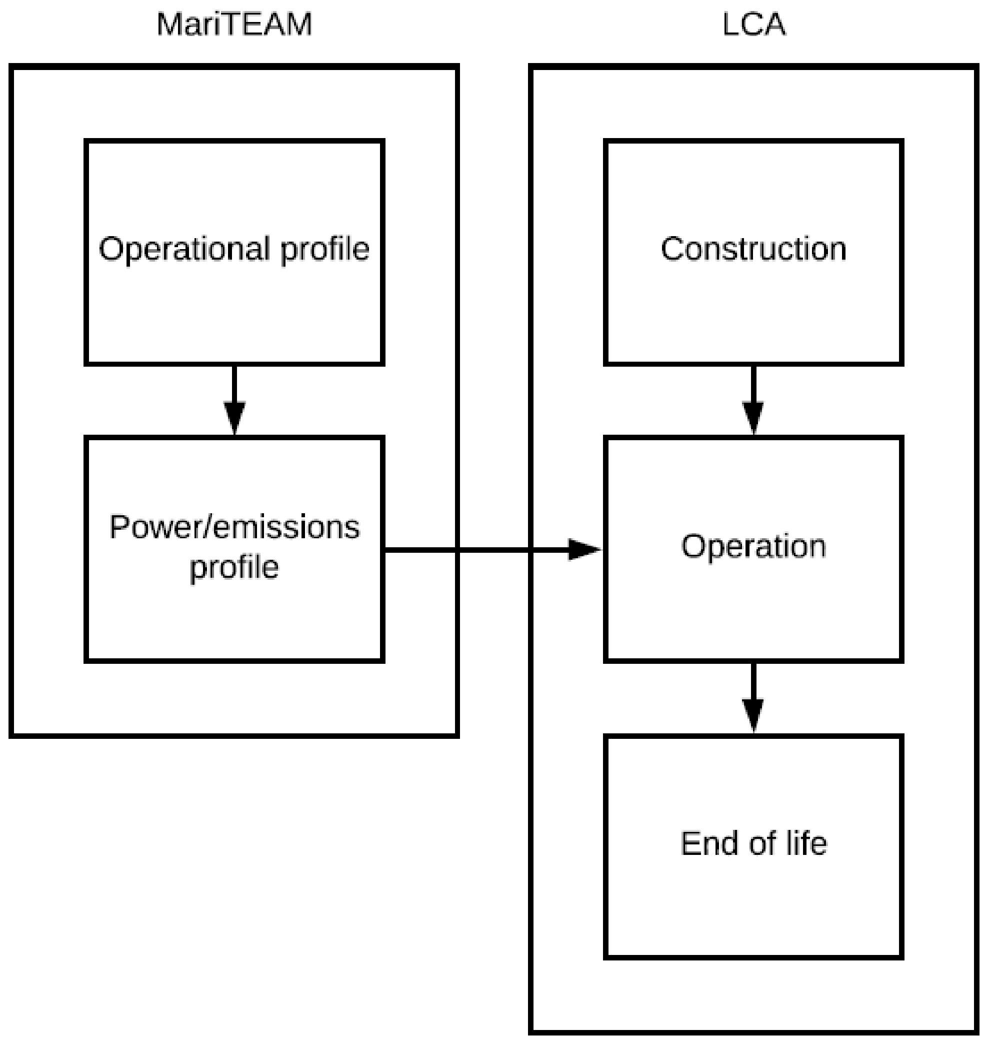


Figure 3.3: Implementation of MariTEAM results in the LCA

Reference: MSc thesis by Julie Sandnes Galaaen, 2020: Comparative Life cycle assessment of a diesel electric and a battery electric ferry, NTNU NTNU, Industrial Ecology.

SMART MARITIME

COOPERATION

SKS DARENT. Docking for silicon antifouling application and installation of ballast water system. Picture: Kristian Gerhard Jebsen Skipsrederi

COOPERATION
INDUSTRY - RESEARCH - ACADEMIA

Smart Maritime enjoys a network of highly motivated industry representatives, striving for knowledge and excellence. The participation of maritime professionals in research is crucial for the good progress of our projects.

Industry participation includes the following:

- Sharing of operational data
- Measurement and test experiments
- Laboratory or test ship for research
- Direct involvement in research work
- Cooperation on model and tool development
- Participation at workshops and webinars
- Scientific discussion, knowledge sharing
- Associated and spin-off projects
- Co-supervision / support to Master theses
- Dissemination, co-authorship

Clipper Quito - Clipper Victory in Ship to Ship operation, Photo: Solvang

NETWORK MEETINGS 2020

Network meetings

Smart Maritime organizes a network meeting twice a year gathering the research team and the Technical Advisory Committee to exchange ideas and experience, keep updated on scientific progress, discuss new challenges and new reseach and innovation initiatives.

In 2020, the networks meetings were carried out as digital meeting places

03 JUNE 2020
Dialog on new research and innovation initiatives
Participants: 58

17 NOVEMBER 2020
Planning of 2021 activities
Participants: 47

WEBINARS 2020

Online seminars are offered to the Centre members for providing update on ongoing research, short presentations of selected topics and scientific discussion with meeting participants. Webinars enable the participations of a wider audience and effective dissemination of scientific activity. During 2020, our digital meetings prove to be important meeting place for the Smart Maritime community.

Topic	Organizer	Presenters	Date	Participants
Alternative Fuels and Flexible Technology Solutions	SINTEF Ocean	E. Lindstad, T. I. Bø, J. B. Nielsen	11 MAR.	53
Maritime Policies EU & IMO updates	SINTEF Ocean	E. Lindstad	30 APR.	53
Hydrodynamic Energy Saving Measures	SINTEF Ocean	K. Koushan	17 JUN.	54
Sustainable Alternative Marine Fuels	SINTEF Ocean	E. Lindstad	6 OCT.	56
SFI Smart Maritime Simulation platform: updates	SINTEF Ocean	J. S. Dæhlen, A. Rialland, B. Lagemann	9 OCT.	55
IMO - GHG Studies and short term measures	SINTEF Ocean	E. Lindstad	20 OCT.	48
IMO - EEDI achievements so far and EEDI phase 4	SINTEF Ocean	E. Lindstad	3 NOV.	48
Green designs and seakeeping capabilities	Kompetanseforum for krevende fartøyoperasjoner	SINTEF Ocean, KG Jebsen Skipsrederi,Sjøfartsdirektorat, VARD	4 NOV.	51
Wind assisted propulsion	SINTEF Ocean	S. A. Alterskjær, A. Östman, J. Kramer	10 NOV.	68
Strategies to reach IMO 2030 and 2050 GHG targets	SINTEF Ocean	E. Lindstad	1 DEC.	51
IMO's work on GHG emission reduction strategy and regulations	NTNU	E. Lindstad	14 DEC.	40

NATIONAL COOPERATION

National research and expertise centres

Cooperation on simulation methods and tools among SFI Smart Maritime, MOVE, EXPOSED, and newly launched SFI Autoship.

Low-emission research centre: Cross-disciplinary cooperation on case study of offshore supply with emission-free fuels, including integration of optimization and simulation models.

Smart Maritime is represented in

NCE Maritime CleanTech

Grønnkystfartprogram

Kompetanseforum for krevende marinoperasjoner

Spin-off and associated projects

New opportunities are explored every year by partners of Smart Maritime for further research or commercialisation activity.

In 2020, based on active collaboration among the Centre partners, 4 innovation projects and 3 knowledge-development project were launched, and additional 2 collaboration project received approval for starting in 2021.

University collaboration

NHH. Norwegian School of Economics. Collaboration with Centre for Applied Research at SNF (Samfunns- og næringslivsforskning) on maritime economics.

INTERNATIONAL COOPERATION

EU's framework programme

Several of the Centre's industry partner are involved in at least one EU project on similar topics as Smart Maritime. Per 2020, SINTEF Ocean and Smart Maritime partners were involved in 5 H2020 projects with high relevance and synergy with Smart Maritime in terms of scientific activity or industrial challenges; 3 of these were launched in 2020.

