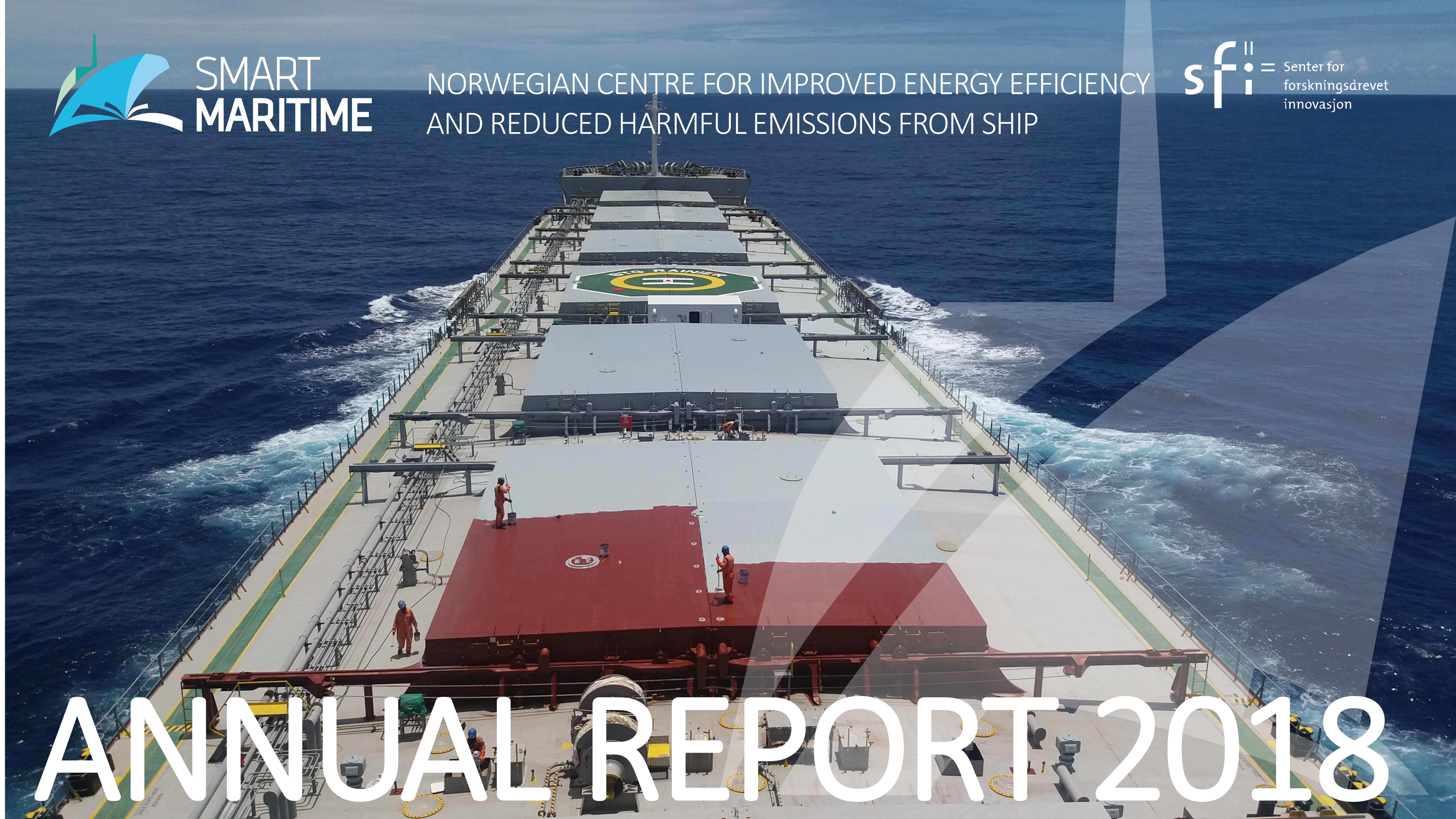


SMART MARITIME

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

sfi = Senter for forskningsdrevet innovasjon

# ANNUAL REPORT 2018

# TABLE OF CONTENTS



*Cover picture: BTG Rainier, KG Jebsen Skipsrederi AS, Photo: Cesar Allan Isidoro*

# SUMMARY OF 2018

Star Harmonia. Photo: Grieg Star

## SUMMARY OF 2018

SFI Smart Maritime is the largest national centre for research-based innovation for improved energy efficiency and reduced harmful emissions from the maritime sector. Our mission is to provide the Norwegian maritime sector with knowledge, methods and tools for effective identification, assessment and verification of solutions and technologies, and contribute to strengthening its innovation capability and competitiveness. The research focus is on technological solutions within hydrodynamics (hull and propellers) and machinery system (energy optimization, exhaust emissions and fuels).

The Centre has been constantly evolving since its establishment in 2015. The first two years were dedicated to exploring distinct technologies and developing individual simulation models and tools in cooperation between research and industry partners. In the third year started the consolidation of Smart Maritime's models and application in business cases. This has been enabled by cross-disciplinary cooperation, both across work-packages, and among PhD students, and active involvement of industry partners.

2018 marks a turn point, with major industry, Post doc and PhD projects being finalised, and focus redirected to concretisation of results for increasing knowledge and technology transfer to industry. Prioritisation is now given to making the Smart Maritime simulation platform a user-ready innovation tool for the Centre partners, i.e. a tool that enables to identify, explore, verify, demonstrate technological solutions and designs for energy efficient and emission reduction.

Another milestone for the Centre is the increase concern by the maritime industry for reducing emissions (IMO 2050 goal), which appeals to Smart Maritime's responsibility to identify realistic and feasible solutions for upgrading the global merchant fleet and reducing shipping emissions by 50%.

SFI Smart Maritime has already provided major contributions, pushing the state-of-the-art within each of the five research areas in focus. The centre has so far made a total of 39 scientific publications across these research areas, 22 academic lectures (respectively 8 and 7 in 2018), and has engaged 6 PhD candidates, 3 Postdocs and more than 20 Master students so far. Further 4 PhD students and one postdoc will join the Centre current 2019.

Smart Maritime enjoys a solid network of highly enthusiastic maritime industry professionals from 17 industry partners, an active Board and a research team focusing on cross-disciplinary R&D.

The Centre serves as a springboard for new initiatives and further cooperation. As a result of effective collaboration among SFI partners, the following associated projects have received research funding from the Research Council of Norway and will be launched in 2019: 1 Competence project (Climate change Mitigation in the maritime sector), 3 Innovation projects (ship routing, route optimization and digital twin yard), and 2 pilot projects on zero emission ships. In addition, upgrade of the machinery lab is ongoing.

In order to achieve higher impact of the research at the industry level, the Centre will work further on demonstration cases and tools to investigate effects of alternative technologies and operations on distinct ship segments.

**Highlights from 2018**

The main scientific achievements are presented in the section "Scientific activities and results" on page 41 - 58.

SIMULATION

- Gymir, business application cases
- MariTEAM Maritime transport environmental assessment model

POWER AND PROPULSION

- Lab development: Constant volume combustion rig
- Methane slip from gas fuelled engines
- Alternative exhaust emission reduction solutions
- Sulphur cap options

HYDRODYNAMICS

- Calculation of added resistance due to waves
- Model tests of added resistance due to waves
- Safe return to port and minimum required propulsion power
- Analysis of in-service data of ship performance

Esvagt Froude, Photo: Havyard Group

## NORSK SAMMENDRAG

SFI Smart Maritime fokuserer på forbedring av energieffektivitet og reduksjon av skadelige utslipp fra skip. Senteret søker å forsterke konkurransekraften til Norsk Maritime industri gjennom ny teknologi, verktøy og effektive løsninger på industriens utfordringer. Målet er å finne svar på hvordan det er mulig å oppnå økt energieffektivitet og reduserte utslipp innen den maritime sektoren, også med bruk av konvensjonell teknologi og drivstoff. De tekniske forskningsområdene er innenfor hydrodynamikk (skrog og propell) og fremdriftsmaskineri (energioptimalisering, avgassutslipp og drivstoff), og det legges vekt på betrakting av skipet som system. Smart Maritime jobber med utvikling av systemorienterte verktøy som analyserer effekten av energieffektiviserende løsninger og tiltak for skrog og propell, kraftsystemer og drivstoff under realistiske fullskalaforhold. Målet er å kunne simulere og optimalisere skipet numerisk før det bygges.

Siden lanseringen i 2015, har Senteret jobbet med å lage oversikt over potensialet for utslippsreduksjon fra skip, uttestet flere teknologi-løsninger, utviklet flere og mer avanserte prediksjonsmodeller, utviklet flere simuleringsverktøy for analyse av energiforbruk og utslipp, gjennomført flere case studier. Formidling av resultater skjer gjennom vitenskapelige publiseringer, nyhetsbrev, workshops, webinars. På Senterets halvårlige nettverksmøter prioriteres strategiske diskusjoner.

Dialogen mellom forsknings- og industripartnerne i Senteret er veldig konstruktiv. Smart Maritime fungerer i dag som en relativt viktig møteplass og samarbeidsplattform innen energieffektive og miljøvennlig shipping. I tillegg har Senteret fungert som et springbrett for nye initiativer og ytterlige samarbeid.

Blant bedriftspartnerne er toneangivende bedrifter som Rolls Royce Marine, Bergen Engines, Vard Design, Havyard Group, ABB, SIEMENS, Norwegian Electric Systems, Jotun, Wärtsilä Moss og DNV GL, samt viktige brukere som Wallenius Wilhelmsen Ocean, Solvang, Grieg Star, Kristian Gerhard Jebsen Skipsrederi og Norges Rederiforbund. I tillegg er sentrale aktører som Kystrederiene og Sjøfartsdirektoratet partnere i SFI Smart Maritime.

I 2018 har Smart Maritime har holdt en høy aktivitetstempo og konstruktiv dialog mellom sine partnere.  Senteret har oppnådd en god balanse mellom langsiktig forskning og mer kortsiktig anvendt forskning.  Ledelsen har jobbet aktivt med å lytte og involvere industripartnerne i planlegging av prioriteringsområder. I forbindelse med midtveisevaluering, har Senteret samlet tilbakemelding fra alle sine medlemmer om verdiskaping og innovasjonspotensial for industrien, og etablering av Senterets strategien for den siste perioden. I denne prosessen, har Senterets Styret spilt en viktig rolle, oppfordret til å spisse aktiviteten mot simuleringsverktøyene og gjøre disse mer tilgjengelige for industri partnere. I tillegg har Styret gitt klar beskjed om å øke senterets synlighet gjennom gode demonstrasjon av verktøy og skipskonsepter.

I 2018 ble også flere assosierte prosjekter initiert i form av prosjektsøknader. Følgende prosjekter har fått innvilget støtte fra Forskningsrådet og vil starte i 2019: 1 kompetanseprosjekt (Climate change  Mitigation in the  maritime sector), 3 innovasjonsprosjekt (ship routing, route optimalisation og digital twin yard), og 2 pilot prosjekt om  zero emission ships. I tillegg ble det initiert oppgradering av laboratorier.

Fra 2019 vil Smart Maritime spisse aktiviteten mot simuleringsverktøyene og skip konsepter som vil demonstrere mulige løsninger for å oppnå energieffektivisering og utslippsreduksjon som er nødvendig for en mer bærekraftig maritime sektor.

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. This position will be gained through innovative use, improvement and combination of technologies, which are cost-, energy- and emission efficient, and will strengthen the competitiveness of the Norwegian maritime industry.

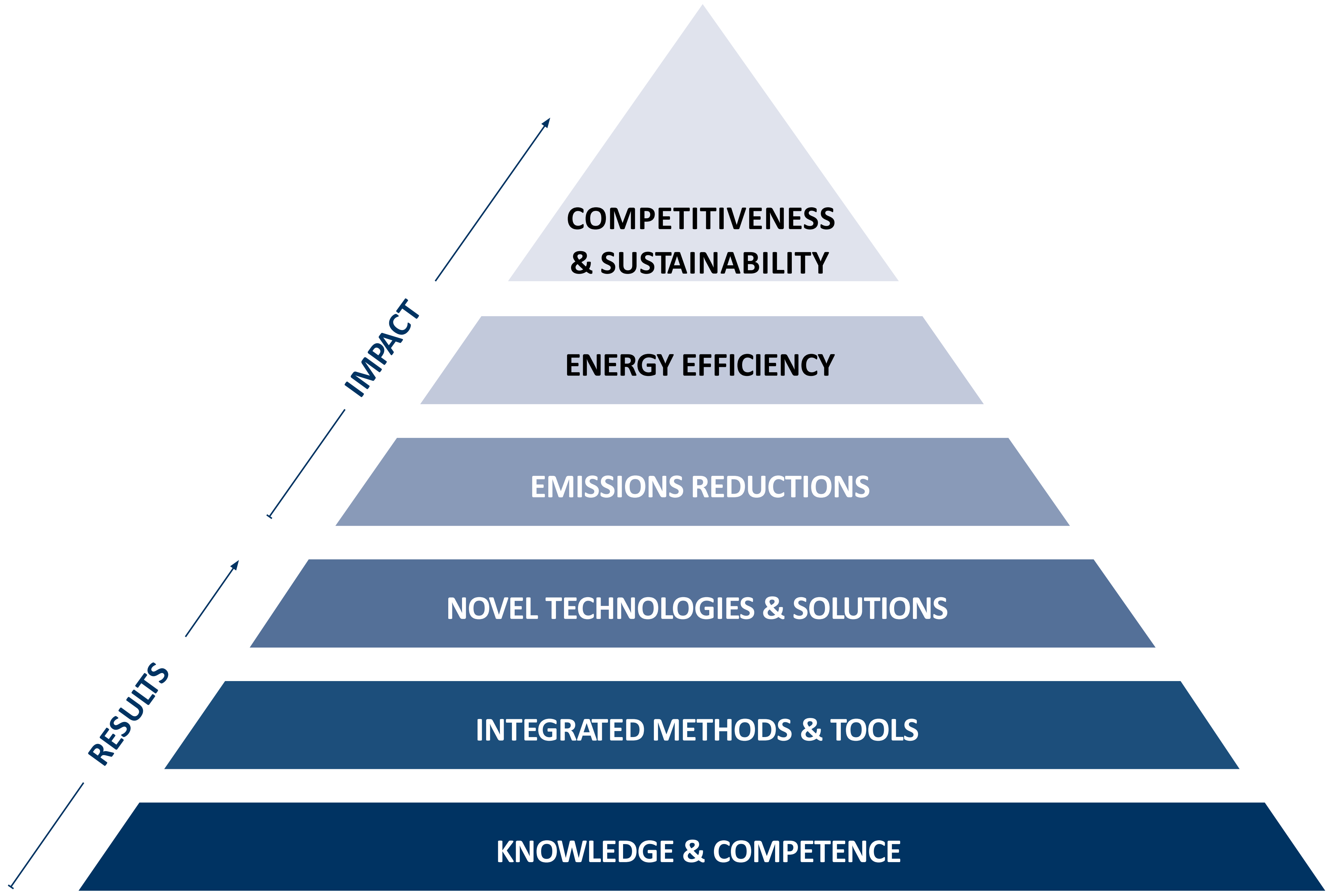
Our mission is to provide the Norwegian maritime sector with knowledge, methods and tools for effective identification and assessment of solutions and technologies.

Photo: Rolls-Royce Marine

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.*

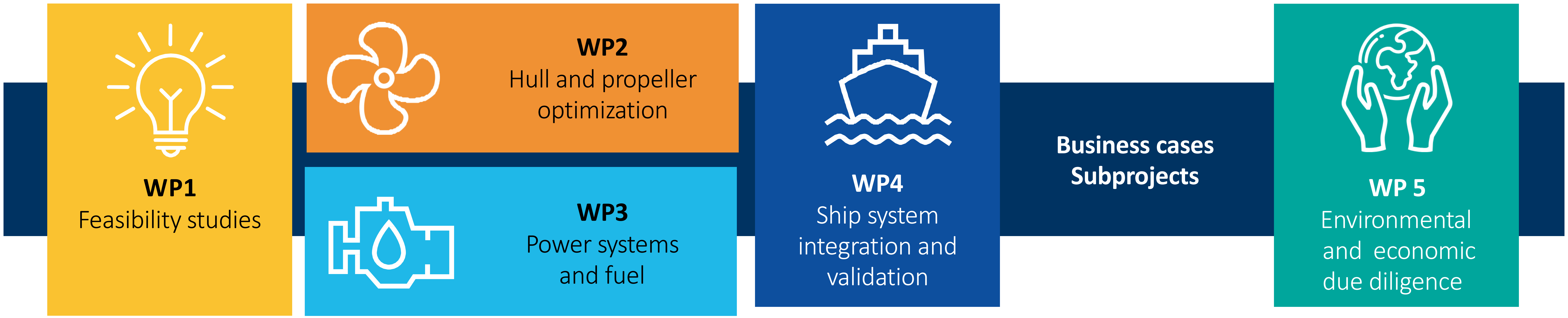
**The expected outcomes include:**

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.



# RESEARCH STRATEGY AND PLAN

Photo: Siemens




To fulfil a vision of environment- and energy efficient maritime transport, SFI Smart Maritime will provide models, methods and tools for improved design, assessment and validation of innovative technologies and solutions. Doing so, the Centre aims at strengthening the competitiveness of the Norwegian Maritime industry.

During its 8-year period, the SFI Smart Maritime will finance 11 PhDs and 5 Postdocs.

The research activity is divided into five work packages (WP). These WP follow a concept development process: WP1 produces feasibility studies to screen the most promising options for energy and emissions reductions. These are further explored and tested in WP2 and WP3. Thereafter WP4 offers a ship system integration platform based on models developed in WP2 and WP3, and used to validate solutions and technologies through simulation of ship performance. Finally, WP5 completes the concept development process by providing environmental and economic due diligence of concepts and solutions at ship and fleet level.

# 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) |

### Focus 2018

- Hybridization and other options for meeting EEDI 2025
- Measures and options for 50% GHG reduction
- 2020 Sulphur cap options
- Contribution to specification of rapid hull model estimator to be implemented in the simulator Gymir

# 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<br>Novel overall-design (main dim.) | Effect of waves and off-design operation<br>Evaluation of in-service performance | Wave-foil propulsion<br>Optimization of sail-assisted merchant vessels | Speed loss<br>Interaction with engine<br>Operational profile<br>Above-water geom. |

### Focus 2018

- Frictional resistance reduction
  - Effect of roughness and fouling
  - Use of super-hydrophobic surface, flow separation control and detection
- Utilization of in-service data
  - «Big data» analysis and machine-learning methods
- Performance in a Seaway
  - Safe return to port calculations
  - Speed loss and added power due to steering and manoeuvring
  - Supporting the tools development related to Gymir
  - Added resistance – Amplitude dependence, model test analyses
  - Engineering-type calculation of added resistance due to waves

# WP3: Power systems and fuel

## Objective

Improve current designs and explore novel technologies, systems and solutions for energy efficient low emission propulsion power systems.

## 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 systems |
|---|---|---|---|
| Modeling and simulation of power components and systems<br>Fuel consumption estimation<br>Steady-state and transient operation modes<br>Alternative propulsion concepts | Advanced combustion control<br>Novel injection strategies<br>Alternative fuels (LNG, biofuels, alcohols, hydrogen, ammonia)<br>Exhaust gas cleaning | Energy recovery<br>Alternative power cycles and power system arrangement<br>Thermoelectric power generation<br>Heat management | Hybrid concepts<br>Energy storage systems (batteries)<br>Energy converters and transmissions<br>Optimal control |

## Focus 2018

Models for simulation of power system performance in steady-state and transient operation modes

Fully operational marine-size constant volume combustion rig capable for both liquid (including biofuels) and gas (potentially hydrogen) fuel studies

- Modelling of emission abatement systems and alternative power cycles
- Assessment of feasibility and advantages of WHR systems

Better utilization of batteries for different applications in maritime sector through optimization of power and energy management

# 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<br>Support of Discrete-event simulation to enable long simulation durations<br>Model library database | Methods for assessing system performance against operational profiles<br>KPI's for benchmarking of alternative designs<br>Ship configuration and scenario management | Methodologies for collection, filtering and use of full-scale measurement data<br>Validate and calibate the ship system simulations |

## Focus 2018

Proof-of-concept implementation of Gymir, incl.:

- Hull and propulsor models from WP2
- Machinery simulator from WP3

Testing Gymir on use cases:

- deep-sea shipping
- offshore supply
- road-ferry vessel segments

Validation study comparing simulated and measured fuel consumption.

# WP5: Environmental and Economic Due Diligence

**Objective**

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

**Research need and background:**

Both maritime trade and international 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 costs assessment of current and novel ship designs. In addition, there is a lack ofgood approaches for integration of such assessments with ship designand engineering workflows. WP5 will integrate state of the art methods for detailed environmental and economic analyses.

**Research tasks**

| MariTEAM | Spatial-temporal impact | Life cycle assessment | Scenario analysis |
| --- | --- | --- | --- |
| Software development<br>Theory-guided big data analytics | Environmental impacts located in time and space | Environmental impacts throughout supply chain and service life time established | Fleet and route development<br>Comparisons of technology option |

**Focus 2018**

Data access, aquisition, cleaning:

- Weather data
- Ship profiles
- Port call

Model development and test

- Implement and test weather drag module
- Develop and test ship track completer
- Matching of each vessel's location with instantaneous wind and waves
- Creation of emission curves for species: CO2, SOx, NOx,BC, CO, OC, EC

# SUB-PROJECT SP1: Alternative fuels and technologies to meet IMO Tier III

## Objective

Meeting IMO Tier III emissions restrictions with focus on Heavy Fuel Oil (HFO), Marin Gas Oil (MGO) and Natural Gas in form of LNG. The purpose of the sub-project is to perform a full economic, technical and environmental analysis of the different alternative fuels and abatements technologies, as well as an assessment of technology trends and future legislation development.

## Activities 2018

### Methane slip

- Analyses of measured data of methane slip from ships and laboratory tests.
- Results to be published in scientific article: Methane slip from gas fuelled ships - a comprehensive summary based on measurement data

### Scrubber and EGR

- Measurement on board Clipper Harald comprising exhaust gas emissions, smoke number and cylinder pressure on each cylinder
- Particulate Matter level using scrubber investigated in laboratory testing at Wärtsilä Moss
- Results to be published in scientific article: NOx Tier III and ECA sulfur compliant operation on heavy fuel: combining EGR (exhaust gas recirculation) and sea water scrubbing

Solvang ASA

Wärtsilä Moss

Bergen Engines

# SUB-PROJECT SP7: Simulation-based concept design

## Objective

Improving early stage design decisions by enabling simulation of long-term performance of new ship technology and design solutions and validate simulations against full-scale performance.

## Activities 2018

### Simulation framework

Gymir embedded in Vista simulation workbench.

- Active usage by naval architects, improving their ability to do long-term design evaluations as a supplement to conventional design and simulations.
- Giving vital feedback to WP4 for improvements and further work

VARD a Fincantieri company

### Deep-sea case

- Existing vessel simulated in realistic trade scenario to evaluate simulator flexibility
- Concept vessel evaluated in same scenario for comparison, giving indications of increased energy effecieny for a slightly altered design

GRIEG STAR

### Ferry case

- Simulation of new concept for Kystruten, improving competitiveness
- Evaluation of road-ferry concepts to document compliance with customer specifications

HAVYARD CHANGE OUR INDUSTRY

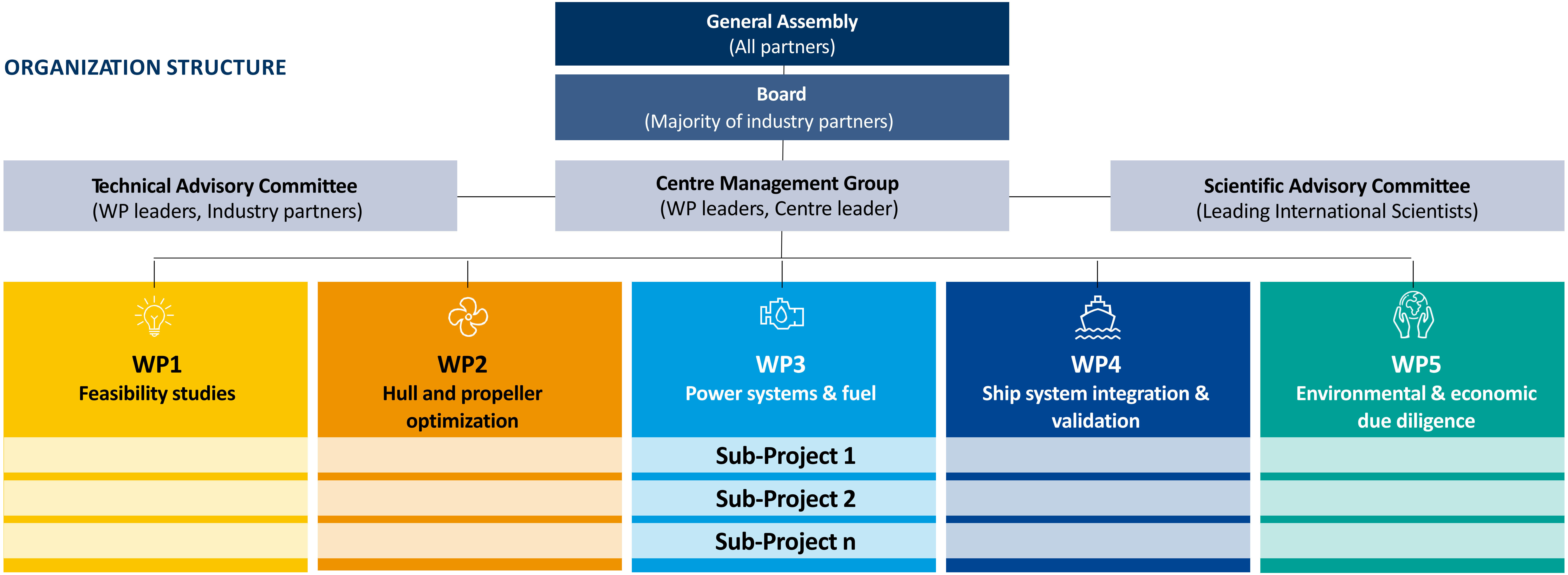
SMART MARITIME



# ORGANIZATION

Clipper Quito. Photo: Solvang.

## ORGANIZATION STRUCTURE




Matrix organization with long-term research performed in **Work Packages** (WP), and short-term cross-disciplinary applied research in collaboration with industry partners performed in **Sub-Projects** (WP).

**Board**: operative decision-making body (7 members, mostly from industry)

**General assembly**: ultimate decision-making body of the Project

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

**Technical Advisory Committee** (TAC): advise the Centre Management on prioritization of R&D activities (WP and SP) to be conducted within Smart Maritime. The TAC is gathered together twice a year at the biannual Network Meetings.

| Board Members | Affiliation |
|---|---|
| Jan Øivind Svardal *(Chairman)* | Grieg Star |
| Jan Fredrik Hansen | ABB |
| Per Ingeberg | Rolls-Royce Marine |
| Kjell Morten Urke | Vard Design |
| Lars Dessen | Wallenius Wilhelmsen |
| Beate Kvamstad-Lervold | SINTEF Ocean |
| Bjørn Egil Asbjørnslett | NTNU |
| Sigurd Falch (observer) | Norwegian Research Council |

## General Assembly Chairman

| | |
|---|---|
| Stig-Olav Settemsdal | Siemens |

## Industry Coordinator

| | |
|---|---|
| Roar Fanebust | Grieg Star |

Jan Øivind Svardal

Lars Dessen

Per Ingeberg

Jan Fredrik Hansen

Beate Kvamstad-Lervold

Kjell Morten Urke

Bjørn Egil Asbjørnslett

Stig-Olav Settemsdal

Roar Fanebust

## BOARD MEETINGS 2018

**June:**

Review of ongoing activities

**August:**

Strategy meeting with Centre Management team
Meeting the Scientific Advisory Committee

**November:**

Planning and budget 2019,

preparation for General Assembly 2018

| Centre Management Group | Affiliation | Role and responsibility |
|---|---|---|
| Per Magne Einang | SINTEF Ocean | Centre Director 2015-2018 (october) |
| Trond Johnsen | SINTEF Ocean | Centre Director (from November 2018) |
| 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 | |
| Sergey Ushakov | SINTEF Ocean | WP3 Power systems and Fuel |
| Trond Johnsen & | SINTEF Ocean | WP4 Ship system Integration |
| Jon Dæhlen | SINTEF Ocean | |
| Anders Strømman & | NTNU | WP5 Environment and economy |
| Helene Muri | NTNU | |

| Centre administration | | |
|---|---|---|
| Jan Andre Almåsbakk | SINTEF Ocean | Controller |
| Agathe Rialland | SINTEF Ocean | Administrative Coordinator |


Per Magne Einang


Trond Johnsen


Anders Valland


Elizabeth Lindstad


Sverre Steen


Sverre Anders Alterskjær


Sergey Ushakov


Jon Dæhlen


Anders Strømman


Helene Muri


Agathe Rialland


Jan Andre Almåsbakk

| 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 |

**September2018**

Joint meeting with Board and Scientific Advisory Committee

## MEETING THE SCIENTIFIC ADVISORY COMMITTEE

## PARTNERS

The Centre collaborates closely with global industry players, national and international research communities and maritime networks.

SINTEF Ocean hosts the Centre in collaboration with research partners NTNU and NTNU Aalesund. The industry partners, together forming the Technical Advisory Committee, cover major parts of the maritime value chain: ship system suppliers, ship designers, ship owners and stakeholder groups.

These partners are involved in scientific activity through business cases and subproject activity across the WPs.


Photo: Wallenius Wilhelmsen Group

## INDUSTRY PARTNERS

**Design, shipbuilding & equipment**
Roll-Royce
Bergen Engines
Vard Design
Havyard
Norwegian Electric Systems (NES)
ABB
Simens
Jotun
Wärtsilä Moss

**Ship operators**
Wallenius Wilhelmsen
Solvang
Grieg Star
KG Jebsen Skipsrederi

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

## RESULTS

**Knowhow Technologies**
**Concepts Solutions**

**Problem description**
**Operational experience**
**Personnel and resources**
**Infrastructure**
(ships & equipment)

SMART MARITIME
SINTEF Ocean
NTNU

**Education**
**Basic/applied research**
**Maritime experience**
**Laboratories**

**International network and customers**

**International R&D partners**

## RESEARCH PARTNERS

**SINTEF Ocean (host)**

**NTNU**
Department 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.

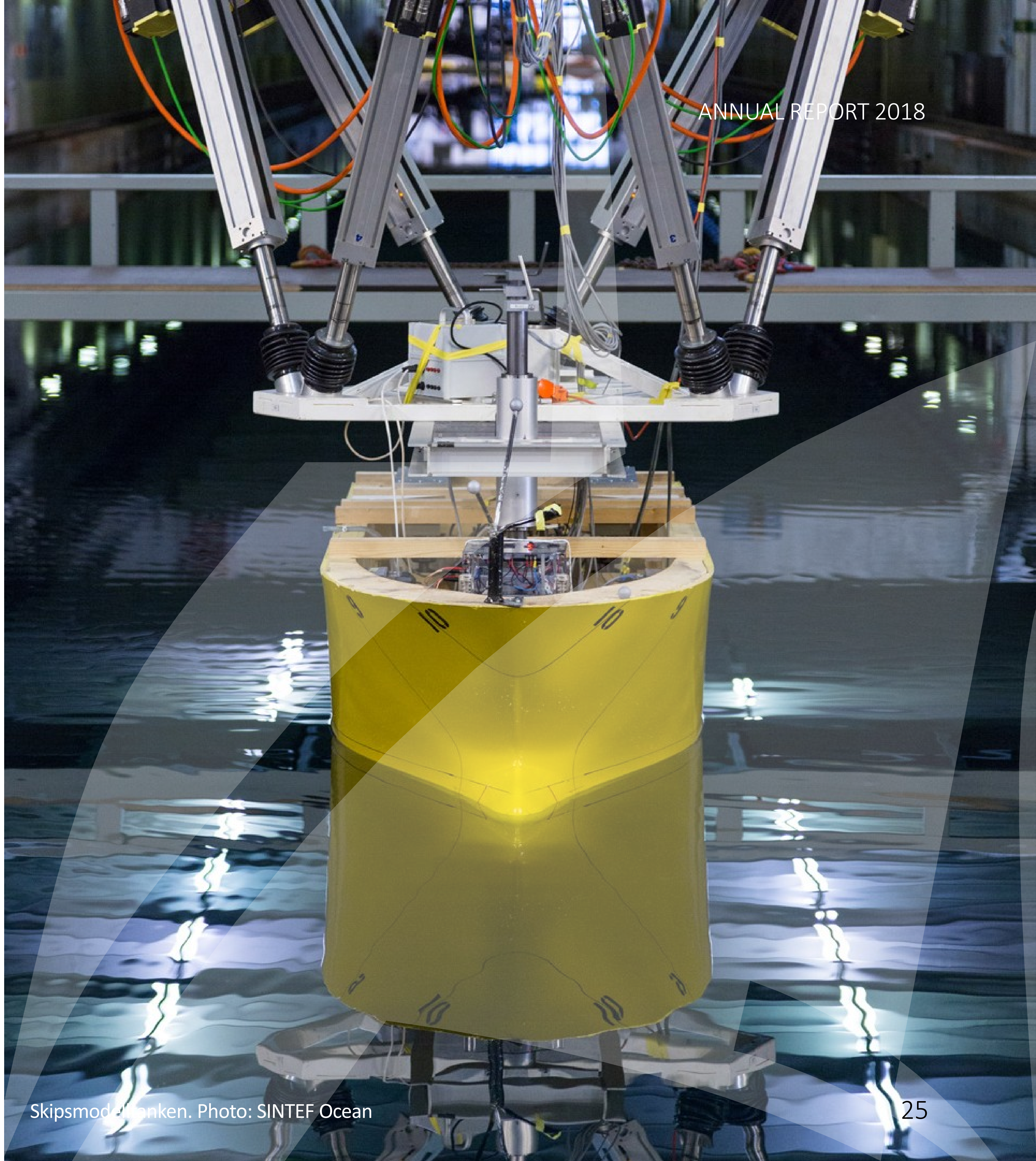
## FUTURE INTEGRATION INTO THE OCEAN SPACE CENTRE

NTNU and SINTEF Ocean have developed a joint strategy for Ocean Space Centre where Smart Maritime is one of five strategic areas for research and education.

SINTEF Ocean is planning to carry on Smart Maritime activity beyond 2023 and ultimately integrate it into the Ocean Space, thus continuing the joint effort between SINTEF Ocean, NTNU and the Norwegian maritime industry.

The Ocean Space Centre (OSC) Centre is estimated to come into place by 2025, and will be the largest single investment in maritime research infrastructure in modern times in Norway.

SFI Smart Maritime will contribute strongly to the development the OSC machinery and seakeeping laboratories in terms of building the necessary competence to run the next generation laboratory, to educate the researchers and to develop competence and systems that integrates physical testing in laboratories and in field with numeric models and simulation.



Skipsmodelltanken. Photo: SINTEF Ocean

## RESEARCH PARTNERS

SINTEF Ocean (Host institution)
Performs research, development and verification of technological solutions, business and operating concepts for the shipping, marine equipment, ocean energy and petroleum industries.

NTNU – Department of Marine Technology
Educates MSc, PhD and postdoc, and conducts research on marine systems and marine structures.

NTNU – Industrial Ecology Programme
Internationally leading institution within its field and has five authors contributing to the forthcoming WG III assessment report of the IPCC.

NTNU – Department of Ocean Operations and Civil Engineering (Ålesund)
Educates candidates on BSc and MSc level. The Faculty conducts research in the fields of maritime systems and operations.

## INDUSTRIAL PARTNERS – SHIP OWNERS

**Wallenius Wilhelmsen Logistics ASA**

Global logistics company, serving the manufacturing industry with special focus on vehicles, machinery, rail and the energy sector. WWL ASA has a combined fleet of 127 vessels with more than 800,000 CEU capacityulty conducts research in the fields of maritime systems and operations.

**Grieg Star AS**

Fully integrated shipping company operates a fleet of around 40 vessels transporting parcel cargo, break bulk and dry bulk cargo (30 under ownership).

**Solvang ASA**

One of the world leading transporters of LPG and petrochemi-cal gases. The fleet consist of 23 vessels – semi-refrigerated/ethylene carriers, LPG ships and VLGC.

**Kristian Gerhard Jebsen Skipsrederi AS**

KGJS is a fully integrated shipping company involved in tankers, dry cargo and specialized cement vessels over 50 ships under management.

## INDUSTRIAL PARTNERS – DESIGN & SHIPBUILDING

HAVYARD
CHANGE OUR INDUSTRY

**Havyard Group ASA**
Fully integrated Ship Technology company and deliver products and services within the complete value chain from vessel design to support of vessels in operation. Market segments include Energy, Seafood and Transport.

Rolls-Royce

**Rolls-Royce Marine AS**
Leading provider of innovative ship designs and systems, and a manufacturer of power and propulsion systems to oil & gas, merchant and naval sectors.

VARD™
a Fincantieri company

**Vard Design AS**
Major global shipbuilder of offshore and specialized vessels for offshore oil and gas exploration, production and service.

## 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 System AS
NES is an innovative, high-tech electrical company with a focus on diesel electric and hybrid electric systems for the global marine market.

SIEMENS AS avd corporate centre & real estate
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 (parent) delivers solutions for ship machinery, propulsion, automation, ship design, automation systems and liquid cargo solutions.

## SERVICE AND STAKEHOLDER ORGANIZATIONS

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 in the field of Norwegian shipping and offshore activities.