Academic and research cooperation

- Scientific advisory committee, consisting of 5 Professors with expertise covering research area of the Centre. Chalmers University (SE), U. Strathclyde (UK), DTU (DK), TU Hamburg (GE)
- Cross-university PhD program (Cotutelle) NTNU / DTU Denmark.
- Cooperation with Chalmers University of Technology, Sweden on fouling and anti-fouling for reduction of friction.
- Cooperation with UC Berkeley on utilization of super-hydrophobic surfaces and flow separation detection and control (partly financed by a Peder Saether Grant).
- KEDGE Business School (FR) and KLU Kühne Logistics University (GE) on maritime economic studies.
- Aalborg university: cooperation on shore-side power supply.

International cooperation on policy development

- IPCC International Panel on Climate Change: Prof. A. H. Strømman and Dr. Helene Muri (NTNU) designated as co-author for the IPCC's Sixth Assessment Report due in 2021.
- ESSF: European Shipping Sustainability Forum: Chief-scientist Elizabeth Lindstad expert advisor, contributor and task-lead for working groups: Alternative Fuels and Ship Energy Efficiency, coordinating submissions to IMO and ISO.
- IMO / MEPC: SFI Smart Maritime participants are actively involved in IMO consultations, either through Norwegian delegation or international forums and industrial initiatives.
- UNCTAD: contribution to UNCTAD expert assessment for IMO.
- MAREFORUM. Dr. Lindstad regular panel speak at one of the most global and influential forums for the maritime and shipping industry.
- SNAME fellowship attributed to Dr Elizabeth Lindstad in 2017
- WSA – Wind Ship Association: SINTEF Ocean associated member
- ITTC – Technical committee member

ASSOCIATED PROJECTS

Project title	Period	Funding	Smart Maritime Partners
HOLISHIP - HOLIstic optimisation of SHIP design and operation for life cycle	(2016-2020)	EU H2020	Kongsberg Maritime, DNVGL, SINTEF
Hybrid testing - Real-Time Hybrid Model Testing	(2016-2020)	MAROFF, KPN	NTNU, SINTEF
SATS - Analytics for ship performance monitoring in autonomous vessel	(2018-2020)	MAROFF, KPN	NTNU, SINTEF
Open simulation platform	(2018-2020)	JIP	DNV GL, Kongsberg Maritime, SINTEF, NTNU
Digital twin for lifecycle operations	(2018-2022)	MAROFF	DNV GL, Kongsberg Maritime, SINTEF, NTNU
CLIMMS - Climate change mitigation in the maritime sector	(2019-2023)	MAROFF, KPN	NTNU, SINTEF, Rederiforbund + all 8 ship owner SFI-partners
SmartShipRouting	(2019-2020)	MAROFF, IPN	NCS, NES, Havila, Havyard, SINTEF
RuteSim: Simuleringsbasert Ruteplanlegging	(2019-2020)	MAROFF, IPN	Grieg Star, WWO, KGJS, SINTEF, Nansen
Digital twin yard	(2019-2021)	MAROFF, IPN	DNVGL, Rolls-Royce, NTNU, SINTEF
FreeCO2ast	(2019-2022)	PILOT E	Havyard, Havila , SINTEF
Extension of Hybrid Lab	(2019-2019)	ABB	ABB, SINTEF
Autoship	(2019-2022)	EU H2020	Kongsberg, SINTEF
RedRes - Innovative surface structures to reduce friction	(2020-2023)	MAROFF, KPN	JOTUN, SINTEF, NTNTU, Grieg Star
IPIRIS - Improving Performance in Real Sea	(2020-2023)	MAROFF, KPN	VARD, Havyard, Kongsberg, SINTEF, NTNU
CruiseZero – Zero-emission expedition cruise	(2020-2021)	MAROFF, IPN	VARD, ABB, SINTEF
PEZOS - Plug-In Electric Zero-emission Offshore-ship	(2020-2021)	MAROFF, IPN	VARD, SINTEF
Bio4-7seas - Biofuels in deep sea shipping for climate change mitigation	(2020-2023)	ENERGIX, KPN	NTNU, SINTEF
ZeroCoaster - Zero-emission coastal bulk shipping	(2020-2022)	MAROFF, IPN	VARD, ABB, DNV GL, SINTEF
Air-lubrication	(2020-2022)	MAROFF, IPN	Jotun, SINTEF
Gaters	(2020-2022)	EU H2020	Strathclyde, SINTEF
Aegis	(2020-2023)	EU H2020	SINTEF
VesselAI	(2021-2024)	EU H2020	Kongsberg, SINTEF
CCShip – Carbon Capture and Storage onboard ships	(2021-2024)	NFR, KSP	Klaveness, Wärtsila, SINTEF, NTNU
ProfSea	(2021-2024)	NFR, KSP	Kongsberg, SINTEF, NTNU

THE RESEARCH TEAM

Smart Maritime's research team consists of over 20 research scientists from two institutions NTNU and SINTEF Ocean.
The Centre has so far financed 11 PhD students and 3 Postdoc researchers.

Höegh Traveller, Höeh Autoliners_Photo credit: Ignacio-Rey

PHD AND POSTDOC
ONGOING RESEARCH PROJECTS

Esvagt Froude, Havyard Design, Photo: HAV Group

Prateek Gupta

PhD student WP2
(2018–2021)

Ship Performance Monitoring & Optimization using in-service measurements & Bigdata Analysis methods

Main achievements 2020

- Established a new statistics-based hydrodynamic performance indicator, formulated in the form of generalized admiralty coefficient ($\Delta^m V^n / P_s$) with displacement and speed exponents estimated statistically using in-service data.
- The trend observed in the new performance indicator was found to be in good agreement with the corresponding trend obtained in the traditionally used hydrodynamic performance indicator for ships, i.e., fouling friction coefficient (ΔC_F).
- The new performance indicator completely removes the dependence on empirical methods (used for ship's resistance estimation) providing ship owners with a more robust method to monitor the hydrodynamic performance of ships based only on the in-service data recorded onboard the ships.

Results to be published in the Journal of Applied Ocean Research:
Gupta, et al. (2021). Statistical Modeling of Ship's Hydrodynamic Performance Indicator.
Preprint: http://dx.doi.org/10.13140/RG.2.2.10492.56964

Research topics

The focus of the project would be to convert the highly dimensional in-service measurement data recorded onboard a ship into meaningful information. Initially, data integrity and quality assurance procedures must be implemented and applied on the data set(s). The cleaned data will be further used to quantify the hydrodynamic performance of the ship. The project will apply big data analysis, data science, and machine learning for data processing.

The in-service data will be linked with environmental data from open sources, like for instance ECMWF, HYCOM and CMEMS to improve the ability to detect the environmental condition.

Topics like prediction of ship speed loss, speed-powering variation, hull-propeller performance, seakeeping performance, influence of environmental factors will be covered under the hydrodynamics aspect of the project.

Industrial goal

- Monitor and optimize the hydrodynamic performance of a ship using in-service measurements from onboard installed sensors.
- Estimation of calm-water resistance of the ship from total engine power consumption and environmental load conditions using in-service measurements and hind-cast information.
- Establishing standardized bigdata processing and cleaning framework for the in-service data recorded onboard the ships.

Scientific questions

- How to quantitatively represent the hydrodynamic performance of a ship using in-service measurement data?
- How to separate calm-water resistance from the total resistance?
- How to convert large amount of sensor data into small number of meaningful hydrodynamic performance parameters?
- How to effectively and efficiently process large amount of in-service data recorded onboard a ship?
- How to establish a standardized data processing and cleaning framework for ships?

Supervisor:	Prof. Sverre Steen (NTNU)
Co-supervisor:	Prof. Adil Rasheed (NTNU, SINTEF)

Photo: Private

Eshan Esmailian

PhD student WP2 (2019–2022)

Optimization of Ships for Operation in Real Sea States

Research topics

Optimization of ship designs has been a focus of research and development for a long time, but mostly optimum performance in calm water has been the issue. However, ships should be designed for operation in real sea states, meaning that performance in representative conditions with respect to time-varying components such as wind, waves and current, as well as loading conditions and transit speed should be taken into account. Moreover, there are typically uncertainties needed to be considered in the design phase. To make a design optimization method involves many aspects; proper design approaches for the optimization and tools to enhance the accuracy of design methods must be selected (or developed). Finding reliable and practical methods to ensure optimal energy efficiency of ships in real sea states that are both sufficiently accurate and robust and at the same time sufficiently computationally effective is expected to be a major task. Another research question concerns developing frameworks to be able to evaluate the performance of the suggested approaches for different case studies.

Industrial goals

• Improve the design methods for ships operating in real sea states and harsh sea conditions.

• Ensure high performance of designed ships in various scenarios such as routes, loading, and varying weather conditions etc.

• Improve the energy efficiency of ships

• Enhance Gymir capabilities

• Proposed solutions can be also useful for the following applications:

- Modern ship design
- Passenger comforts
- Offshore operations
- Autonomous ships

Main achievements 2020

- Implementation of a performance prediction tool considerably faster than ShipX, to be used in the optimization.
- Developing two new methods for design optimization of ships.
- Working on a new approach to improve the prediction of the added resistance in waves.

Supervisor:	Prof. Sverre Steen (NTNU)
Co-supervisor:	Prof. Kourosh Koushan(SINTEF Ocean), Prof. Stein Ove Erikstad (NTNU)

Jarle Vinje Kramer

PhD student WP2 (2014–2017 and 2020 - 2021)

Hydrodynamic modelling of wind-powered merchant vessels

Main achievements 2020

- Implementation of sails models in a route simulation framework using both a discrete lifting line method and a Vortex Lattice Method. The methods are necessary for modelling wing-to-wing interaction which are seen to strongly affect both the thrust and the side force from sails.
- The MMG manoeuvring model was implemented in a route simulation framework, with slight modifications to the rudder model in order to improve the accuracy. Test procedures and algorithms for tuning the model with CFD data was made.
- The route simulation model along with the tuning procedure was validated by executing a large set of validation experiments using CFD.

Results are currently under review at Ocean Engineering:

Kramer, et al. (2021). Simplified Test Program for Hydrodynamic CFD Simulations of Wind-Powered Cargo Ships.

Research topics

Most types of modern wind power devices, such as wing sails, rotor sails, and suction sails, generate thrust from the wind by creating a lift force. As a consequence, there is usually a side force from the sails which can be serval times as large as the thrust, depending on the apparent wind direction. This side force makes the ship move with a steady drift-, rudder- and heel-angle which could both increase the resistance of the vessel, and potentially pose a safety risk.

The goal of my research is to figure out how important these negative effects from wind power is for typical cargo ships. When problems are discovered, the goal is to find ways to reduce them to a minimum by either suggesting design alterations or new control principles. Different modelling approaches are investigated with the goal of making numerical tools that are usable in a design loop for wind-powered vessels.

Industrial goal

- Generate efficient numerical tools for evaluating both the hydrodynamics and the aerodynamics of a wind-powered merchant vessel during a design loop.
- Detect and quantify potential problems with wind-power devices for typical cargo ships.
- Suggest solutions to problems and figure out how merchant vessels can extract large amounts of power from the wind in order to reach future greenhouse gas reduction goals.

Scientific questions

- How important are the hydrodynamic effects due to the side force of a sail?
- How can we model the negative hydrodynamic effects due to wind power accurately and efficiently?
- What can we do to minimize the negative hydrodynamic effects?
- Which design alterations are necessary for vessels where a large amount of the power comes from the wind?

Supervisor: Prof. Sverre Steen (NTNU)
Co-supervisor: Luca Savio (NTNU, SINTEF)

Benjamin Lagemann

PhD student WP4 (2019-2022)

Concept Ship Design for Future Low-Emission Shipping Technology

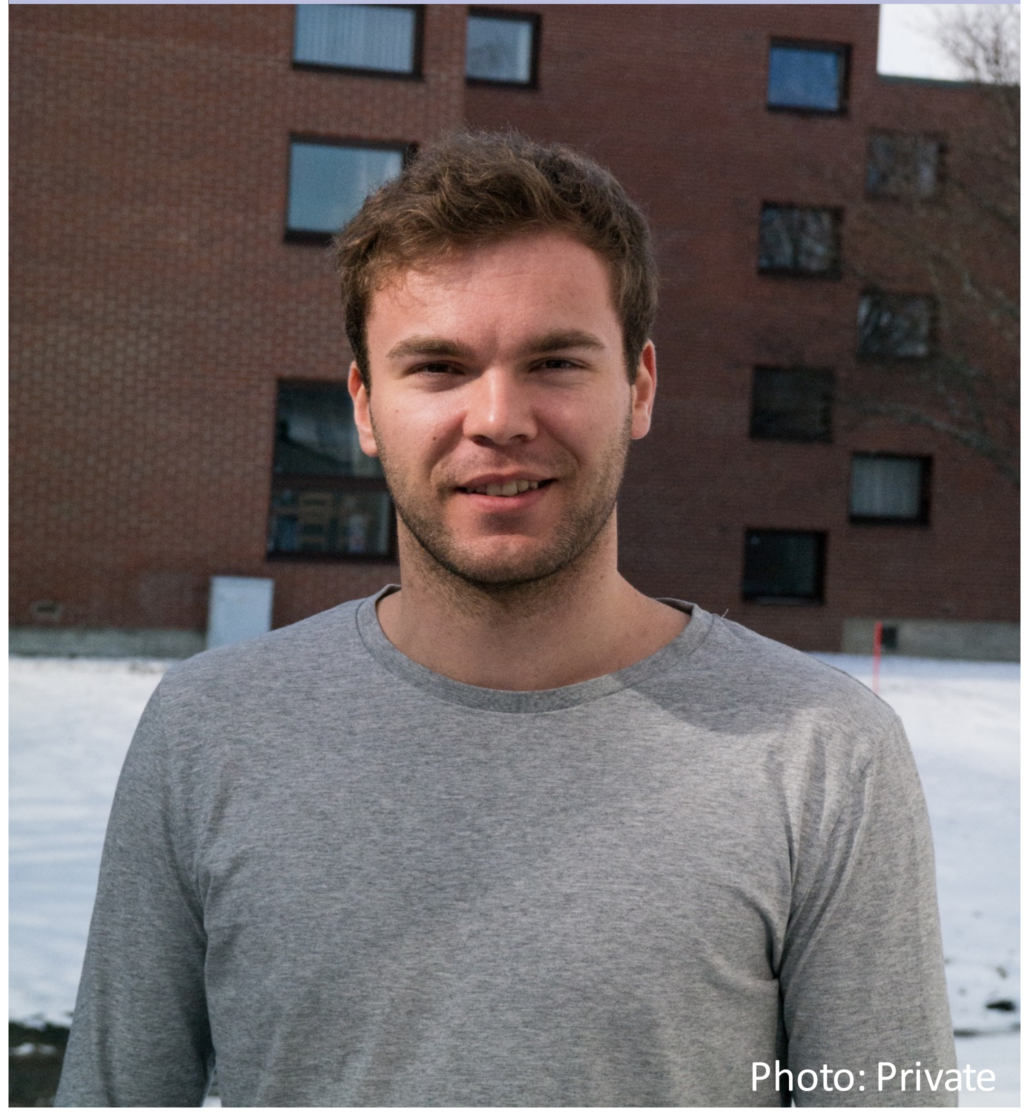


Photo: Private

Supervisors

Supervisor: Prof. Stein Ove Erikstad
Co-supervisors: Prof. Bjørn Egil Asbjørnslett
Prof. Sverre Steen

Research topic

The overarching research question for this project is *How to systematically design innovative, future-proof and low-emission ships at a conceptual level?*

The main research question is divided into three sub-questions:

- How to rapidly explore different conceptual ship designs?

A large number of different systems and principles (alternative fuels, fuel cells, sails etc) for lowering ship emissions are available today. The aim is to find out how these principles can be systematically combined and assessed on a case basis for new conceptual designs.

- Can changeable/retrofittable ships be an adequate response to external future uncertainties?

Fuel prices or potential taxes have a large impact on a ship's lifetime performance. The future development of these factors is however uncertain. This question seeks to answer whether retrofittable, potentially modular ships could be a worthwhile investment.

- How can rapid design space exploration and quantitative lifetime performance prediction be integrated into the design process??

Given tools for ship synthesis and lifetime analysis are available, this question shall address how to effectively engage with and integrate all relevant stakeholders in the conceptual design phase. A good stakeholder integration is essential for exploring innovative solutions (e.g. slower speed for sails, new fuels).