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

## 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

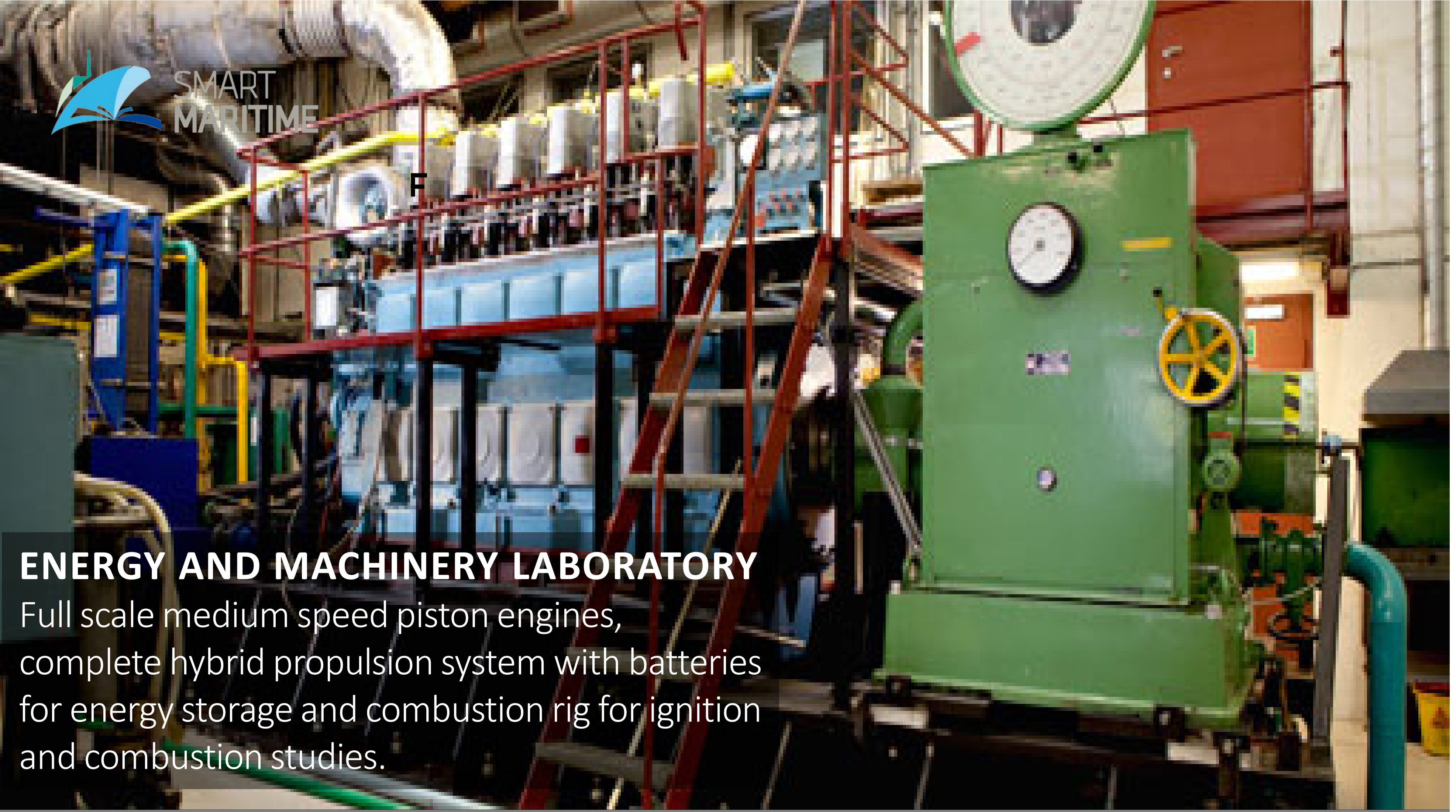
- Energy and machinery laboratory
- Hybrid power laboratory
- Towing tank
- Ocean basin
- Cavitation tunnel
- Circulating water tunnel
- Wave flume
- Marine Cybernetics Laboratory
- High Performance Computing

-- Under development --

- Fuel cell and hydrogen laboratory

### 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 (Rolls-Royce Marine -Bergen Engines)
- Clipper Harald, LPG tanker equipped with EGR, owner Solvang
- Simulation Centre (Rolls-Royce Marine)



## ENERGY AND MACHINERY LABORATORY

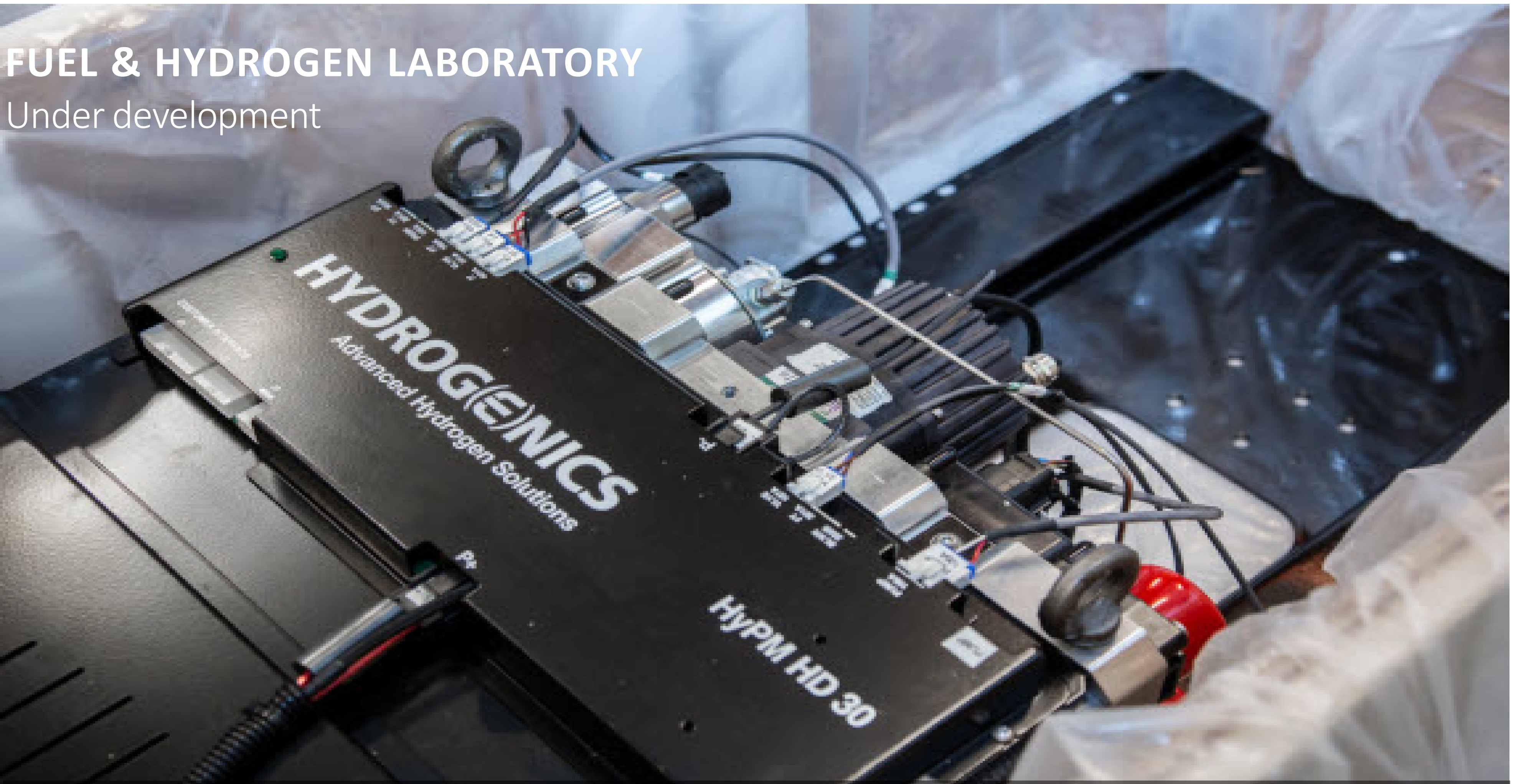
Full scale medium speed piston engines, complete hybrid propulsion system with batteries for energy storage and combustion rig for ignition and combustion studies.

Energy and Machinery Laboratory. Photo: NTNU/Sintef Ocean

## COMBUSTION RIG

Combustion rig for ignition and combustion studies.

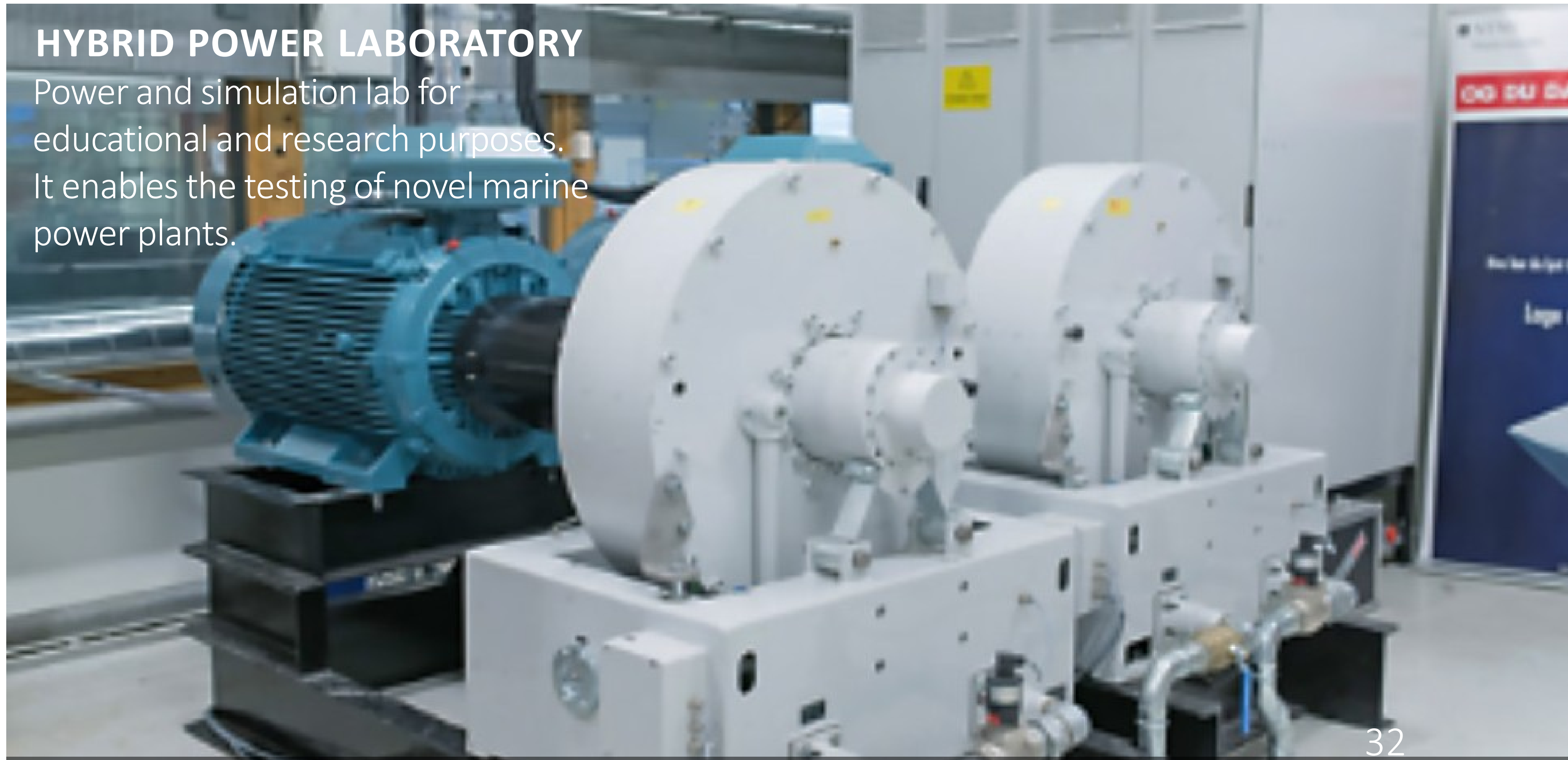
Energy and Machinery Laboratory. Photo: NTNU/Sintef Ocean




## FUEL & HYDROGEN LABORATORY

Under development

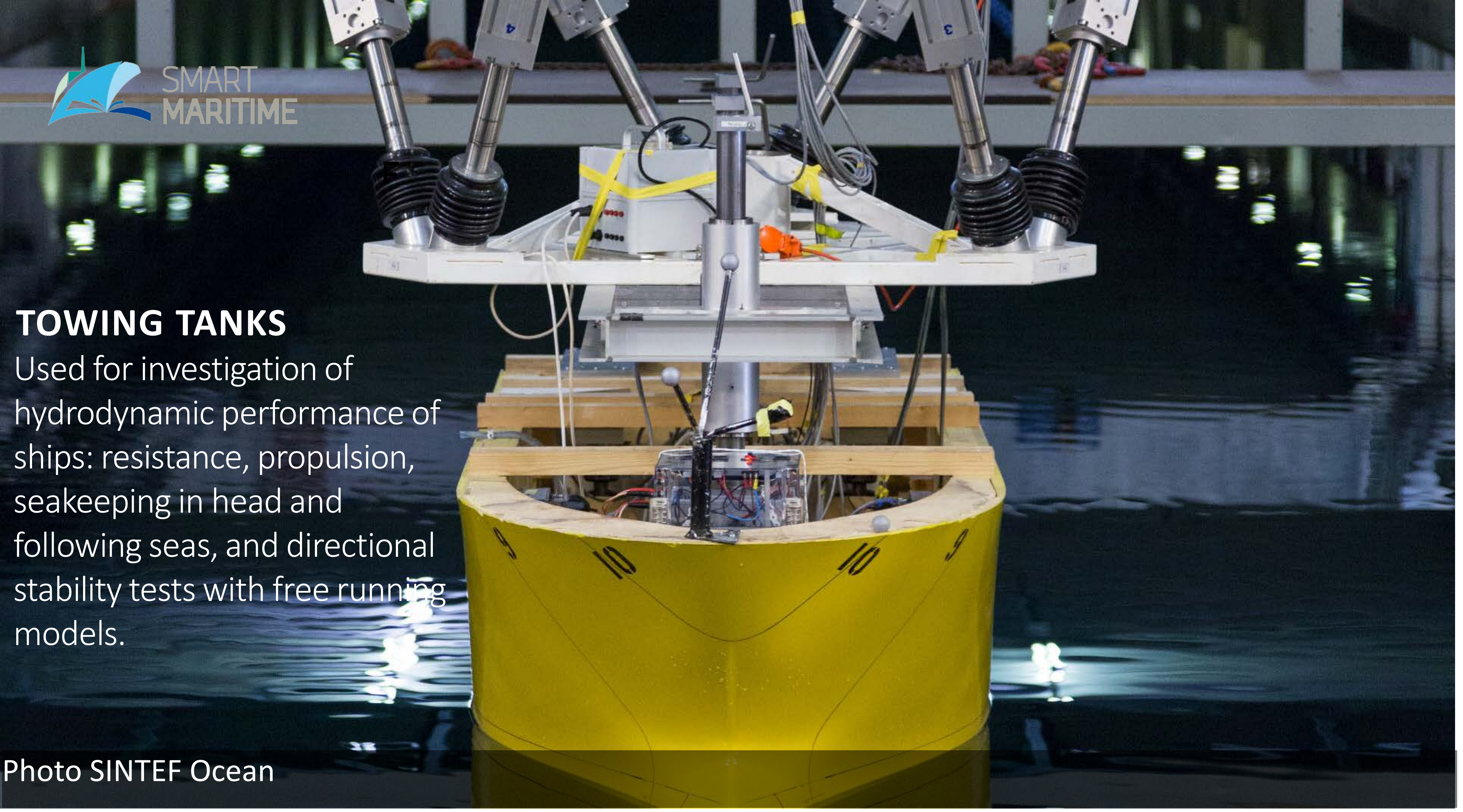
Energy and Machinery Laboratory.



## HYBRID POWER LABORATORY

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

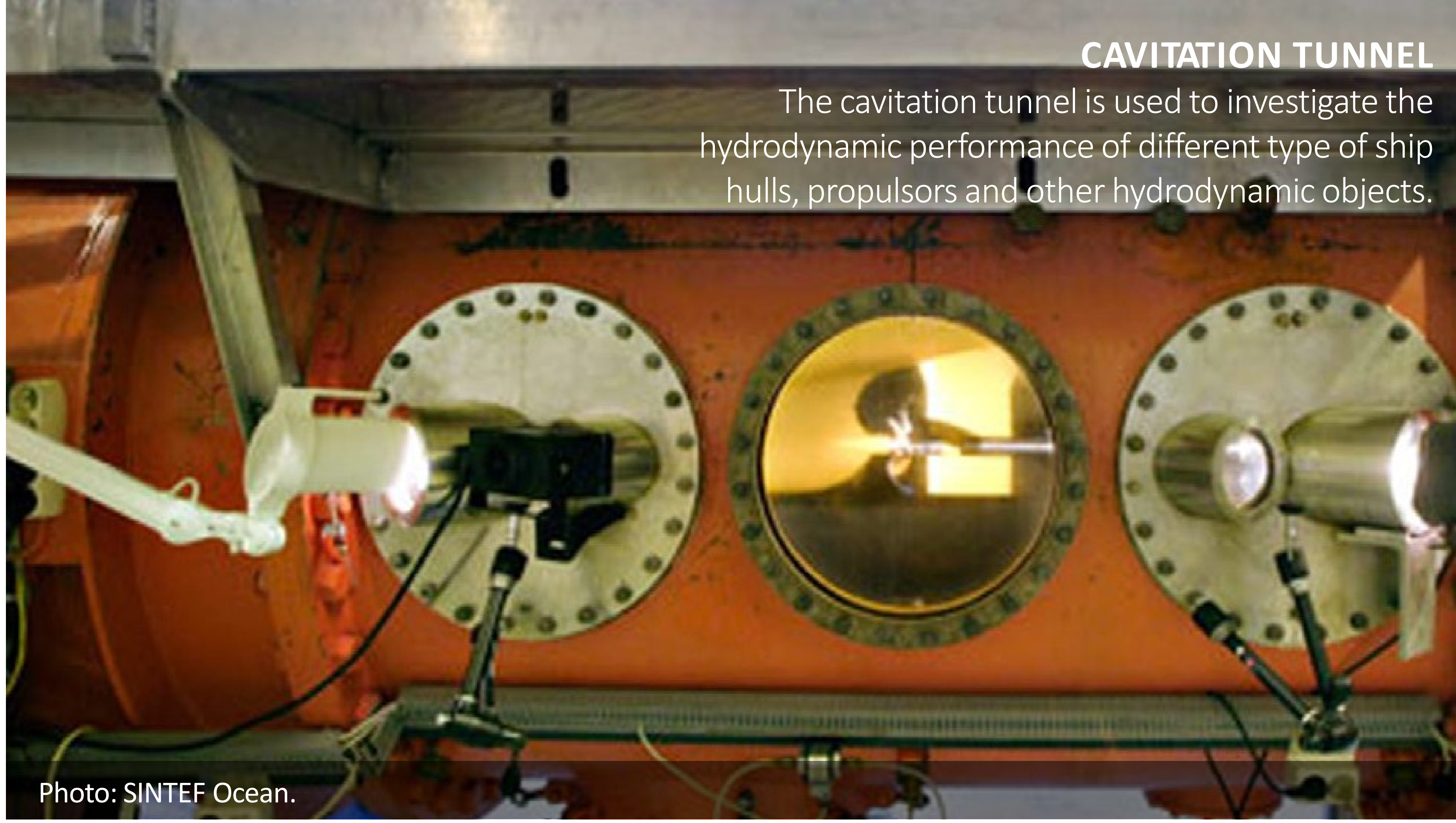
Hybrid Power Laboratory. Photo: NTNU.



## 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 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

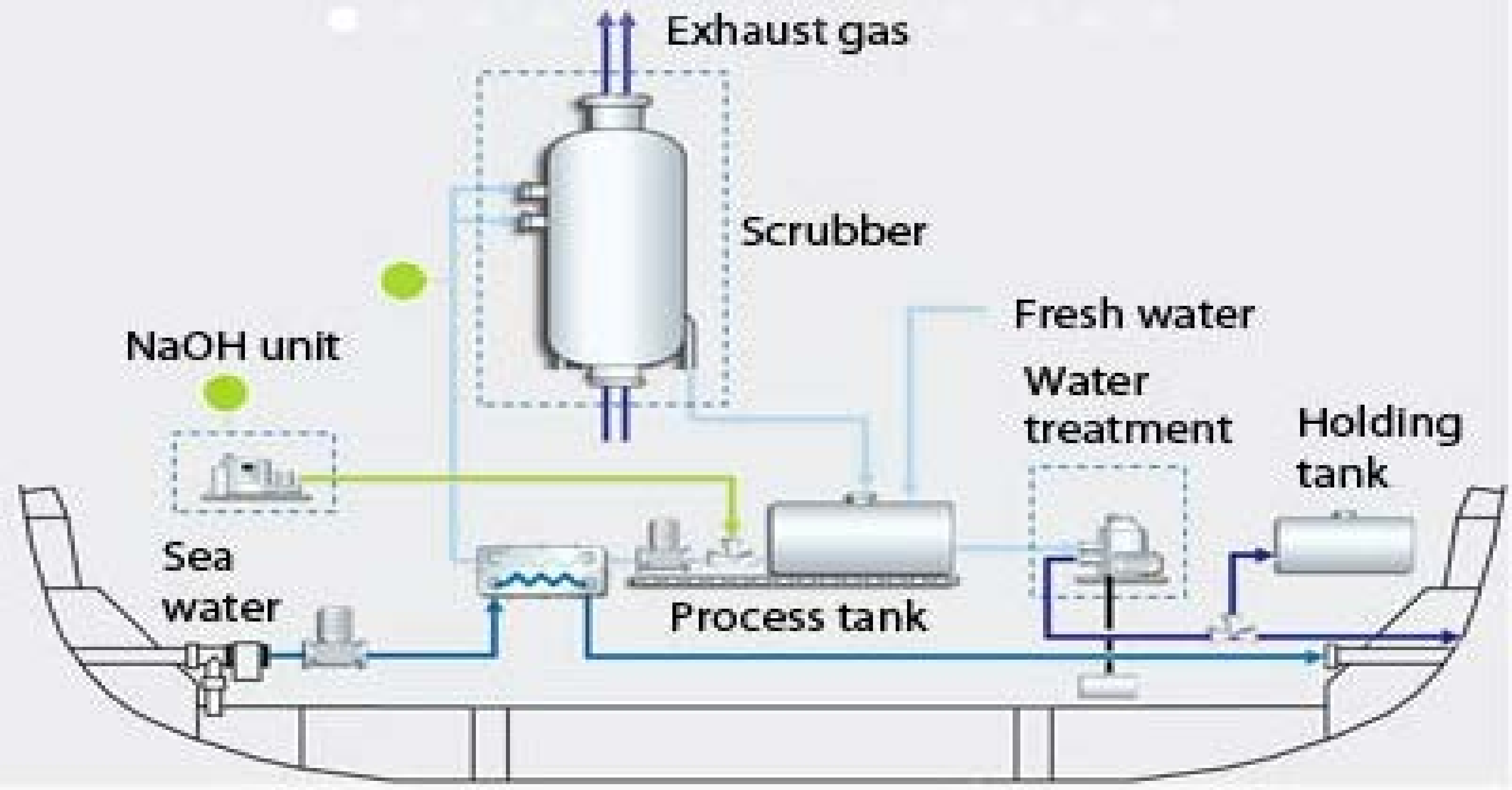
Test facility dedicated to optical measurement techniques and flow visualization.