Main achievements 2020

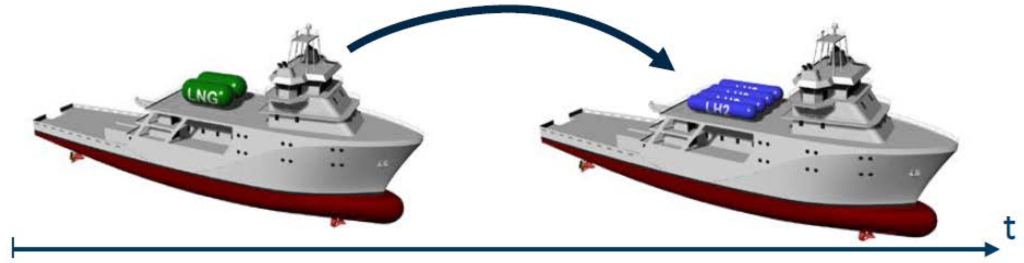
As for the first research question the paper "Modular Conceptual Synthesis of Low-Emission Ships" was presented at the HIPER conference in fall 2020.
Work on quantitative lifetime performance and changeability is currently underway.

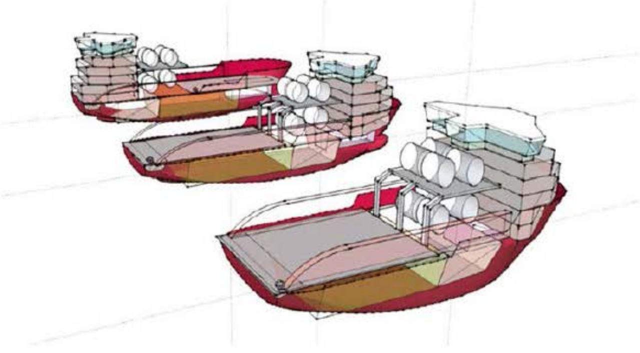
Industrial goals:

A large fraction of costs and ship life-time emissions are determined by decisions made during the preliminary ship design phase. Thus, the goal of this project is to support both ship designers and ship owners in their decisions during this early design phase. Illustrative questions that shall be supported can be "How to select a fuel for our next newbuild?" or "Should and can the ship be prepared for a later retrofit?"

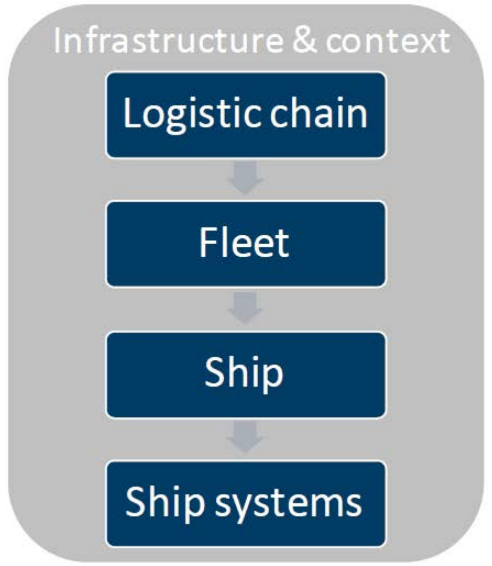
Expected results

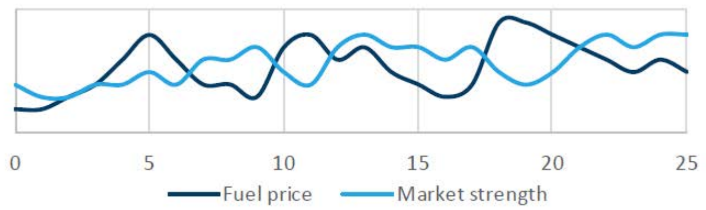
- Methodology and tool to investigate aspects such as flexibility, modularity, infrastructure, visualization, and uncertain future contexts on the ship design process and ship life cycle emissions.
- Prove the tool's performance in different case studies.





source: Vestbøstad 2011





Yuan Tian

PhD student WP3 (2021-2023)

Modelling and simulation of ship exhaust gas cleaning system

Problem formulation:

The whole shipping industry is now speeding up to reduce ship exhaust gas pollutions, according to more and more stringent regulations from International Maritime Organization (IMO). And these regulations can't be met without retrofitting ships with exhaust gas cleaning system as in today's industry. Therefore, there is urgent demand on studies of efficiency and effectiveness of the exhaust gas cleaning systems. This is what the present project aims to contribute.

Research questions:

1. How to build a numerical model for ship exhaust gas cleaning system that can represent the physical system.
2. How to define various scenarios and do simulations under these scenarios.
3. How to analyze results from the simulation and guide the real application.

Expected outcomes:

The overall goal of this project is to study how to reduce ship emissions more effectively by investigating ship exhaust gas cleaning systems, given the shipping industry must meet the more and more stringent regulations for ship emission from IMO.

This project's primary approach is to build numerical models of ship exhaust gas cleaning system and do simulations of the system under various scenarios. Several experiments for validating the model and collecting essential data will possibly be conducted. The combination of different research methods gives a factual basis to achieve the expected outcome that this project could contribute to the industry by offering an insightful evaluation of the ship exhaust gas cleaning system's performance.

Supervisor: Eilif Pedersen, NTNU IMT.
Co-supervisor: Jørgen B. Nielsen, SINTEF Ocean.

Kamyar Maleki

PhD student WP3 (2019-2022)

Simulator Approach to Concept Analysis and Optimization of Marine Power Plants

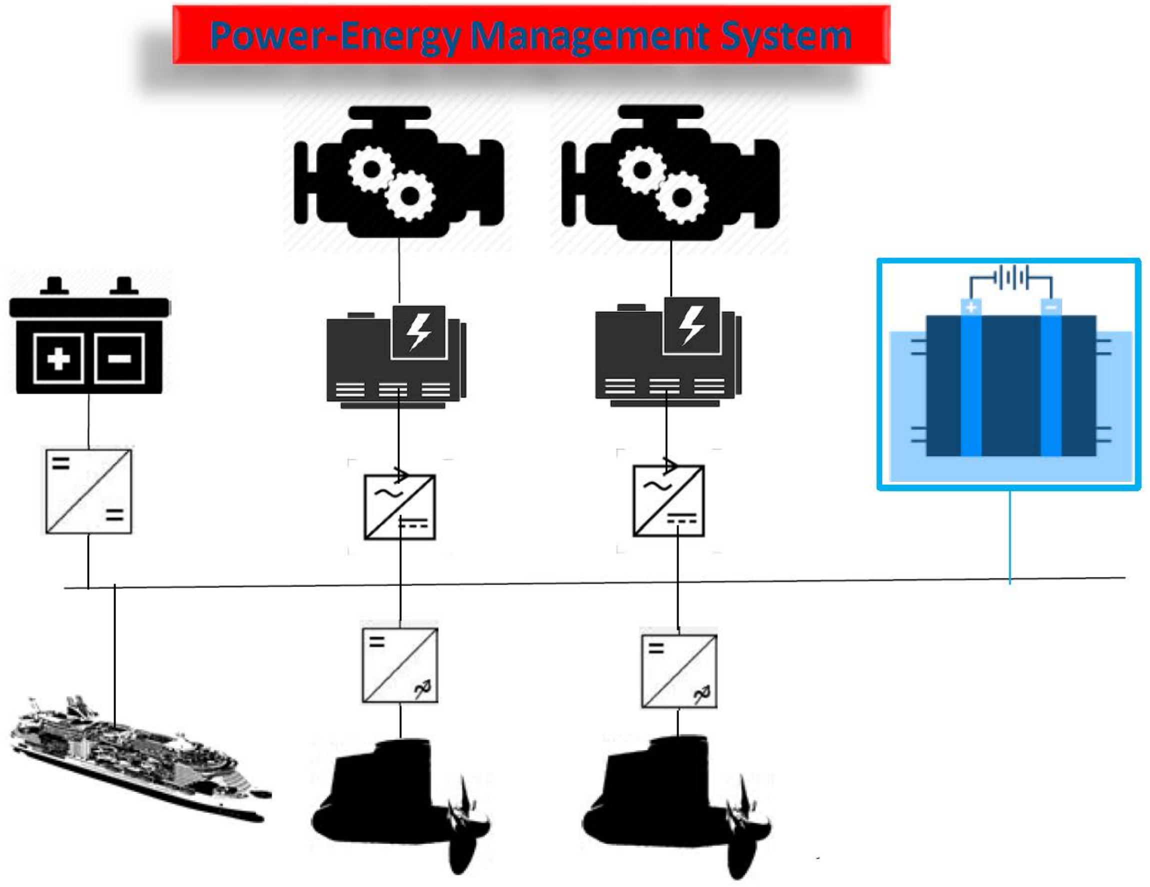
Objective

In this PhD project, the main goal is reaching a package and methods of suggesting optimum hybrid power systems with flexibility in sizing, components configuration, system integration, and operations. Indeed, Multidisciplinary Design Optimization (MDO) is the fundamental optimization method that will be implemented in this project. The main objective in the first stage is developing a package of high-fidelity model of Fuel Cells (FC) with the ability to suggest optimum size and construction. After defining the main parameters of FCs, the model will provide the specific FC operation in power system with an emphasis on dynamic response and control-oriented approach. The second stage, that will be developed in parallel, is implementing the optimum algorithm of energy management decision making. This algorithm will permit the system components such as generators, batteries and fuel cells to operate in an efficient way for reaching the goal of reducing fuel consumption and emission.