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 Marine -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 (owner: Solvang). Photo: Solvang.

## POWER SYSTEM LABORATORY (NORWEGIAN ELECTRIC SYSTEMS)

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Photo: Norwegian Electric Systems

## INTERACTION ACADEMIA – INDUSTRY – RESEARCH

### Project cooperation

Smart Maritime enjoys a network of highly motivated industry representatives, striving for knowledge and excellence. The participation of user partners in research is generally high and is crucial for the good progress of our projects. In-kind participation lies around 20% of the annual budget.

Industry participation includes the following:

- Sharing of operational data
- Participation in measurement and tests experiments
- Laboratory or test ship made available for research
- Direct involvement in research work
- Cooperation on model and tool development
- Participation at workshops and webinars
- Scientific discussion, knowledge sharing, competence development
- Associated projects, joint initiatives for spin-off projects
- Co-supervision of and support to Master theses
- Dissemination, cooperation on scientific publication

### Network meetings

Smart Maritime organizes a network meeting twice a year when the research team and the industry partners (functioning as the Technical Advisory Committee) gather for two days. The purpose is to provide a meeting place for the partners to exchange ideas and experience, receive updates and scientific lectures from the research team, discuss new challenges and launch new initiatives, and help prioritize R&D activities.

### Webinars

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.

## NETWORK MEETINGS, 4-5 April 2018

**Host:** Grieg Star
**Place:** Bergen
**Participants:** 47
**Obective:** Gathering feedbacks and expectations from indsutry partners, and launch discussion on future activities at the Centre

## NETWORK MEETINGS, 16-17 October 2018

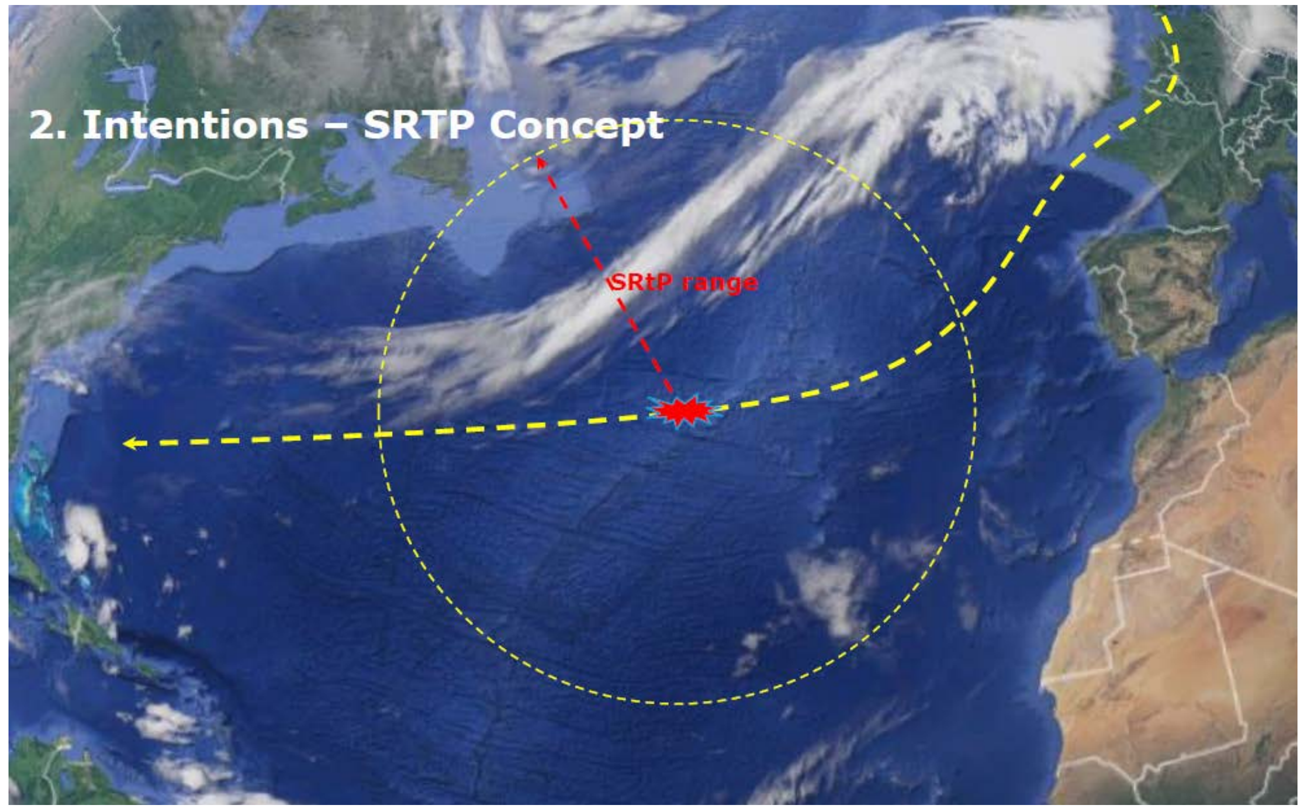
**Host:** SINTEF Ocean
**Place:** Værnes
**Participants:** 45
**Objective:** Presenting the achievements from 2018 and together prepare for the business cases to be launched in 2019.

Photos: Rialland.

## WEBINARS 2018

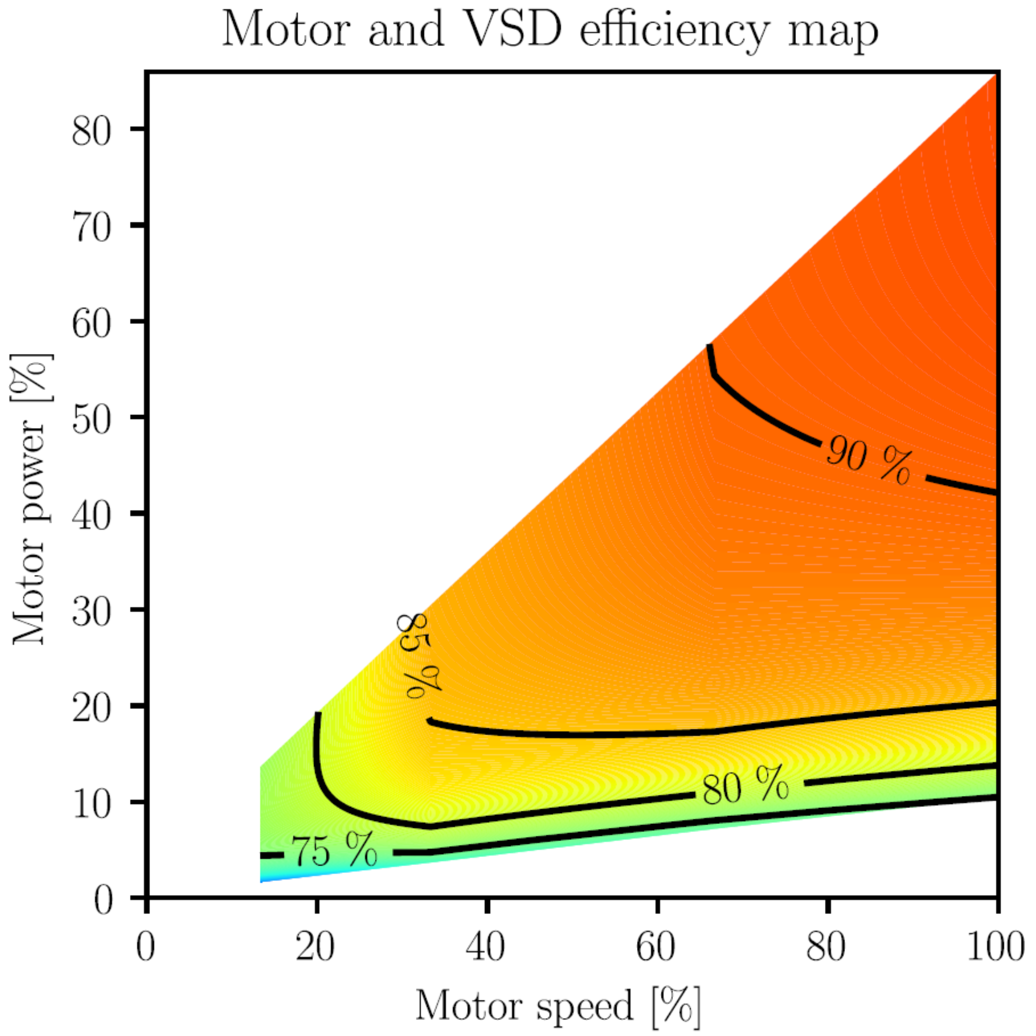
### Safe Return to Port & Minimum Required Power in Waves

**Organizer:** SINTEF Ocean, DNV GL
**Presenter:** Sverre Anders Alterskjær SINTEF Ocean, Lisbeth Iversland DNV GL
**Obective:** Documentation of Safe Return to Port capabilities (for passenger ships with length >120m) and Minimum Required Power (applies to oil tankers, bulk carriers and combination carriers having more than 20,000 DWT)



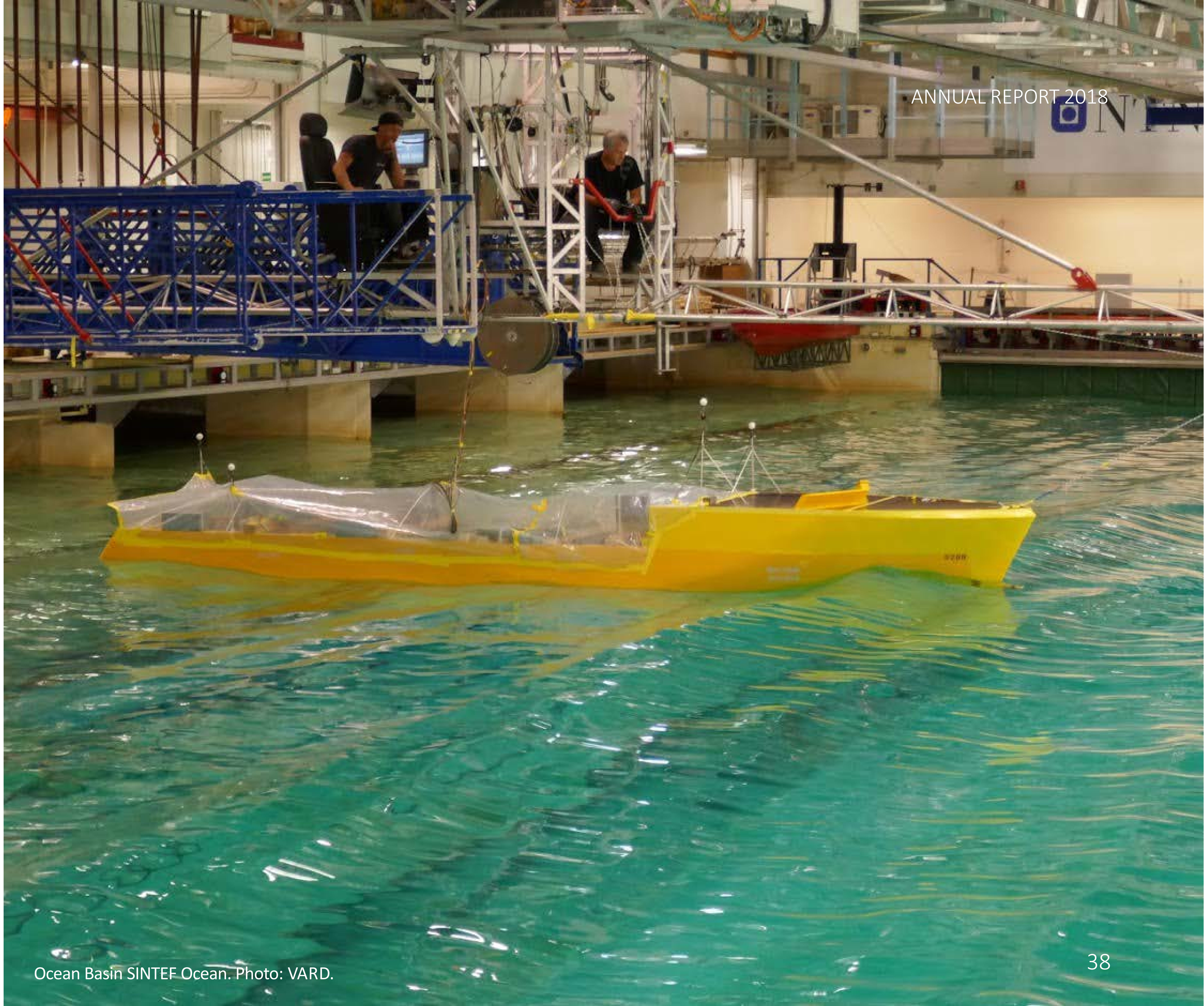

### Hybrid Propulsion – Summary of Postdoc work

**Organizer:** SINTEF Ocean
**Presenter:** Torstein Ingebrigtsen Bø
**Obective:** Summary of Postdoc work and articles by Torstein Bø at SFI Smart Maritime



# SCIENTIFIC ACTIVITIES AND RESULTS 2018





Ocean Basin SINTEF Ocean. Photo: VARD.

## ACTIVITY 2018

| WP1 Feasibility studies | WP2 Hull and propeller optimization | WP3 Power systems & fuel | WP4 Ship system integration & validation | WP5 Environmental & economic due diligence |
|---|---|---|---|---|
| FCA methodology<br>Potential energy efficiency and emissions reduction<br>Feasibility studies – cases | Calm water performance<br>Energy Saving Devices<br>Novel propulsion systems<br>Operations in water | Power systems optimization<br>Combustion engine process<br>Waste heat recovery<br>Hybrid systems | Integration of power system sub-models<br>Virtual ship design<br>Simulation framework | Parameterized lifecycle model<br>Fleet level assessment<br>Inventory database |

**SP1 – Alternative fuels and abatements technology**

- Methane slip from gas fuelled ships
- Scrubber and EGR

**SP7 – Simulation-based concept design**

- Deepsea shipping case
- Offshore supply case
- Road-ferry vessel case

**AD HOC ACTIVITIES: WEBINARS, THEMATIC / LITTERATURE REVIEW, WORKSHOPS, MSc these**

## SCIENTIFIC RESULTS

## Using GYMIR to substantiate performance of a new vessel design

*Contact: Jon Dæhlen, SINTEF Ocean*

The GYMIR simulator has proven efficient for substantiating performance predictions for new vessel designs. There has been two distinct cases where one of the SFI's industrial partners has applied the simulation tool actively in introductory sales for actual tenders.

**Kystruta** is a passenger route along the Norwegian coast, and a new vessel design competing for this tender were simulated on the Gymir platform. Actual vessel tracks were replicated, and simulations were performed for a one year operation. Estimated power demand were evaluated against the tender, and the design iterations were re-evaluated to optimize power demand.

**Road ferries** undergoes a major transition into the electric age, and optimization of energy efficiency is essential due to battery cost and local power grid capacity.

GYMIR has been adapted to enable simulation of typical ferry operation, including day schedule, of a given route across several years of operation. The simulation builds upon vessel models verified in scale experiments, and detailed historical weather data can be retrieved from national sources such as The Norwegian Metrological Institute (met.no).

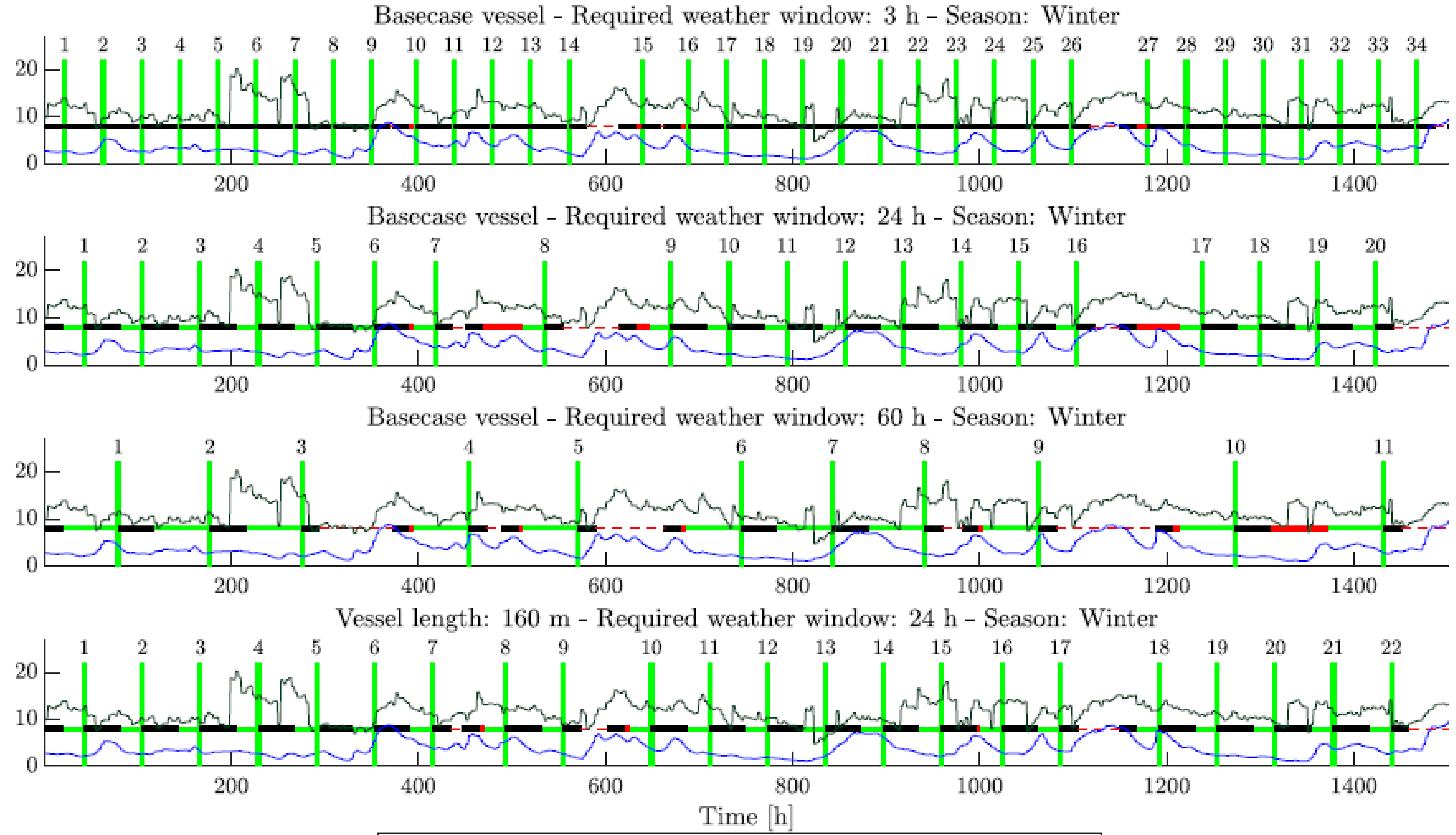
A SFI Smart Maritime partner used the simulator extension for several road ferry tenders, giving valuable information to the introductory sales, as well as feedback for further development.