Research topics

Increasing strict regulations on emitted pollution of maritime operations directed the energy efficiency practical approaches toward hybrid solutions. Moreover, modelling and simulation have a significant role in the investigation of systems behaviour for the aim of developing, enhancing and optimizations. Furthermore, numerical modeling and optimization methods enhance the approach of designers for obtaining the most efficient point of system configuration for specific goals and constraints. Since, for the aim of reaching the optimum state of the hybrid system configuration, the primary step is providing a high-fidelity model with flexibility in parameters and considering a control-oriented approach.

In previous PhD projects, the main components of hybrid power systems, such as generators, batteries and other mechanical and electrical devices have been accomplished. However, there are two research gaps, the first is a model of fuel cells package by flexibility in design, size and operation. The second is optimum decision-making strategy of the energy management system. As a result, developing these two areas facilitates investigating operation state of each component in way of minimizing the consumed fuel and emission regarding the load requirements.



Results-2020

- Flexible physical based modelling of PEM fuel cell system
- Optimization of PEM fuel cell system components
- Modelling of simple DC hybrid power system with PEMFC and battery

Supervisor: Prof. Eilif Pedersen (NTNU)

Siamak Karimi

PhD student WP3 (2019-2022)

Design and optimization of shore to ship charging systems for all-electric and plug-in hybrid ships

Supervisor: Associate Professor Mehdi Zadeh (NTNU)

Background

Electrification of marine vessels has become an important and efficient solution for moving toward the zero and low-emission sea transportation. Existing technologies for reducing emissions include diesel-electric, hybrid and fully battery-electric propulsion systems. While hybrid or plug-in hybrid propulsion systems can reduce the consumption of fossil fuels, fully battery-electric solutions can eliminate all emissions from regular operation. Hybrid propulsion systems allows for onboard batteries to be recharged by diesel generators or discharged to supply peak loads. Furthermore, another way to recharge the onboard batteries is shore charging which can allow for sustainable energies, such as wind, solar and hydropower energies available in onshore power systems to be utilized for propulsion in the onboard power system. Often, the electricity generated on land is also cheaper and more sustainable than the electricity generated by onboard diesel engines. The main challenge of using batteries in maritime vessels is their low energy density. In other words, a marine battery pack which weighs about tens of tones and spaces hundreds of square meters cannot guarantee the propulsion power for long distances. Thus, due to the current range limitations of marine batteries, they are often installed on short-distance and coastal ferries. With tight schedules for short-distance ferries, it is important to take advantage of docking time efficiently, introducing the need for fast charging. Another challenge of shore-charging systems for motor/car ferries is that usually the ports are located in remote areas with limited capacity in the local power grid. This means that the local grid may not be able to provide high power demand for fast charging. To overcome this challenge, stationary energy storage systems are used as energy buffers and to support the weak grid during the charging. However, these stationary batteries introduce other challenges such as the excessive energy loss and reliability of multiple battery systems. Therefore, energy efficiency and reliability have to be taken into account in the design phase.

Scope

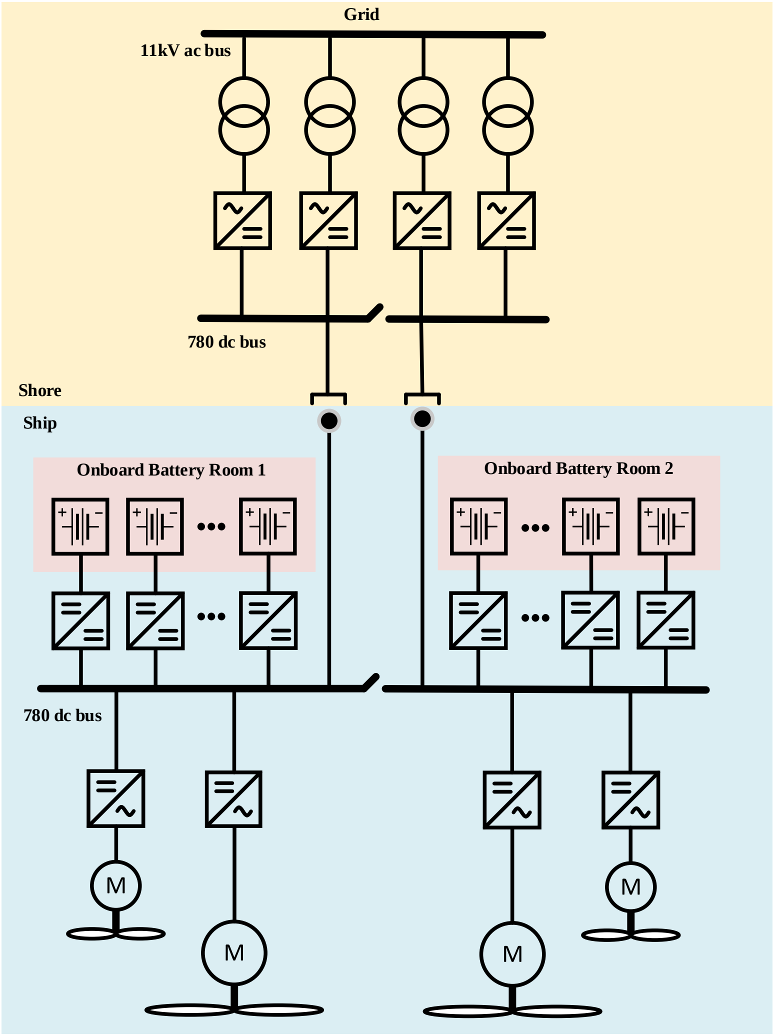
- Power system architecture of solutions for shore-to-ship charging systems (S2SCS); wired AC and DC as well as inductive charging.
- Energy efficiency evaluation of S2SCS solutions, so-called, “grid-to-propeller energy efficiency".
- Reliability assessment of S2SFBC in terms of charging load curtailment index. Cost-based redundancy design of the S2SCS.
- Control and operation management of S2SCS.

Main Achievements in 2020

- Presented the energy efficiency evaluation for the shore to ship charging systems in ISIE 2020, Delft, Netherland.
- Published an article about the infrastructure and power architecture of the shore to ship charging systems in IEEE Electrification Magazine.
- Established a reliability analysis method for the shore to ship charging systems which is accepted for presentation in ITEC 2021, Chicago, US.

Publications

- **S. Karimi**, M. Zadeh and J. A. Suul, "Shore Charging for Plug-In Battery-Powered Ships: Power System Architecture, infrastructure, and Control," in IEEE Electrification Magazine, vol. 8, no. 3, pp. 47-61, Sept. 2020,
- **S. Karimi**, M. Zadeh and J. A. Suul, "Evaluation of Energy Transfer Efficiency for Shore-to-Ship Fast Charging Systems," 2020 IEEE 29th International Symposium on Industrial Electronics (ISIE), Delft, Netherlands, 2020, pp. 1271-1277
- **S. Karimi**, M. Zadeh and J. A. Suul, “Reliability Analysis of Shore-to-Ship Fast Charging Systems," 2021 IEEE Transportation Electrification Conference & Expo (ITEC), Chicago, US (Accepted for presentation)



Single line diagram of an all-electric ship with shore-to-ship charging

Marius Ulla Hatlehol

PhD student WP3 (2021-2024)

Modeling, Design and Control of Hybrid Electric Power and Propulsion for Future Low-Emission and Autonomous Vessels

Research topic

Throughout the last decade, the focus on sustainability and reducing the environmental footprint has changed- and is still shaping the maritime industry. This transformation is driven by the motivation to combat climate change by reducing harmful greenhouse-gas (GHG) emissions. This has led to the development of hybrid power- and propulsion systems. As a result, modern vessels combine energy storage systems (ESS) with internal combustion engines (ICE) and fuel-cells (FC) as well as wind-assisted propulsion. The mix of energy sources can serve different purposes depending on the operation to minimize fuel-consumption, emissions, and down-time. In addition, all-electric ships (AES) are becoming more common as the quality and lifetime of energy storage systems are being improved. Considering the new era of autonomy and digitalization, all-electric- and hybrid power and propulsion systems will play an integral part to enable reliable, robust, and dependable autonomous vessels. As a result, onboard power systems are becoming an essential part of ships of the future.