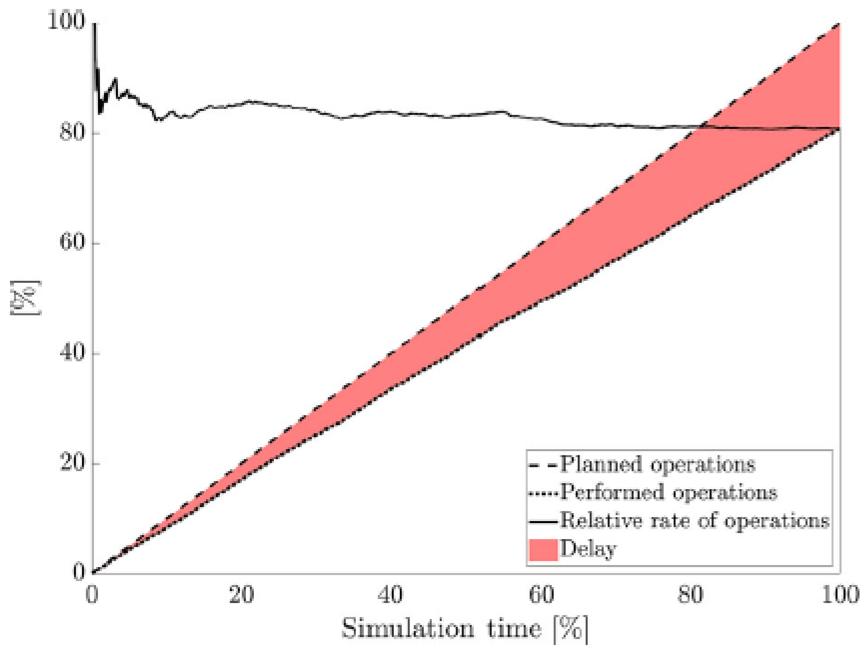
## Application of Discrete-event simulation for evaluation of weather impact on marine operations

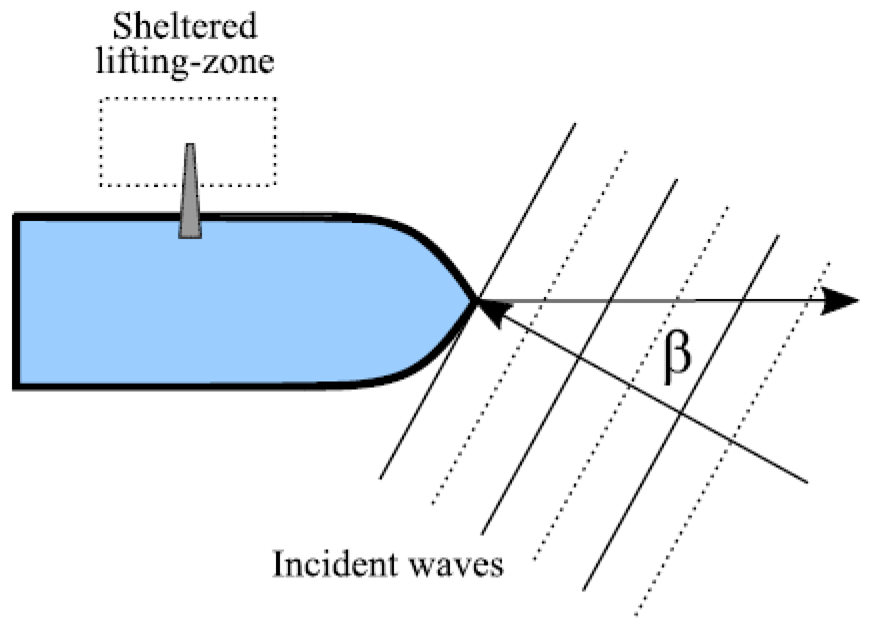
*Contact: Endre Sandvik, NTNU*

The GYMIR simulation platforms ability to simulate complex marine operations in realistic environmental conditions makes it suited to evaluate how to execute such operations efficient, as well as a particular operations susceptibility to weather.

A study has been conducted applying the GYMIR simulation strategy for such a purpose, and published in an article in Ship Technology Research. In that study, the simulation routine replicates the execution of operations in a long-term perspective by applying weather data time series and vessel response-based operational criteria. Weather windows are taken as the basis for the operation startup criterion. The capabilities of the simulation methodology towards reflecting the inherent weather challenges in operational scenarios and the ability to distinguish between alternative design concepts were examined in a case study. Comparison was performed towards the percentage operability method and integrated operability factor to uncover advantages of the presented approach.
Application of the simulation methodology was found to yield further knowledge of the inherent operational persistence and weather delay susceptibility of proposed vessel designs in the early phases of ship design.

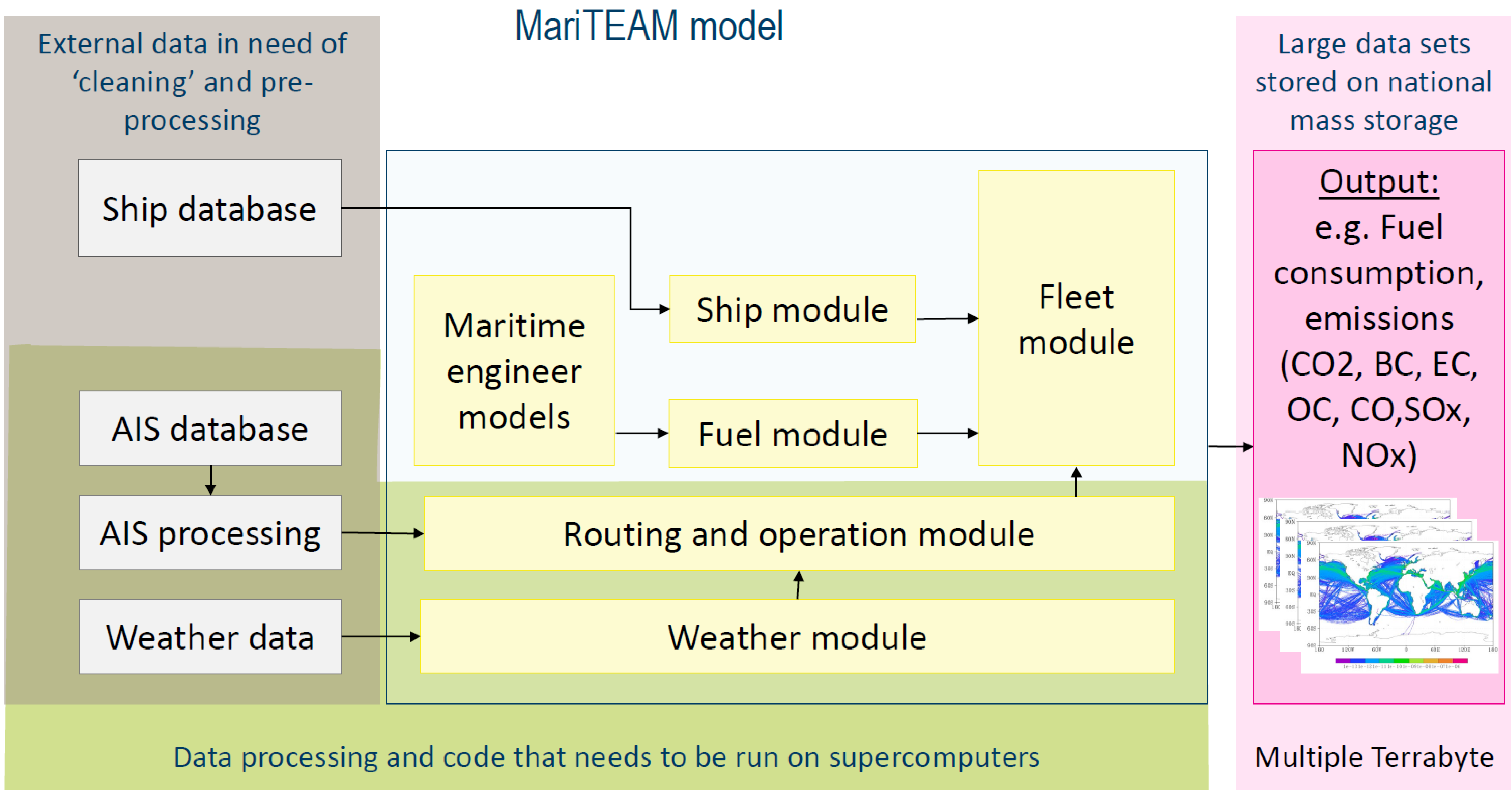


## MARITIME TRANSPORT ENVIRONMENTAL ASSESSMENT MODEL (MariTEAM)

*Contact: Helene Muri & Anders Strømman, NTNU*



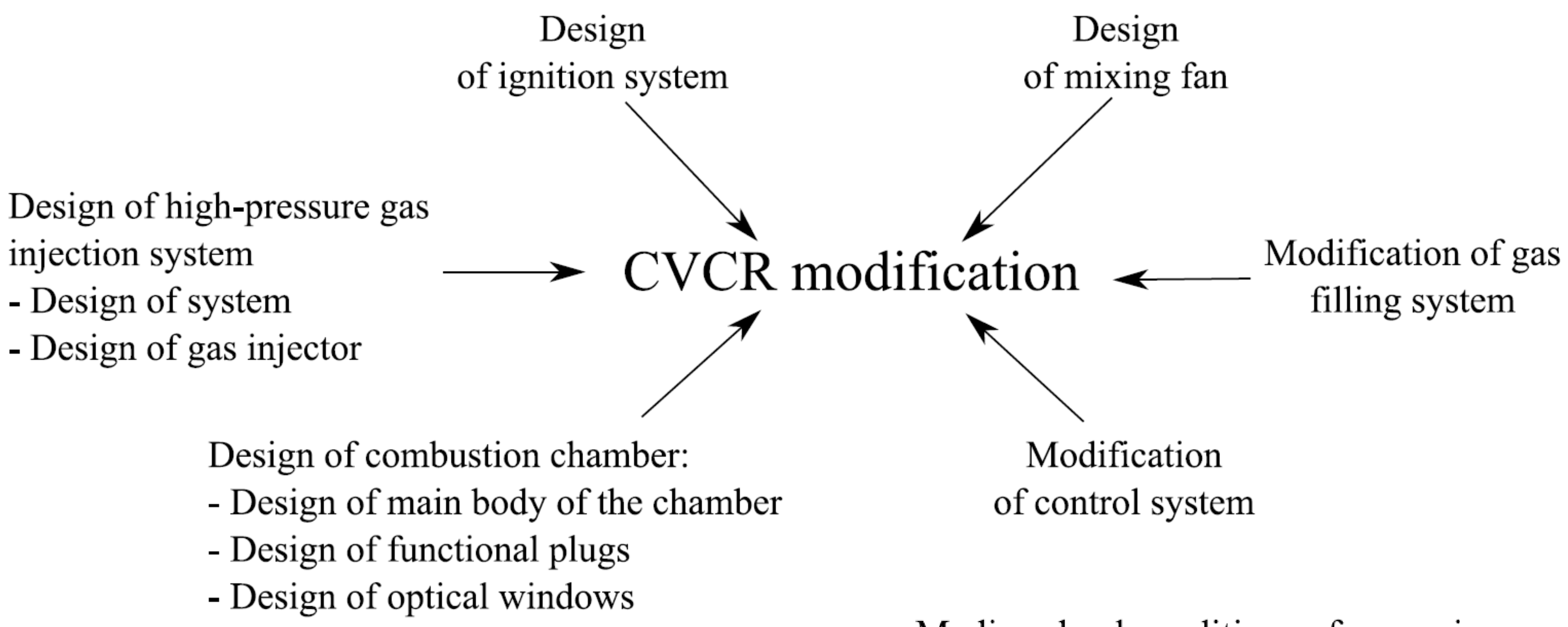

From ship technology to fleet level assessments

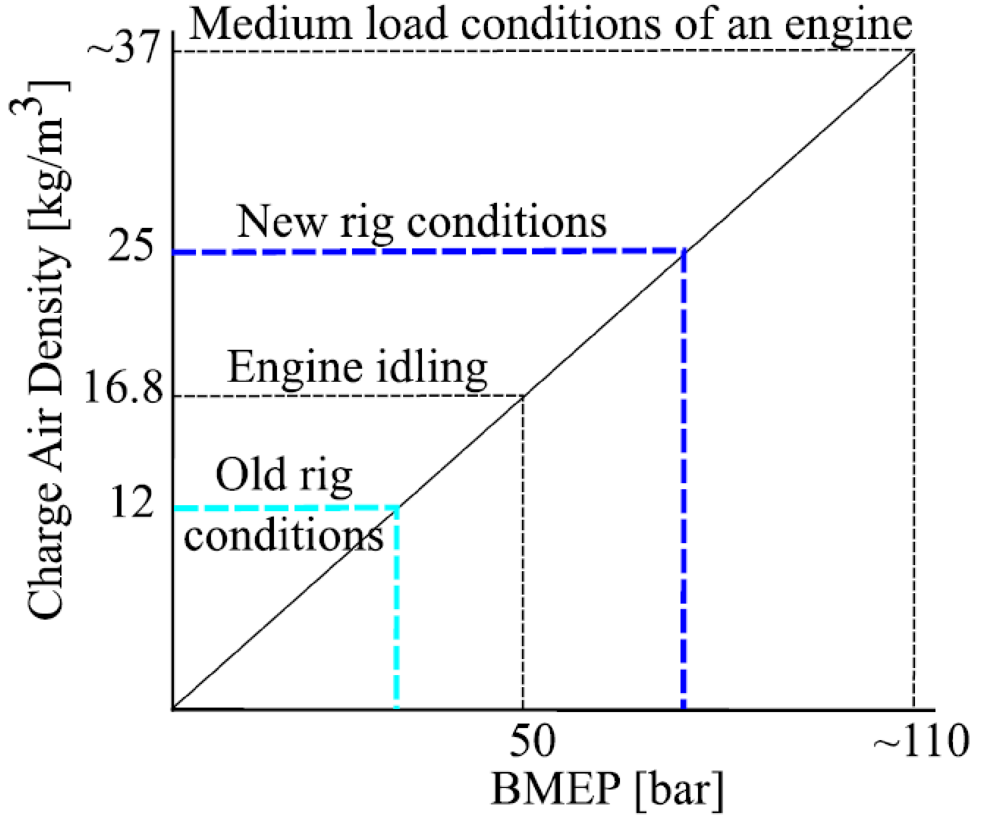
## DEVELOPMENT OF CONSTANT VOLUME COMBUSTION RIG (CVCR) TO STUDY HIGH-PRESURE GAS INJECTION CONCEPT FOR MARINE APPLICATION

*Contact: Vladimir Krivopolianskii and Sergey Ushakov, both NTNU*

Normally in order to achieve a clear conclusion regarding the effect of certain operational or design factor of the engine on its performance a full-scale test is required. This is not very convenient when large marine diesel engines are considered. Moreover, when alternative fueling options are assessed, the more detailed analysis of the injection system and combustion process should be performed. In such cases, optically accessed combustion test rigs are especially valuable.

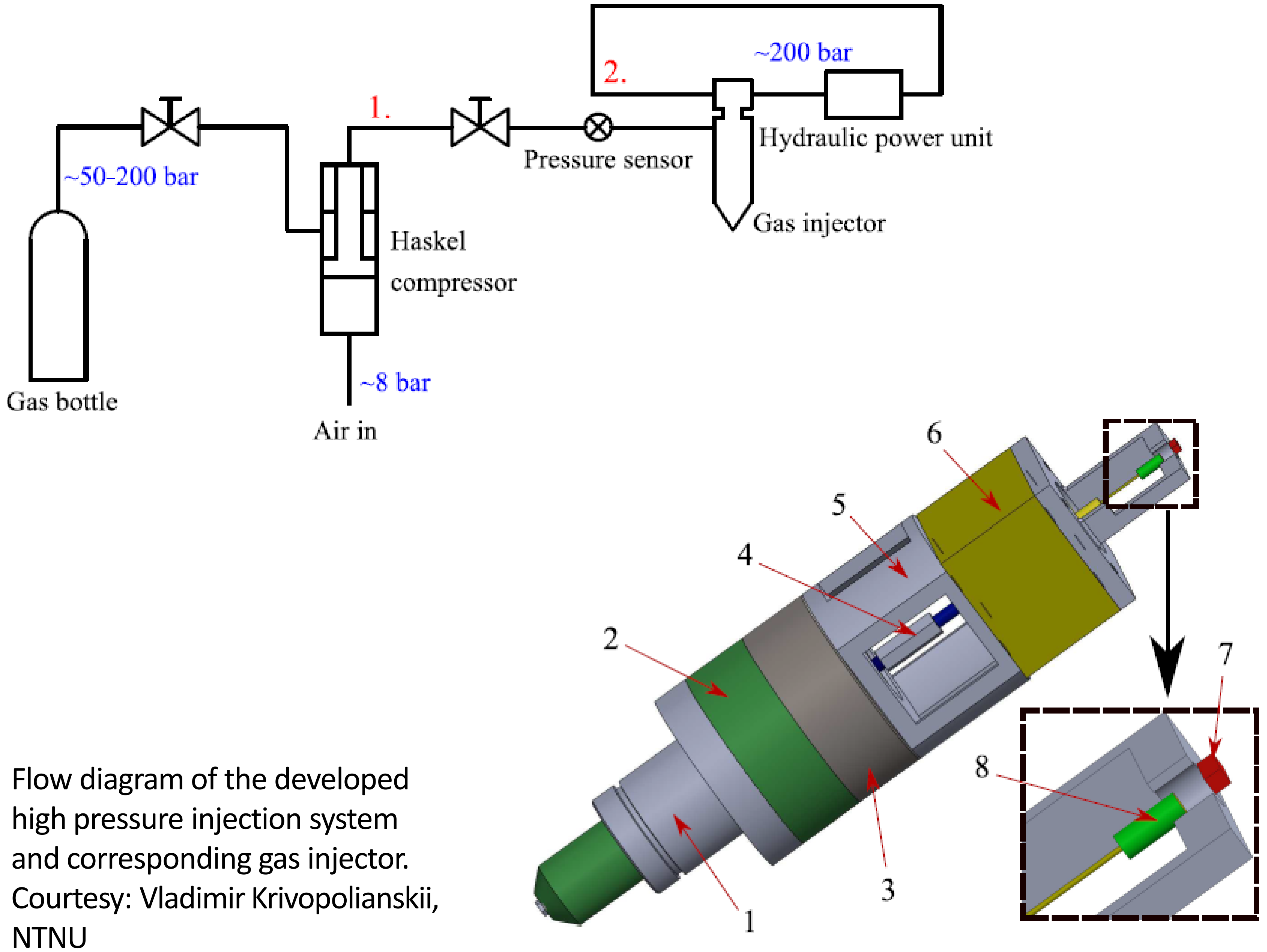
Department of Marine Technology, NTNU and SINTEF Ocean jointly have initiated the development of large volume (6.9 L) CVCR using the hardware from earlier combustion rig studies. To acquire fully operational and reliable system capable for modern research tasks a number of modification has been performed during 2016-2018 as can be seen on the diagram to the right. This allowed to improve the operational conditions of the rig, thus allowing to simulate modern engine performance conditions.




Overview of the undertaken CVCR modification work and corresponding old and new operational conditions of the rig.
Courtesy: Vladimir Krivopolianskii, NTNU.

The most important is that the injection system of the CVCR was also upgraded for high-pressure gas operation which can be used both to validate existing marine gas injection systems and to help in developing new ones.




Flow diagram of the developed high pressure injection system and corresponding gas injector. Courtesy: Vladimir Krivopolianskii, NTNU

At current stage the gas injection system was tested up to 400 bar with no combustion. The next logical step is to incorporate combustion into the list of studied phenomenon which still requires some technical challenges to be solved and number of safety matters to be addressed. At the end the system will allow to study in details the combustion process of high pressure gas engine concept and will allow to validate the applicability of alternative carbon free fuel (like hydrogen and ammonia) for marine application.