The integration of the various energy sources is made possible by power electronic converters (PEC) to interface the onboard distribution and propulsion systems. Converter dominated shipboard power systems are complex systems with a high degree of flexibility. This leads to a situation where the dynamics of the power systems are determined by the structure of the low-level control systems. The low-level control layer is responsible for the behavioral dynamics, droop and current control. To elaborate further, the power converters are often off-the-shelf based, designed to operate in both terrestrial- and marine power systems with a stable predefined low-level behavior. It has been well documented that instabilities and oscillations occur when these power converters are interfaced to a common DC-bus due to their high-bandwidth controllers. This leads to an unintentional phenomenon known as negative incremental impedance, which could have a deteriorating effect on power system stability. Furthermore, the low-level controllers can also cause inter-harmonics when they interact with several power converters- and subjected to mechanical oscillations propagating through the motor drives and into the power system. A solution to this problem could be to preserve stability structurally through the low-level control to enable the flexibility and connectivity of the different power sources in hybrid power and propulsion systems.

Supervisor: Associate Professor Mehdi Zadeh (NTNU)
Co-supervisors: Prof. Roger Skjetne (NTNU)
Associate Prof. Gilbert Bergna-Diaz (NTNU)

Expected results and industrial goals

- Establish dynamic models of the hybrid power and propulsion systems and use to stability analysis and control system design.
- Design a control structure that accounts for the complex nature of power electronics dominated hybrid power systems and ensures operational stability over a wide range of operating conditions.
- Design a framework and guidelines for the stability, reliability and operability of hybrid power systems, based on the developed models and advanced stability analysis.
- Reconsider the conventional power system design with innovation design solutions, namely modular design to improve the flexibility of the power and energy system.

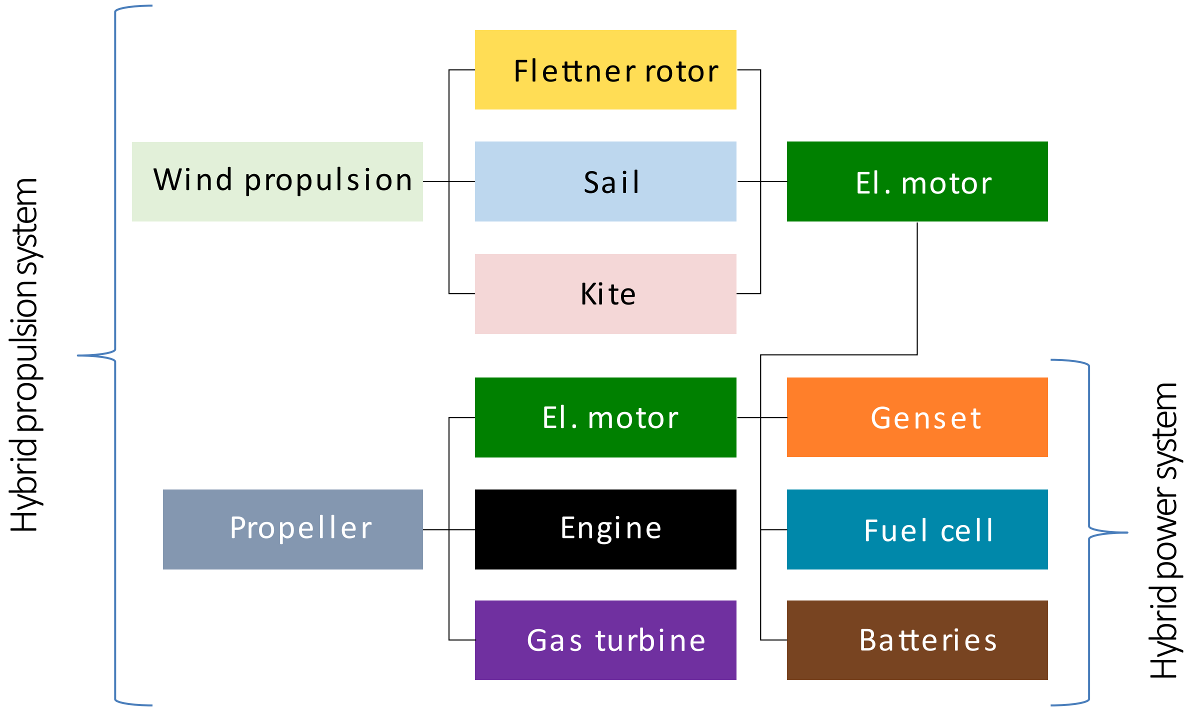
Dražen Polić

Postdoc WP3 (2020-2022)

Impact of wind propulsion on the propeller and power system

Research topic:

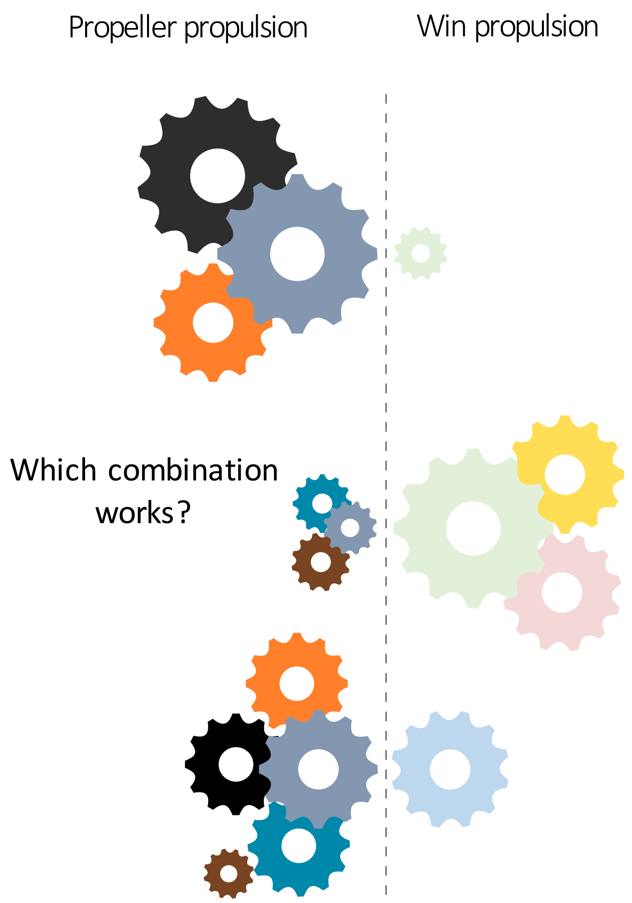
Wind propulsion on modern merchant ships can reduce fuel consumption and hence reduce the emission of greenhouse gasses. The thrust produced by wingsail or Flettner rotor, the most mature technologies, will change the operational range, and energy efficiency of the propeller and hybrid power systems.



Objective:

The goal is to provide coupled models suitable for the selection, design and optimization of hybrid propulsion and power systems. Today, multiple models exist for wind propulsion, propeller, and power plants. However, their efficiency while working together is not well known.

Wind propulsion creates thrust mainly by using the lift, i.e., the force normal to the incoming apparent wind velocity. The apparent velocity is a vector sum of the ship velocity and the velocity of the true wind. Creating the thrust mostly from the lift generates an unavoidable side force, which pushes the ship sideways and causes additional hull resistance. Hence, the hybrid propulsion performance will depend on the ship velocity, wind conditions, the hull hydrodynamics, the side force to thrust ratio of the sail or rotor, the proportion of the thrust generated from the wind, and the flexibility of the propeller and hybrid power system to handle additional thrust.