CVCR installation at NTNU/SINTEF Ocean.
Photo courtesy: Vladimir Krivopolianskii, NTNU

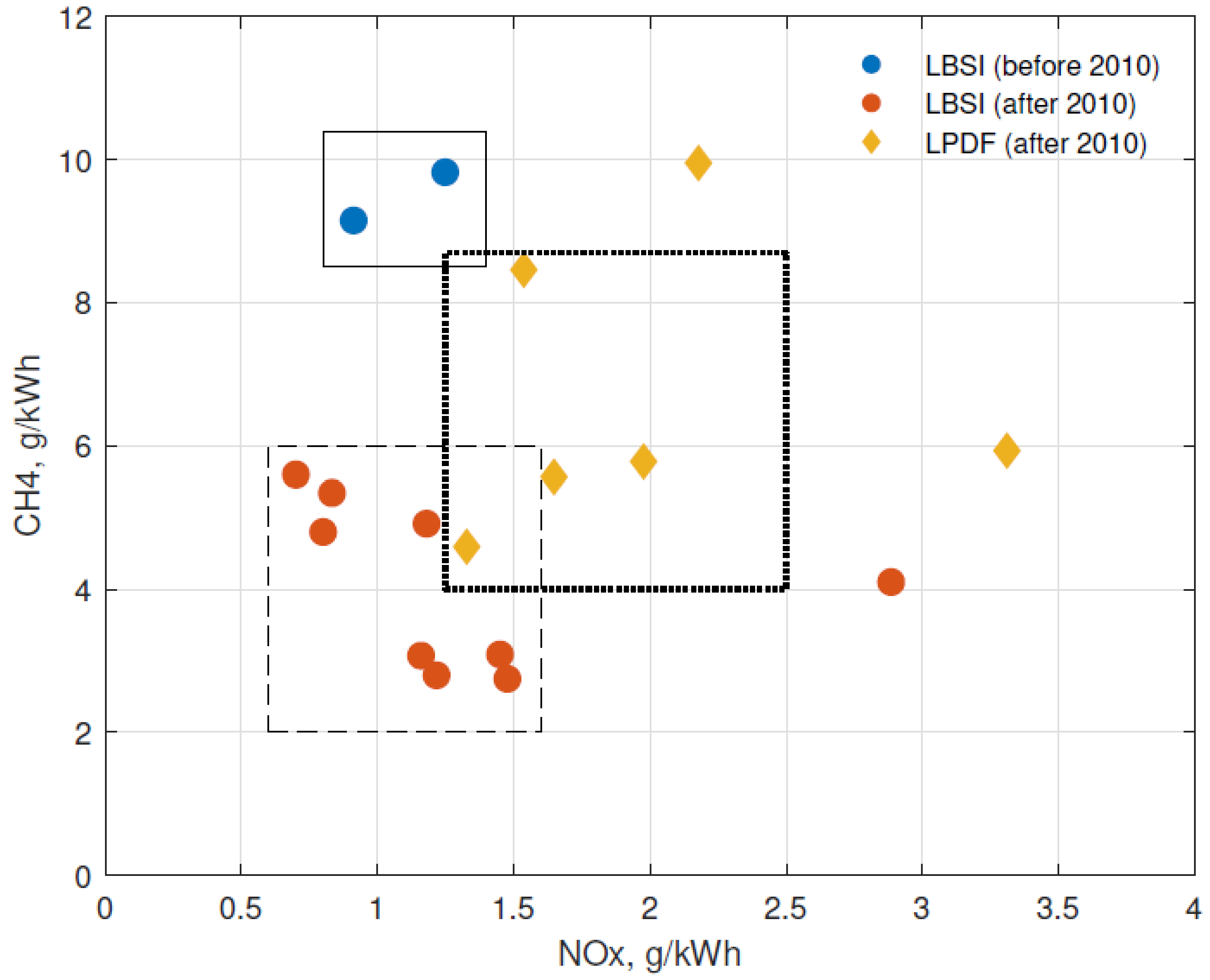
## SUMMARIZING METHANE SLIP FROM GAS FUELLED ENGINES

*Contact: Sergey Ushakov, NTNU;*
*Dag Stenersen and Per Magne Einang, both SINTEF Ocean*

A continuation of study based on direct on-board measurement of methane slip emissions from different gas engine groups (different gas engine concepts, size of engines and engine generation) resulted in the comprehensive summary on methane slip phenomenon. The latter is known as one of the main drawback of low-pressure gas engine concepts typically resulting in lower combustion efficiency at lower loads and corresponding higher equivalent $CO_2$ emissions.

The main results are summarized in an article and highlight the significant improvement achieved in gas technology. This resulted in around 50 % reduction of methane slip both for low pressure spark ignition (LPSI) and low pressure dual fuel (LPDF) engine concepts during the last 8 years. At the same time the importance of on-board emission measurements is also addressed based on certain «measurement artifacts» typical for test-bed results due to wider possibilities of additional engine tuning and imperfections of the adopted standard test cycles.

Reference: Ushakov, S., Stenersen, D. & Einang, P.M. Methane slip from gas fuelled ships: a comprehensive summary based on measurement data. J Mar Sci Technol (2019). https://doi.org/10.1007/s00773-018-00622-z




Overall summary of emission results from the undertaken measurement campaign.
Courtesy: Sergey Ushakov, NTNU

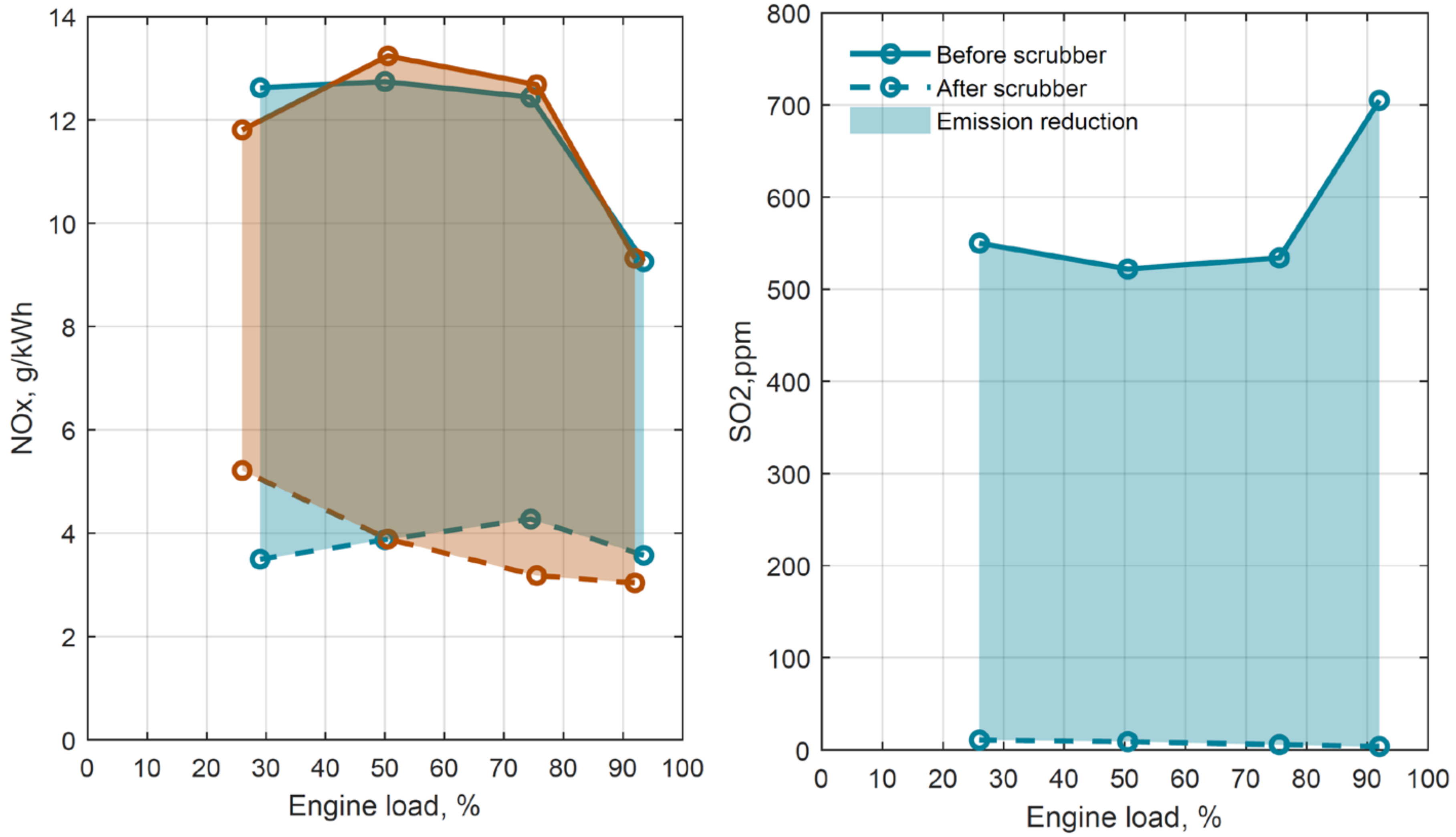
## ALTERNATIVE EXHAUST EMISSION REDUCTION SOLUTIONS FOR ACHIEVING 2020 EMISSION REQUIREMENTS

*Contact: Sergey Ushakov, NTNU;*
*Per Magne Einang and Anders Valland, both SINTEF Ocean*

Facing the need to fullfill both the strict Tier III $NO_x$ requirements (in ECA areas) and lower global sulfur cap in 2020 the interest not only in gas engines, but also in their potentional alternatives (like scrubbers) increases gradually. The main reason for that is different opinions existing about the development of marine fuel prices in the nearest future.

Solvang ASA, a partner in SFI Smart Maritime, believes the application of exhaust emission systems, namely low-pressure EGR and sea water scrubber has number of advantages and allows achieving the upcoming emission regulations while still capable of utilizing high sulfur heavy fuels. This exhaust gas cleaning system is a rather new concept and is still under verification onboard of a LPG-tanker Clipper Harald. SINTEF Ocean and NTNU participate in the process of technology finalization and therefore has summarized the main findings that are based on the measurement campaigns performed on board of the vessel in 2016 and 2018 respectively.

The results indicate 50-65 % reduction of $NO_x$ levels and almost complete (>98 %) elimination of $SO_x$ emissions. The main observed drawbacks are somewhat higher levels og CO, THC and smoke with the latter still be below the visible smoke limit.




Efficiency of the considered exhaust reduction system in case of NOx and SOx emissions.
Courtesy: Sergey Ushakov, NTNU

Special emphasis during the performed measurement campaign was paid to the quality of the wash water discharged back to the sea. For that a number of water samples were analysed in terms of chemical composition with the results later used in relevant environmental risk assessment. The high efficiency of wash water cleaning plant was confirmed for all operational points with certain metals (vanaium and nickel) remained in discharged water at acceptable levels and are mainly responsible for potential risk of environmental damage for marine biota. The study is expected to be continued on a new build vessel equipped with similar emission cleaning system.


A test vessel, LPG-carrier Clipper Harald.
Courtesy: Tomas Østberg-Jacobsen Source: MarineTraffic.com

| Component / property | Unit | Seawater before scrubber | | Seawater after scrubber | | Washwater before discharge | | Reference limit values[a] | |
|---|---|---|---|---|---|---|---|---|---|
| | | IMO[b] (no dilution) | EPA[c] | IMO[b] (no dilution) | EPA[c] | IMO[b] (no dilution) | EPA[c] | Class II (Low) | Class IV (High) |
| **Heavy carbon fractures** | | | | | | | | | |
| C10-C12 fraction | μ g/l | <5 | <5 | <5 | <5 | <5 | <5 | | |
| C12-C16 fraction | μ g/l | <5 | <5 | 17.8 | 24 | 9.3 | <5 | | |
| C16-C35 fraction | μ g/l | <30 | <30 | 506 | 384 | 270 | 83 | | |
| C35-C40 fraction | μ g/l | <10 | <10 | 46 | 38 | 22 | <10 | | |
| C10-C40 fraction (**sum**) | μ g/l | <50 | <50 | 569 | 448 | 302 | 91 | | |
| C12-C35 fraction (**sum**) | μ g/l | N/A | N/A | 524 | 408 | 297 | 83 | | |
| **PAHs** | | | | | | | | | |
| Naphthalene | μ g/l | <0.030 | <0.030 | 1.99 | 1.64 | 1.85 | 0.407 | 2 | 650 |
| Acenaphthylene | μ g/l | <0.010 | <0.010 | 0.027 | 0.029 | 0.026 | 0.032 | 1.3 | 330 |
| Acenaphthene | μ g/l | <0.010 | <0.010 | 0.126 | 0.093 | 0.115 | 0.031 | 3.8 | 382 |
| Fluorene | μ g/l | <0.010 | <0.010 | 0.367 | 0.291 | 0.319 | 0.078 | 1.5 | 339 |
| Phenanthrene | μ g/l | <0.020 | <0.020 | 1.19 | 1.03 | 0.998 | 0.275 | 0.51 | 67 |
| Anthracene | μ g/l | <0.010 | <0.010 | <0.010 | 0.014 | <0.010 | <0.010 | 0.1 | 1 |
| Fluoranthene | μ g/l | <0.010 | <0.010 | 0.125 | 0.075 | 0.065 | 0.018 | 0.0063 | 0.6 |
| Pyrene | μ g/l | <0.010 | <0.010 | 0.101 | 0.09 | 0.046 | 0.031 | 0.023 | 0.23 |
| Benz[a]anthracene | μ g/l | <0.010 | <0.010 | 0.016 | 0.017 | <0.010 | <0.010 | 0.012 | 1.8 |
| Chrysene | μ g/l | <0.010 | <0.010 | 0.012 | 0.023 | <0.010 | <0.010 | 0.07 | 0.7 |
| Benzo[a]fluoranthene | μ g/l | <0.010 | <0.010 | 0.021 | 0.013 | <0.010 | <0.010 | 0.017 | 1.28 |
| Benzo[k]fluoranthene | μ g/l | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | 0.017 | 0.093 |
| Benzo[a]pyrene | μ g/l | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | 0.00017 | 1.5 |
| Dibenz[a,h]anthracene | μ g/l | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | 0.0006 | 0.14 |
| Benzo[ghi]perylene | μ g/l | <0.010 | <0.010 | 0.012 | <0.010 | <0.010 | <0.010 | 0.00082 | 0.14 |
| Indeno[1,2,3-cd]pyrene | μ g/l | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | 0.0027 | 0.1 |
| PAHs (**sum**) | μ g/l | N/A | N/A | 4 | 3.3 | 3.4 | 0.87 | | |
| PAHs carcinogenic (**sum**) | μ g/l | N/A | N/A | 0.049 | 0.053 | N/A | N/A | | |
| **Metals** | | | | | | | | | |
| Arsenic, As | μ g/l | 1.75 | 1.7 | 1.78 | 1.58 | 1.61 | 1.59 | 0.6 | 85 |
| Cadmium, Cd | μ g/l | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.2 | 4.5-15 |
| Cobalt, Co | μ g/l | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 24.5[d] | 2450[d] |
| Chromium, Cr | μ g/l | <0.9 | <0.9 | 1.87 | 1.51 | <0.9 | <0.9 | 3.4 | 358 |
| Copper, Cu | μ g/l | 4.32 | 1.47 | 1.57 | 1.1 | 1.05 | 1.23 | 2.6 | 5.2 |
| Molybdenum, Mo | μ g/l | 11.1 | 10.9 | 11.7 | 11.3 | 10.5 | 10.7 | 7.3[d] | 730[d] |
| Nickel, Ni | μ g/l | 0.917 | 1.7 | 46.4 | 46.1 | 41.7 | 11.2 | 8.6 | 67 |
| Lead, Pb | μ g/l | 0.759 | <0.5 | 0.527 | <0.5 | <0.5 | <0.5 | 1.3 | 57 |
| Vanadium, V | μ g/l | 1.27 | 1.63 | 168 | 175 | 164 | 41.6 | 6[d] | 600[a] |
| Zinc, Zn | μ g/l | <4 | <4 | 11 | 11.5 | 10.8 | 10.3 | 3.4 | 60 |
| **General properties** | | | | | | | | | |
| pH | - | 7.98 | 7.99 | 3.17 | 3.29 | 3.24 | 6.52 | | |
| Turbidity | FNU | 1.1 | 0.48 | 2.22 | 2.53 | 1.75 | 0.87 | | |
| Nitrite ($NO_2$) | mg/l | <10 | <10 | <10 | <10 | <10 | <10 | | |
| Nitrate ($NO_3$) | mg/l | <0.0329 | <0.0329 | <0.0329 | <0.0329 | <0.0329 | <0.0329 | | |

[a] Limit values are based on quality standards for water, sediment and biota by Norwegian Environment Agency [68]

[b] Sampling according IMO MARPOL rules [53] before the discharge

[c] Sampling according US EPA VGP rules [38]

[d] LC50 (lowest concentration that causes 50% mortality on a test population of a given species and exposure time) data for marine species from ECOTOX database [62] with safety factor of 100

Chemical analysis of the sea water samples performed during 2018 measurement campaign.
Courtesy: Sergey Ushakov, NTNU

## 2020 SULPHUR CAP OPTIONS

*Contact: Elizabeth Lindstad, SINTEF Ocean*

Large seagoing vessels currently use heavy fuel oil (HFO) with a sulphur content of up to 3.5%, while smaller vessels use distillates with sulphur content less than 1.0 %. Inside the ECA's all vessels must comply within the 0.1% Sulphur limit, either through low Sulphur fuels or through exhaust gas scrubbers. Maritime transport consumes 7 - 8% of a Global oil production of around 4 billion ton in total. HFO represents 75% of the maritime consumption (IHS 2018), which means that shipping consumes around a third of the 600 – 800 tons of residual oil coming out from the refineries. Diesel represents nearly 25 % of the consumption and LNG represents around 2 %.

The advantage of HFO for the ship-owners is its low price compared to distillates. For the refineries, selling residual fuel has been an alternative to making large investments, to convert more of the residual fuel to distillates or to low sulphur or desulphurised fuel oils (LSHFO). While LNG and LPG are an option for new-buildings it becomes too costly for retrofitting existing vessels due to the need for new fuel tanks and engine modifications or replacements (Acciaro, 2014; Lindstad et al., 2015). For these reasons the existing fleet have three main abatement options to comply with the Global Sulphur cap of 0.5% from 2020 onwards:

- HFO & Scrubber
- Desulphurised heavy fuel oil (HFO<0.5%S)
- Distillate, such as marine diesel oil (MDO)

At high seas, emissions to air of Sulphur and Nitrogen will mostly deposit in oceans, while in coastal areas much will deposit on land. While the acidifying changes in the sea due to nitrogen and sulphur compounds are only a fraction of the effects from CO2, the effects compounded in coastal areas are likely more damaging and undesirable in general. With open loop scrubbers this acidification in coastal areas will increase since the washed out sulphur is dumped in the sea together as part of the wash water. This in contrast to today, where the Sulphur is spread out over a large area both at sea and land through the exhaust gas. With closed loop scrubbers and hybrid scrubbers this acidification effect can be avoided if the wash water from the scrubber is delivered in ports for after treatments together with the sludge.