The size of the gear presents the amount of propulsion power produced by each system (system color matches the left figure)

Scope:

- Develop medium-fidelity wind propulsion system model
- Evaluate a coupled hybrid propulsion machinery system
- Adopt/include added hydrodynamic ship resistance due to the side force

Limitations:

- Limited validation of the coupled system model, most likely only numerical
- The result is a set of multiple promising designs of the hybrid propulsion machinery

Expected result:

- Minimum of three journal publication and facilitate collaboration with and among Ph.D. students in WP 2-4

Supervisor: Prof. Eilif Pedersen (NTNU)

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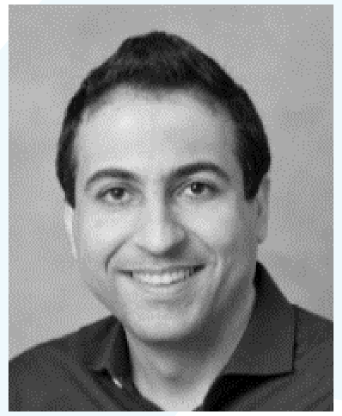
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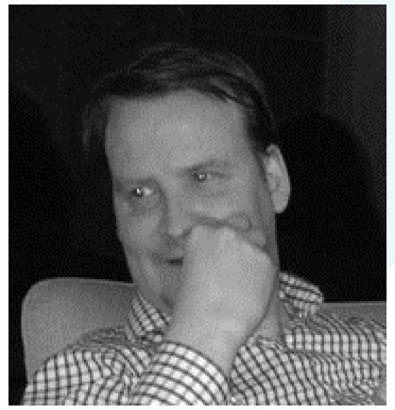
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Roar Fanebust, **Grieg Star**
Coordinator of T.A.C

SMART MARITIME

COMMUNICATION AND DISSEMINATION

Zero-emission ferries, HAV Design

COMMUNICATION

Priority is given to communication towards the Centre's industry partners, Technical Advisory Committee and Board, to ensure good dialog with the core research team and involvement in research projects.

Our main communication channels are:

Website

www.smartmaritime.no contains *public information* about the Centre and a publication database accessible by the Centre members. News and events are also administrated on the website.

E-mail communication

News letters, updated information, invitation to webinars administrated by e-mail.

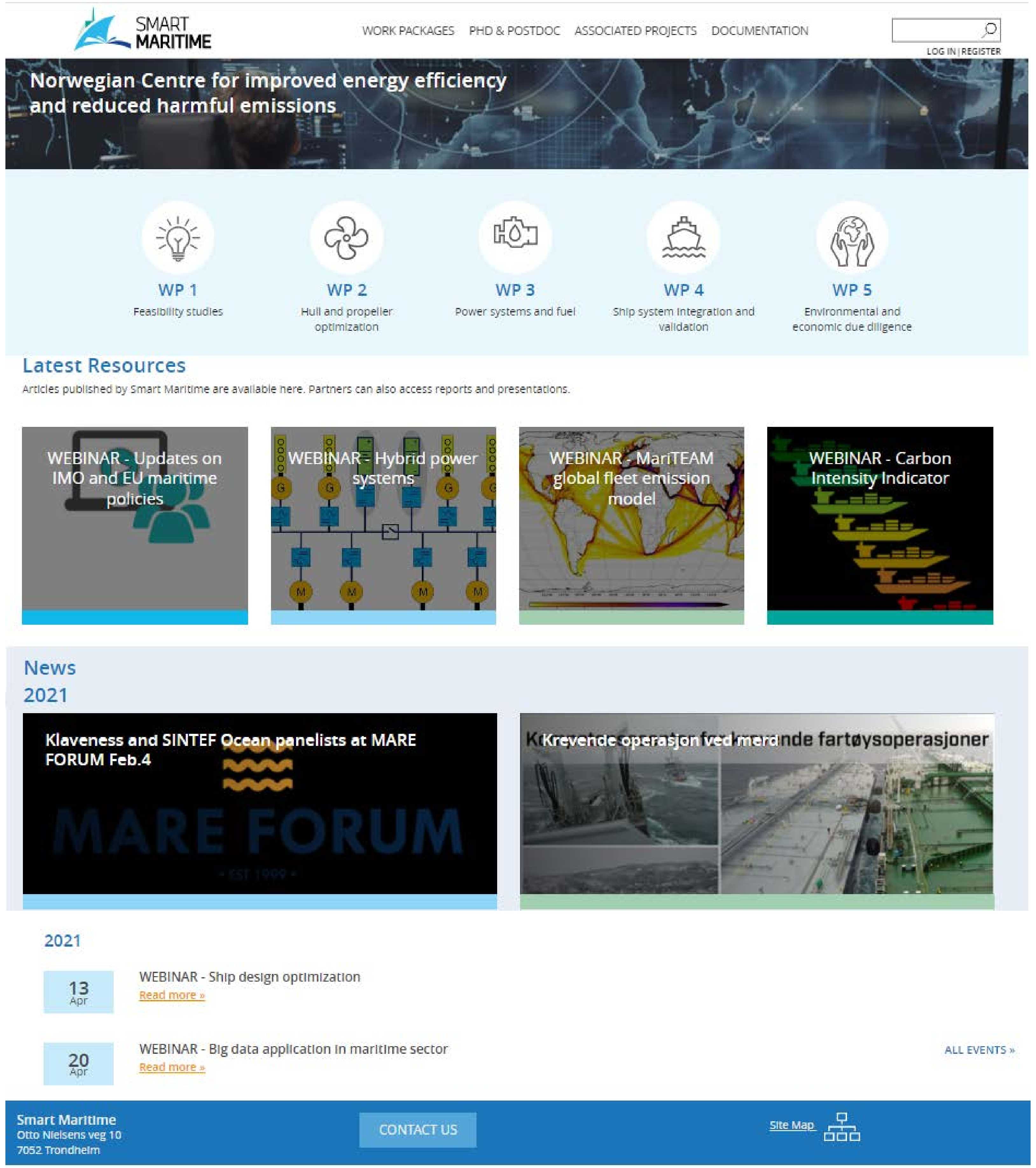
Workshops

The large majority of technical workshops on research topics and associated projects meetings has been handled as digital meetings in 2020.

Webinars

Smart Maritime has increased the frequency of Webinars in 2020 in order to keep partners regularly updated on scientific progress and maintain the dialog between research team and industry partners despite the covid-19 restrictions.

Webinars have been extended to other forums, open to external participants, and involving industry partners in the preparation and discussion.



DISSEMINATION > Smart Maritime in the media

IMO-KRAV TIL KLIMAUTSLIPP

Åtte rederier, Sintef og NTNU skal finne løsningene på hvordan de største skipene kan nå klimamål

I 2030 skal internasjonal skipsfart ha kuttet klimagassutslippene med 40 prosent. Mye må gjøres med dagens flåte og de neste skipene som skal kontraheres.

Rederiet Solvang jobber hardt med å få ned sine utslipp. Her er LPG-skipet Clipper Harald med på SCOPE 2017 - en oljevern- og kriseøvelse. (Bilde: Tore Stensvold)

NULLUTSLIPPSKIP

Klaveness skal bestille nullutsslippsskip innen 2030

Rederiet har som mål å utvikle og kontrahere et nullutslipps kombinasjonsskip i løpet av ti år.

MV Baru på jomfrutur. Skipet er på 82.500 dødvekttonn og er ett av tre kombinasjonsskip som ble levert fra verft i Kina i 2019. (Foto: Klaveness Combination Carriers)

Vard designer cruiseskip med vindkraft

Med et budsjett på 10 millioner kroner skal Vard i løpet av to år designe et cruiseskip med vindkraft. Det forteller Henrik Burvang i Vard ...

Millioner til utslippsfri transport

Myndighetene strekker ut enda en hjelpende hånd med penger utslippsfri transport. Nye Pilot E-midler skal deles ut i høst.

Oppdraget: Et skip som går Bergen - Kirkenes med lavest mulig energiforbruk. Da må det tusenvis av simuleringer til

Når Havyard Design & Solutions utvikler de nye kystruteskipene er tusenvis av små og store endringer og justeringer testet med simulatorverktøy mange ganger.