Desulphurising residual fuel to less than 0.5% Sulphur to comply with global requirements from 2020 or the 0.1% Sulphur ECA limits implies cost and complexity similar to conversion from residual to distillate. This in comparison to sulphur removals from distillates which is common technology for all refineries (Concawe, 2009; Concawe 2012; Shell 2016; Shell 2017; Silva 2017). We hence estimate desulphurisation to be 10 – 15% of the crude oil cost due to the large energy consumption for the conversion conversion plus around 25 USD per ton to pay for the large investments required (Lindstad et al 2017). When the Sulphur cap comes into force in 2020, the its reasonable to assume that the refineries and bunker traders will try to take out higher margins for diesel and for the desulphurised fuel oils (LSHFO), however price differentials might normalize even before the end of 2020.
Figure 2 a,b below presents the fuel price and differentials as a function of crude oil price

We use two typical engine sized installed on seagoing vessels to assess the economic impact of the three main abatement options suited for existing vessels (HFO & Scrubber; LSHFO; Distillate). Here the 15' dwt chemical tanker with an installed main engine of 5 000kW represents the smaller vessels currently using HFO. If this vessel operates at design speed when steaming at sea half the year, it will consume around 5 000 ton of fuel, while if it operates at lower speeds as in 2012 (Smith et al 2014) it will consume from 3 500 ton upwards. With its 5 000 kW installed a hybrid scrubber comes at 2.25 MUSD + 0.07MUSD * 5 MW = 2.6 MUSD, i.e. an annual cost increase of 0.52 MUSD if we use 5 years as the payback time for retrofits (without including return on capital.

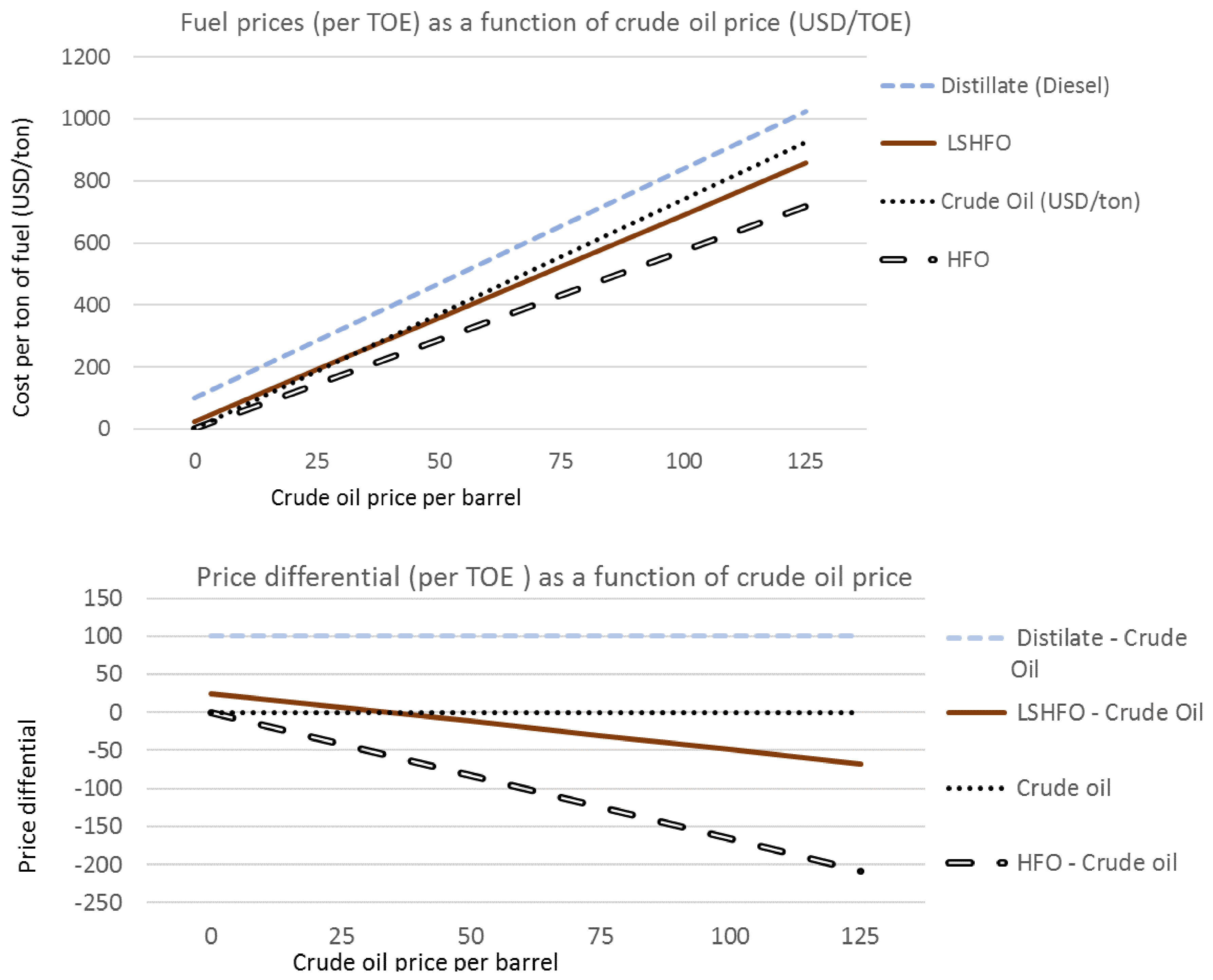



Figure 1 a & b: Fuel price and differentials as a function of crude oil price

Figure 2 shows Sulphur cap options for vessel with main engines in the 5 000-kW range as a function of crude oil price. The light blue dashed line shows the abatement cost for the diesel option. The solid brown curves show the abatement cost with scrubbers as an abatement option, where the marked one shows abatement cost with a low annual fuel consumption and the plain one with a high fuel consumption.

We observe that with a low annual fuel consumption, the scrubber abatement cost starts at 150 USD per ton at a low crude oil price increasing up to nearly 170 USD/ton at a high crude price due to the cost effect of the fuel consumption of the scrubber. Second, the double marked dashed black line shows the abatement cost per ton of fuel for the desulphurised HFO, i.e. the LSHFO<0.5% S, which here gives the lowest cost for all crude oil prices. Third that diesel is competitive for crude oil prices up to 50 – 75 USD per barrel. Fourth even for new-buildings, the Scrubber option might be less competitive than the LSHFO option for vessels types in this engine segment.

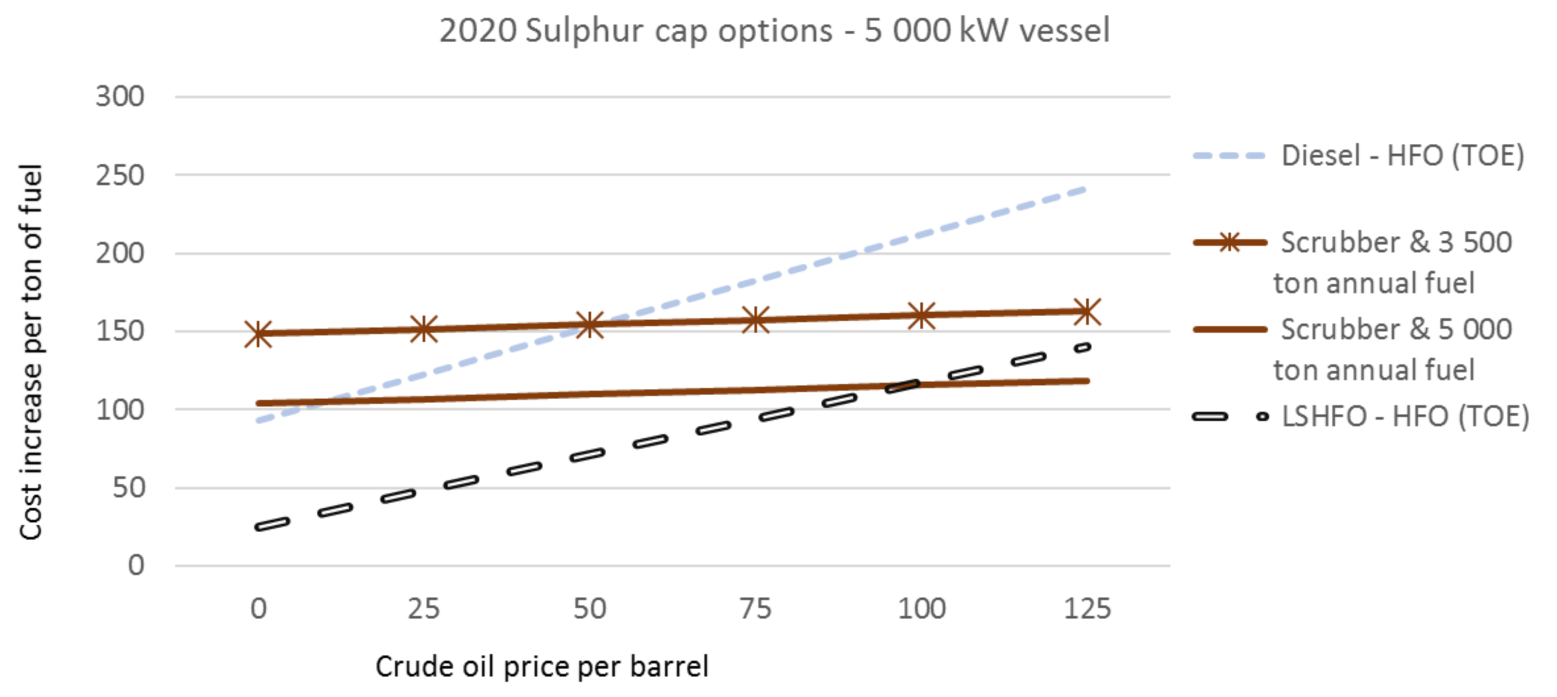


Figure 2: Assessment of Sulphur cap options for 5000-kW vessels

Main observations from Figure 3 are that LSHFO gives the lowest cost for crude oil prices up to around 40 USD per barrel, i.e. 25 with high annual fuel consumption and 60 USD per barrel with a low consumption. Second diesel is not a competitive at any crude oil price. Third for new-buildings, the Scrubber option is more competitive than the LSHFO unless crude oil prices drop below 25 USD per barrel.

To summarize: First, for the vessels with highest fuel consumption, on-board exhaust gas scrubbing and continued use of HFO gives the lowest cost. Second, in a case with crude oil prices lower than 50 USD per barrel, diesel is an interesting abatement option for the smaller vessels that currently use HFO. Third, desulphurised HFO (LSHFO < 0.5 % S) comes at a production cost which makes it a competitive abatement option for all vessels apart from the largest fuel consumers.

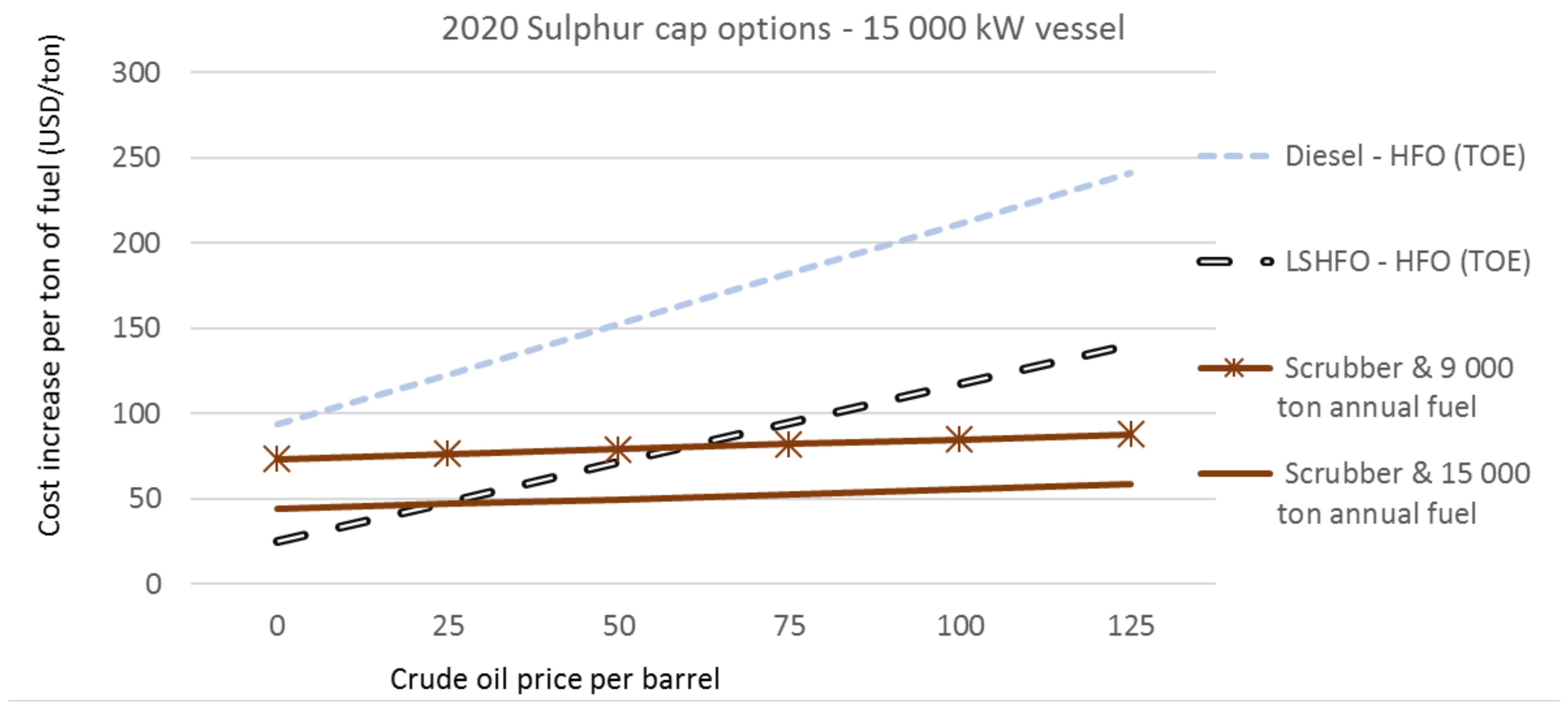


Figure 3: Assessment of Sulphur cap options for 15 000-kW vessels

## CALCULATION OF ADDED RESISTANCE DUE TO WAVES

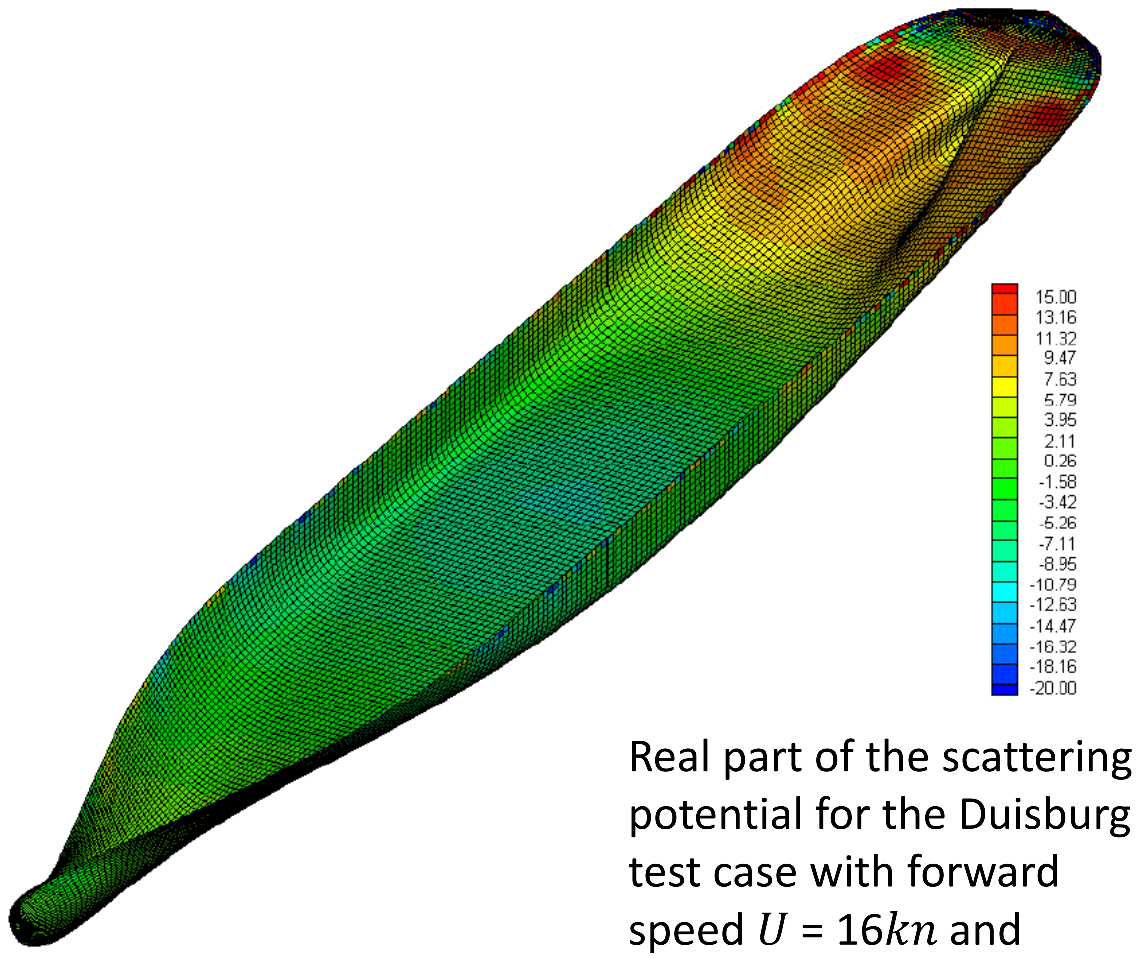
*Contact: S.Anders Alterskjær, SINTEF Ocean & Sverre Steen, NTNU*

Accurate and efficient prediction of increase of resistance due to waves is important for performance prediction of ships travelling in waves, which in turns is important in a variety of applications, such as ship routing, hull condition monitoring, optimization of ship designs for operation in realistic conditions, correction of sea trials and much more. A range of different types of methods are available, from simple semi-empirical tools like STAWAVE 1 and 2 through linear strip theory and 3-D potential flow panel methods to complicated RANS CFD methods. Calculating the added resistance in a single sea state with a RANS CFD method takes weeks on a powerful cluster, while STAWAVE 1 and 2 will calculate the same in fractions of a second on a laptop. In SFI Smart Maritime focus is on improving the available tools for medium-fidelity methods, since a slightly increased computational expense, compared to STAWAVE is unproblematic if increased accuracy can be achieved, while the CFD approach is absolutely unpractical for calculating performance in waves. Two different methods have been pursued:

- 3D panel method based on linear potential flow theory.
- Linear strip theory evaluating added resistance using energy and momentum evaluation in the far field.

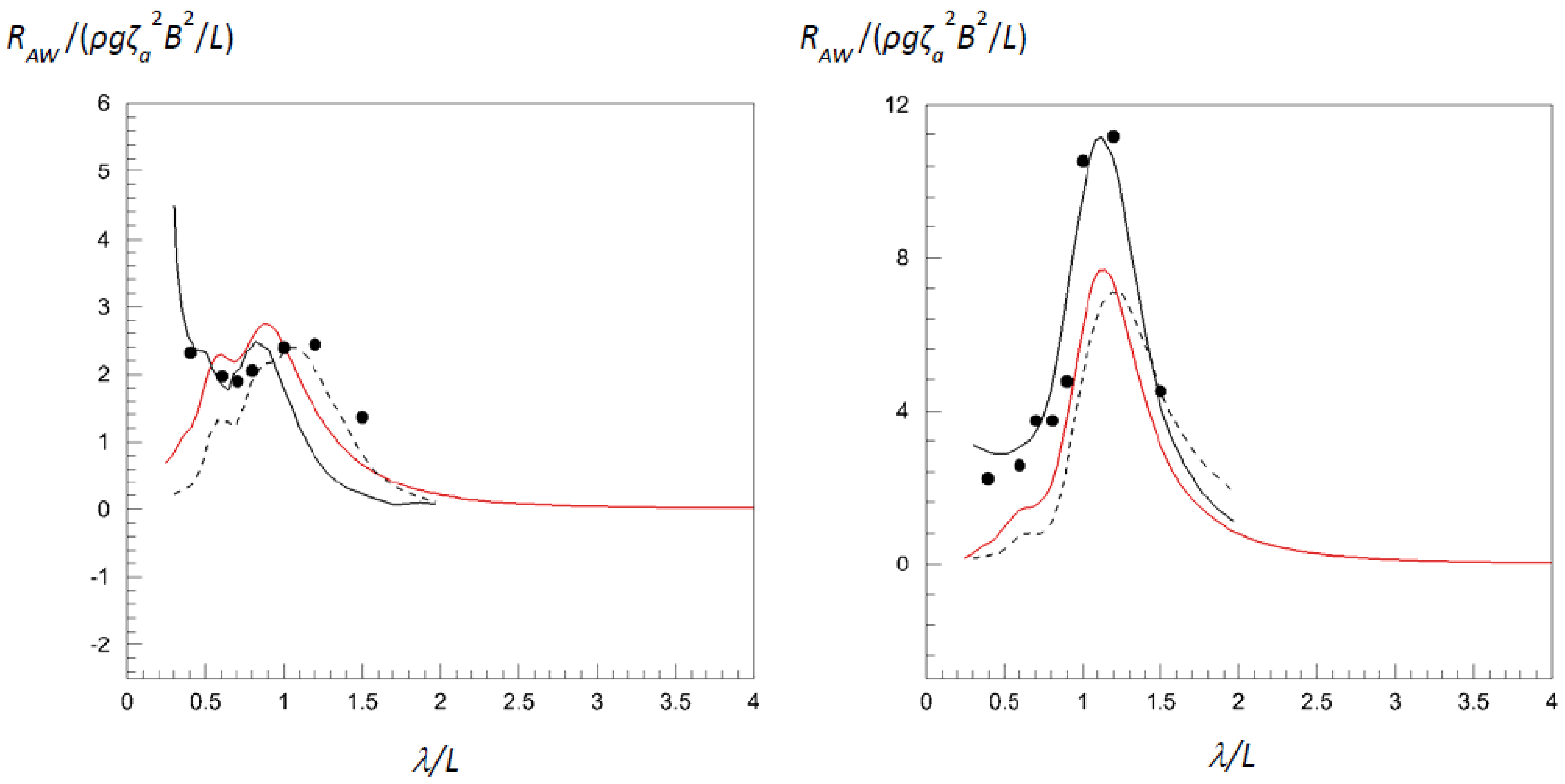
The 3D panel method is a continuation and extension of a long-term development of seakeeping software in Sintef Ocean. The code is applied to the standard test cases, the modified Wigley hulls and the Series 60 hulls.