DISSEMINATION > International arena

SCIENTIFIC PUBLICATIONS

Journal articles

Ghimire, Pramod; Reddy, Namireddy Praveen; Zadeh, Mehdi; Pedersen, Eilif; Thorstensen, Jarle. Dynamic Modeling and Real-Time Simulation of a Ship Hybrid Power System Using a Mixed-Modeling Approach. IEEE Transportation Electrification Conference and Expo (ITEC) 2020

Karimi, Siamak; Zadeh, Mehdi; Suul, Jon Are Wold. Shore Charging for Plug-In Battery-Powered Ships: Power System Architecture, infrastructure, and Control. IEEE Electrification Magazine 2020 ;Volum 8.(3) s. 47-61

Karimi, Siamak; Zadeh, Mehdi; Suul, Jon Are Wold. Evaluation of Energy Transfer Efficiency for Shore-to-Ship Fast Charging Systems. Proceedings of the IEEE International Symposium on Industrial Electronics 2020 s. 1271-1277

Lindstad, Elizabeth; Eskeland, Gunnar; Rialland, Agathe Isabelle; Valland, Anders. Decarbonizing Maritime Transport: The Importance of Engine Technology and Regulations for LNG to serve as a Transition Fuel. Sustainability 2020 ;Volum 12.(21) s. -

Lindstad, Elizabeth; Rialland, Agathe Isabelle. LNG and cruise ships, an easy way to fulfil regulations-versus the need for reducing GHG emissions. Sustainability 2020 ;Volum 12.(5) s. 1-15

Sandvik, Endre; Nielsen, Jørgen Bremnes; Asbjørnslett, Bjørn Egil; Pedersen, Eilif; Fagerholt, Kjetil. Operational sea passage scenario generation for virtual testing of ships using an optimization for simulation approach. Journal of Marine Science and Technology 2020

Shakeri, Nastaran; Zadeh, Mehdi; Nielsen, Jørgen Bremnes. Hydrogen Fuel Cells for Ship Electric Propulsion: Moving Toward Greener Ships. IEEE Electrification Magazine 2020 ;Volum 8.(2) s. 27-43

Conference articles

Lagemann, Benjamin; Erikstad, Stein Ove. Modular Conceptual Synthesis of Low-Emission Ships. I: 12th Symposium on High-Performance Marine Vehicles. Technische Universität Hamburg-Harburg 2020 ISBN 978-3-89220-718-4. p. 134-151

LECTURES

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Alterskjær, Sverre Anders. SFI Smart Maritime senterpresentasjon. Kompetanseforum for krevende fartøysoperasjoner: Hvordan påvirker grønne skipsdesign fartøysegenskaper?; 2020-11-04

Dæhlen, Jon. SFI Simulation Platform: latest developments. SFI Smart Maritime WEBINAR Simulation Platforms; 2020-10-09 -

Koushan, Kourosh. Hydrodynamic Energy Saving Measures. Webinar; 2020-06-17

Kramer, Jarle Vinje. Wind propulsion. SFI Smart Maritime WEBINAR Wind-assisted propulsion; 2020-11-10

Lagemann, Benjamin. Methodology for low-emission concept ship design. SFI Smart Maritime WEBINAR Simulation Platforms; 2020-10-09

Lindstad, Elizabeth. Alternative Fuels overview. Clean Cargo; 2020-11-06

Lindstad, Elizabeth. ESSF - Fuel, Engine technologies and Legislations IMPORTANCE for achieving Maritime GHG reduction : CONVENTIONAL FUELS - LNG - NEW ALTERNATIVE FUELS. European Sustainable Shipping Forum - Ship energy efficiency; 2020-03-02 - 2020-03-03

Lindstad, Elizabeth. ESSF - How to assess and compare fuels. Digitalt web-møte; 2020-05-12

Lindstad, Elizabeth. ESSF - The four IMO GHG studies and Development of carbon intensity 1990 - 2018. Digitalt web-møte; 2020-10-12

Lindstad, Elizabeth. Fuel EU Maritime 18 September 2020. Digitalt web-møte; 2020-09-18

Lindstad, Elizabeth. Trender og utvikling av skipstyper og nullutslippsmaskineri. Kompetanseforum for krevende fartøysoperasjoner - Hvordan påvirker grønne skipsdesign fartøysegenskaper?; 2020-11-04

Lindstad, Elizabeth. Webinar IMO GHG Studies EEDI - EEXI. Digitalt web-møte; 2020-10-20

Muri, Helene. Klimaendringene: Dette skjer rundt deg nå. Ungdommens klimatoppmøte; 2020-02-13

Muri, Helene. Negative utslipp - hvordan fjerne CO2 fra luften?. Orientering for Klimaomstillingsutvalget; 2020-05-18

Östman, Anders Lennart. Wind-assisted propulsion in the CruiZero project. SFI Smart Maritime WEBINAR Wind-assisted propulsion; 2020-11-10

Rialland, Agathe Isabelle; Dæhlen, Jon. RuteSim - Simulation based route planning demo-presentation. SFI Smart Maritime WEBINAR Simulation Platforms; 2020-10-09

Cariou, Pierre; Lindstad, Elizabeth. Container shipping Decarbonizing Pathways. 4TH KMI-WMU SEMINAR: CONTAINER SHIPPING BUSINESS AND MARITIME 4.0 POLICY & STRATEGY; 2020-11-12 - 2020-11-13

Lindstad, Elizabeth. Assement of alternative Fuels. Digitalt web-møte; 2020-10-28

Lindstad, Elizabeth. E-Fuel basert på Hydrogen. Teknologiutvikling av hurtigbåter og ferger 2020; 2020-12-08

Lindstad, Elizabeth. ESSF - Applying a Goal based measure to reduce the carbon intensity of maritime transport and fulfilling IMO's 2030 and 2050 targets (ESSF – Ship Energy Efficiency Subgroup 18th of June 2020). European Sustainable Shipping Forum - Ship energy efficiency; 2020-06-18

Lindstad, Elizabeth. ESSF- Fuel and Engine technologies with focus on GHG and Energy utilization. ESSF - Alternative maritime fuels; 2020-06-17

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Lindstad, Elizabeth. Presentation of draft reports on pathways and update on work on IMO - LCA guidelines. ESSF - Alternative maritime fuels; 2020-12-08

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Lindstad, Elizabeth. The potential impact of decarbonization on ships and operations. UNCTAD ad hoc Expert Meeting on the potential impact of decarbonization measures in shipping on States; 2020-12-14

Lindstad, Elizabeth. Webinar - EEDI achievements so far and EEDI phase 4. Digitalt web-møte; 2020-11-03

Lindstad, Elizabeth. WEBINAR - Sustainable Alternative Marine Fuels IMO & EU. Digitalt web-møte; 2020-10-06

Lindstad, Elizabeth. Webinar Maritime Policies EU & IMO. Digitalt web-møte; 2020-04-30

Lindstad, Elizabeth; Bø, Torstein Ingebrigtsen; Nielsen, Jørgen Bremnes; Valland, Anders. WEBINAR Smart Maritime - Alternative Fuels and Flexible Technology Solutions. Digitalt web-møte; 2020-03-11

Lindstad, Elizabeth; Rialland, Agathe Isabelle. Pathways and investment strategies to reach IMO 2030 and IMO 2050 GHG targets. Digitalt web-møte; 2020-12-01

Master theses

Julie Sandnes Galaaen	NTNU, Industrial Ecology	2020	Comparative Life cycle assessment of a diesel electric and a battery electric ferry.
Anna Spedo	NTNU, Industrial Ecology	2020	Integrated Assessment Model of the International Maritime Sector
Maria Kristine Munkvold	NTNU, Industrial Ecology	2020	Comparative Life Cycle Assessment of a hydrogen fuel cell and diesel-powered high-speed passenger catamaran
Tone Alexandra Dale	NTNU, Marine Technology	2020	Development of simplified methods for ship powering performance calculations

NTNU

SMART MARITIME

STATEMENT OF ACCOUNTS 2020

	Funding		Cost	
Research council	12 946	(45 %)		
The Host Institution (SINTEF ocean)	55 538	(19 %)	12 565	(44 %)
Research Partner (NTNU)	1 829	(6 %)	9 158	(32 %)
Industry partners	8 536	(30 %)	7 084	(25 %)
Equipment			42	(0.1 %)
Total NOK ‘000	28 849		28 849	

Foto: Sjøfartsdirektoratet

Photo: Wallenius Wilhelmsen Group

SMART MARITIME

Centre for Research-based Innovation

The Research Council of Norway

ANNUAL REPORT 2020

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