For these hull forms experimental measurements are available for motions, excitation forces and hydrodynamic coefficients. Further, calculations are carried out for the S175 container ship, the MOERI KVLCC2 tanker and the Duisburg Test Case. The latter represent a rather extreme test case with a large number of panels close to the free surface.

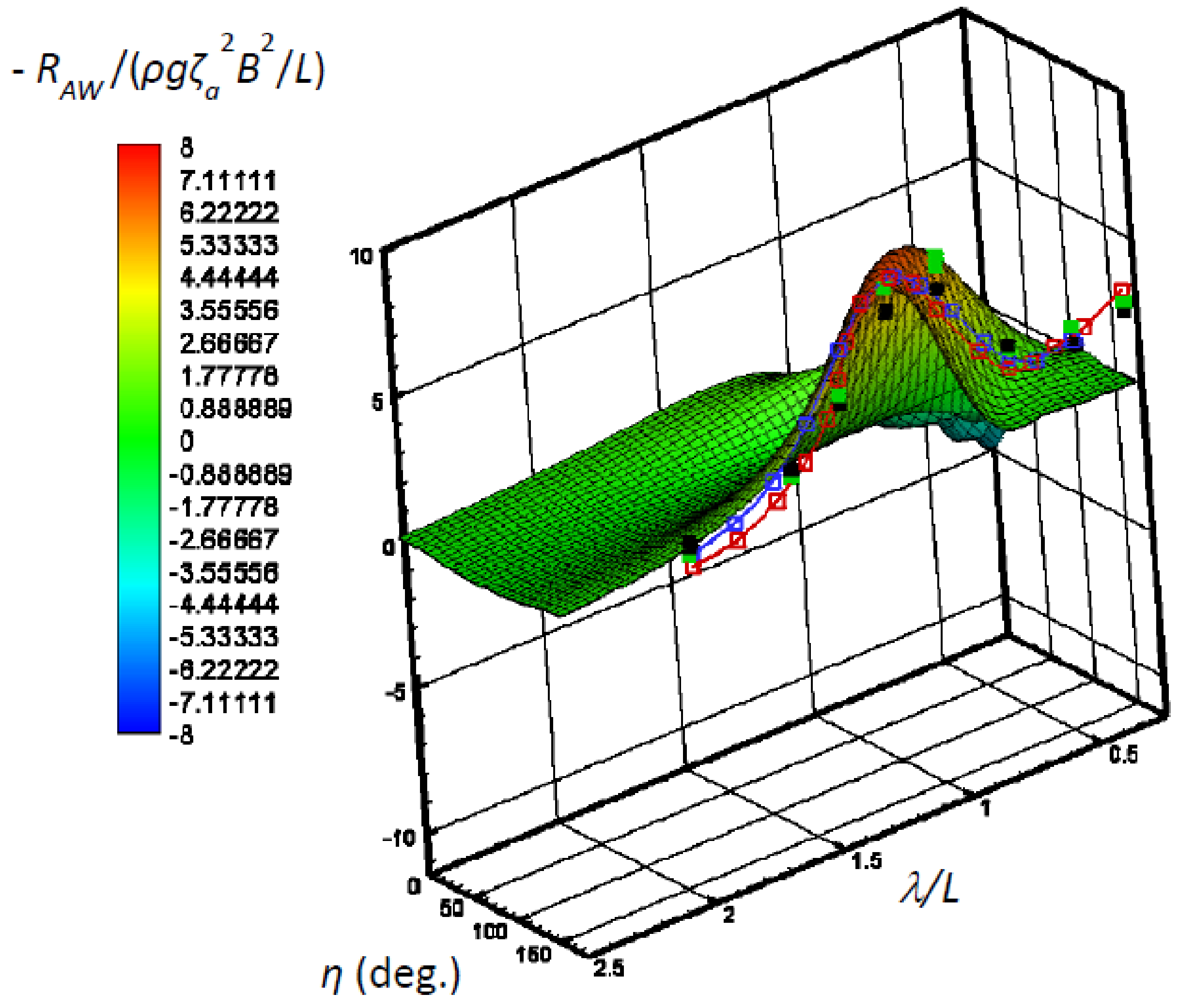



Real part of the scattering potential for the Duisburg test case with forward speed $U$ = 16$kn$ and wave period $T$ = 14.0 sec

The methods capable for calculation of the added resistance in waves according to Maruo (1960, 1963), Salvesen (1974), Faltinsen et al. (1980) and Kuroda et al. (2008) are implemented within the framework of the seakeeping strip theory during Renato Skejic post doc research project in SFI.
The mentioned methods are improved from the perspective of estimation of the added resistance for the displacement ships with the higher block coefficients through removal of the assumptions associated with the seakeeping first order linear strip theories.The post doc work will be properly disseminated in the upcoming PRADS conference in Japan, as well as in Journal of Ship Research.




Added resistance for 'KVLCC2' tanker at Froude number *Fn* = 0.037 and Fn = 0.124. The red curve is the current implementation of the Maruo method. The black solid curve is results by Wickaksano and Kashiwagi (2017). The black hatched curve is enhanced unified theory (Kashiwagi, 1992). Black dots are experimental results.




Added resistance according to the modified Salvesen (1974) theory for 'KVLCC2' tanker at Froude number *Fn* = 0.142. Comparison with Lee et al. (2013) (squares; green and black) experimental results and Seo et al. (2014) (red and blue) computational results.

References:
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Kuroda,M., Tsujimoto,M., Fujiwara,T., Ohmatsu,S., Takagi,K.,2008. Investigation on components of added resistance in short waves. Journal of Japan Soc. Nav. Arch. Ocean Eng. 8,171–176.

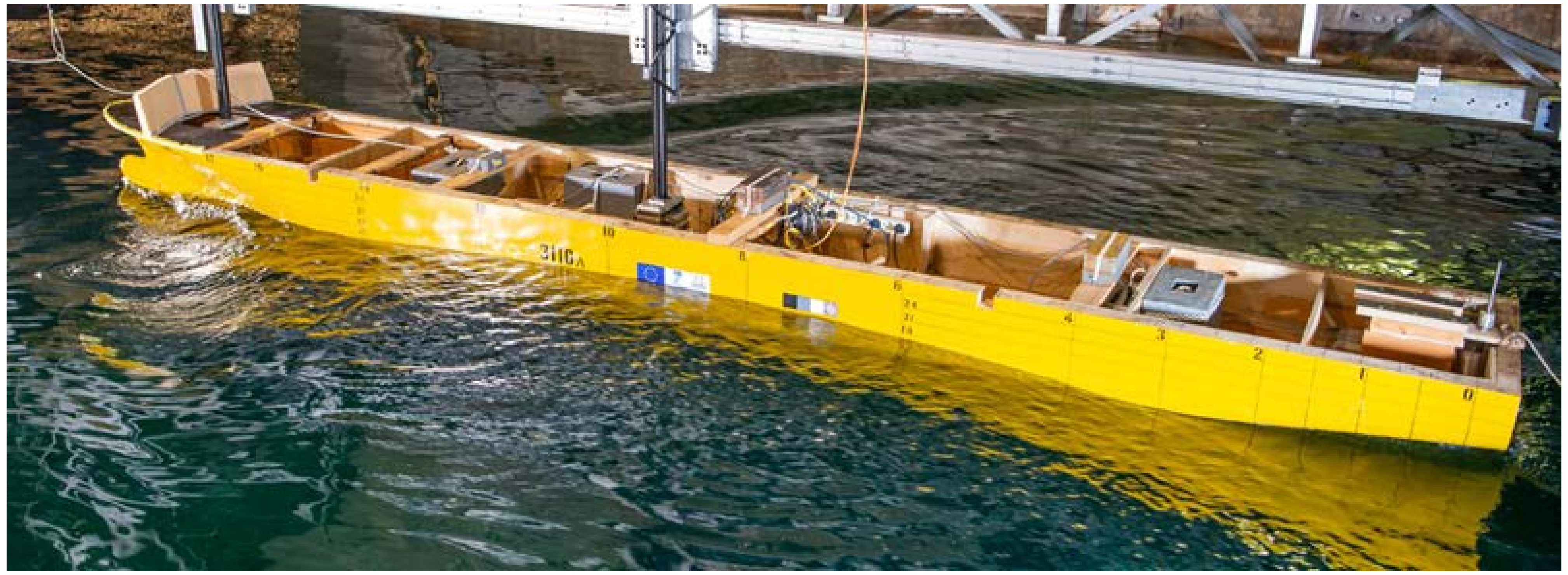
## MODEL TESTS OF ADDED RESISTANCE DUE TO WAVES

*Contact: S.Anders Alterskjær, SINTEF Ocean & Renato Skejic, NTNU/SINTEF Ocean*

Added Resistance transfer functions are commonly applied to calculated the added resistance in arbitrary sea states. The transfer functions can be derived from potential flow methods, model tests in regular waves or CFD calculations in regular waves. However, we know that the superposition principle is not completely applicable. This is also the experience when tuning numerical models to model test results in irregular waves.
This phenomenon should be considered in for instance the following:

- Establishing model test programs
- Choosing numerical modelling methods
- Validation and comparisons of numerical tools

The effect is undoubtedly dependent on the vessel geometry, but very little literature exists on the subject. A model test campaign was thus set up to quantify this effect for an open vessel geometry, i.e. the Duisburg Test Case. The Duisburg Test case has also been used in other settings within the SFI smart maritime such as numerical tool development.



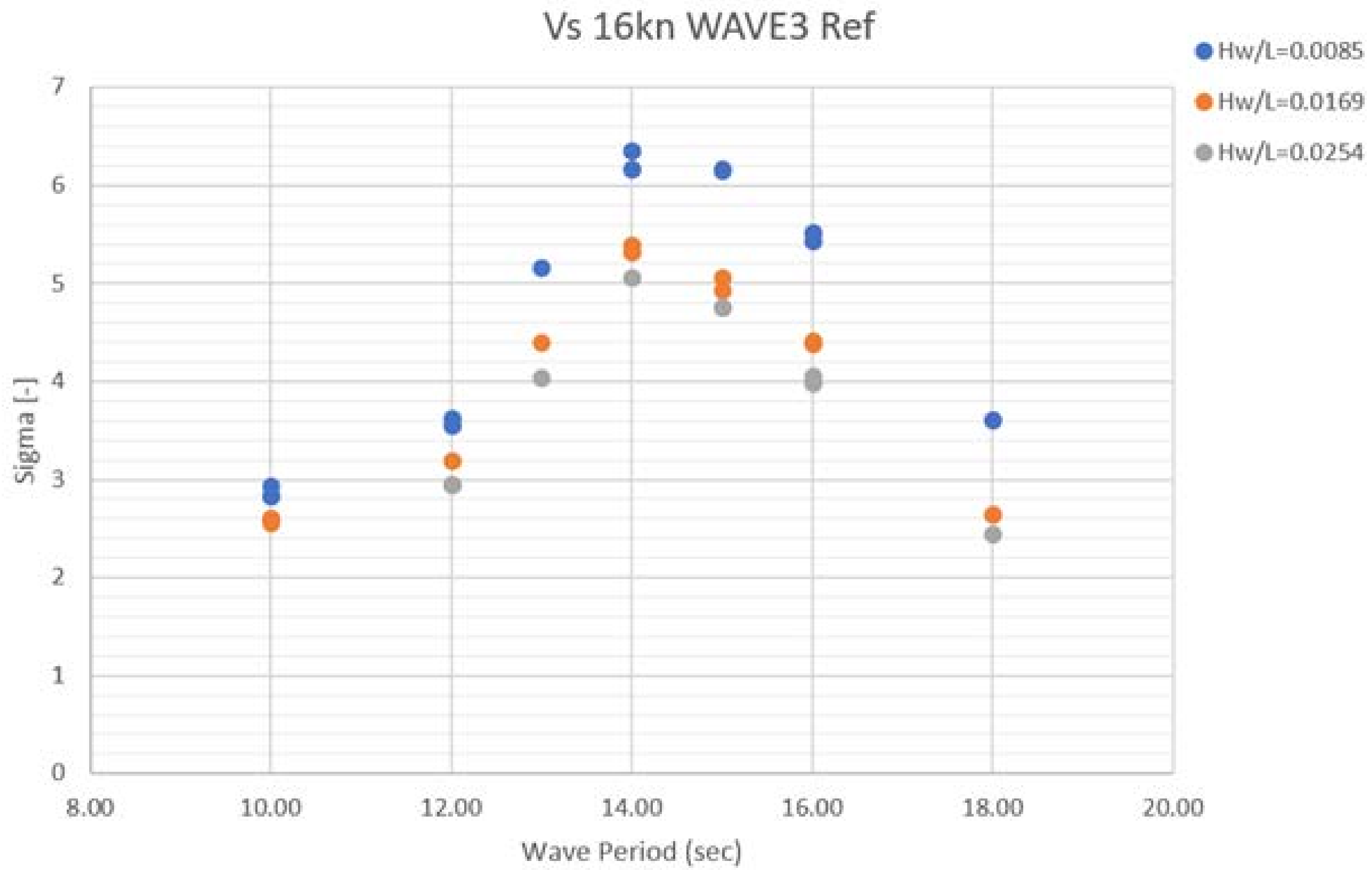
Resistance tests in regular waves of the Duisburg Test Case (DTC) model in SINTEF Ocean's large towing tank

Through fully automated testing techniques in regular and irregular waves in SINTEF Ocean's large towing tank, a large test matrix could be conducted efficiently.

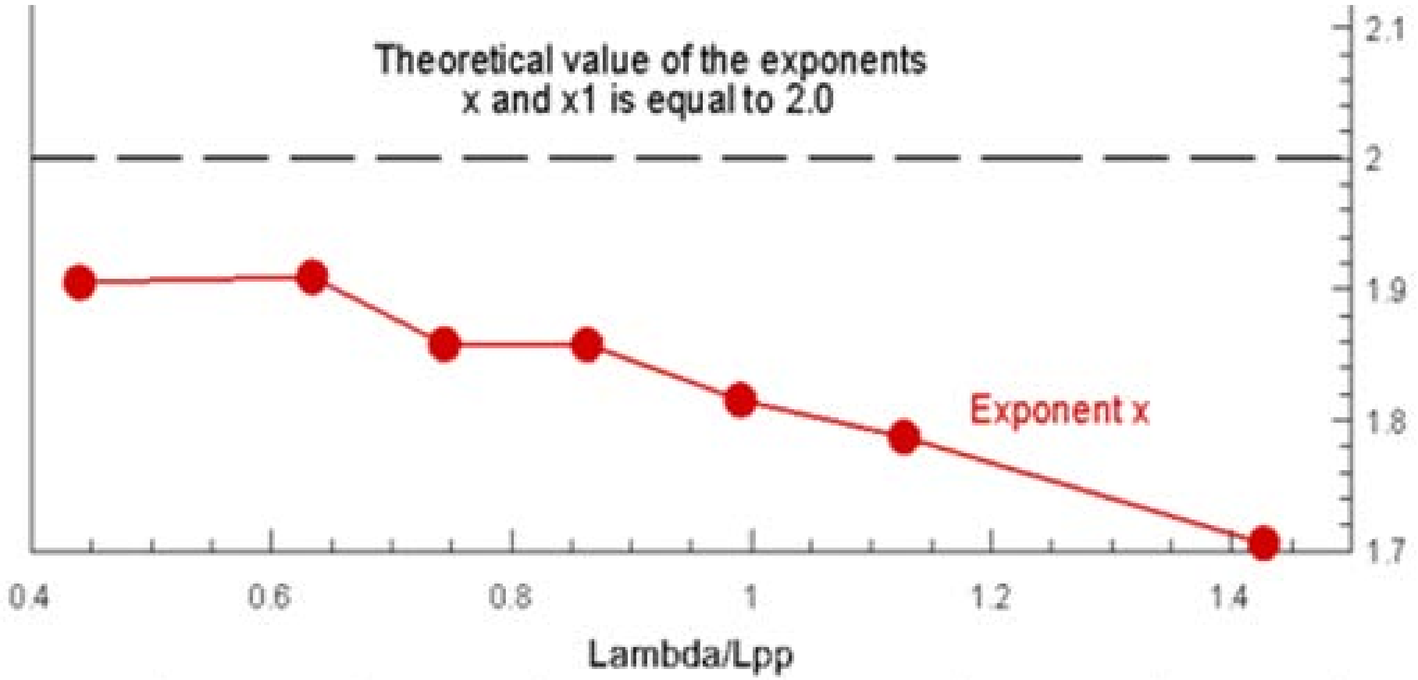
- Calm water reference resistance curve
- Regular waves
  - Wave period range λ/Lpp = [0.44 – 1.43]
  - 3 Wave heights Hw/Lpp = [0.0085, 0.0169, 0.0254]
  - Speeds 12, 16 and 20 knots
- Irregular wave tests
  - 16 knots
  - 3 sea states

•Several repetition runs => 140 test recordings

Preliminary analyses of the results indicate a noticeable amplitude dependence of the added resistance transfer function.




Normalized added resistance coefficient based on three different wave heights




Matching of added resistance coefficient from tests in Hw/Lpp = 0.0085 and Hw/Lpp = 0.0169

## SAFE RETURN TO PORT AND MINIMUM REQUIRED PROPULSION POWER

*Contact: S.Anders Alterskjær & Ørjan Selvik, SINTEF Ocean*

While aiming for optimized hull and propeller solutions that reduces power consumption and emissions in normal operation, it is important to ensure that the safety of the ship, crew and passengers in adverse conditions are not compromised.

SOLAS regulation Safe Return to Port (for passenger ships) and IMO Res. MEPC.232 «minimum required propulsion power» are in place to make sure that the installed power in new vessels are sufficient to operate safely in adverse conditions.

A study on a cruise vessel, a car carrier and a bulk carrier was initiated within the SFI with the purpose of

- Testing and comparing various numerical and experimental approaches to document compliance to the regulations, especially related to added resistance due to waves
- Comparing magnitudes of the resistance components
- Evaluate the effect of simplifications and assumptions
- Evaluate the effect of different sea state definitions
- Identify technologies and design modifications that increase operability in adverse conditions (superstructure design, controllable pitch propellers, power system and drive train arrangement)

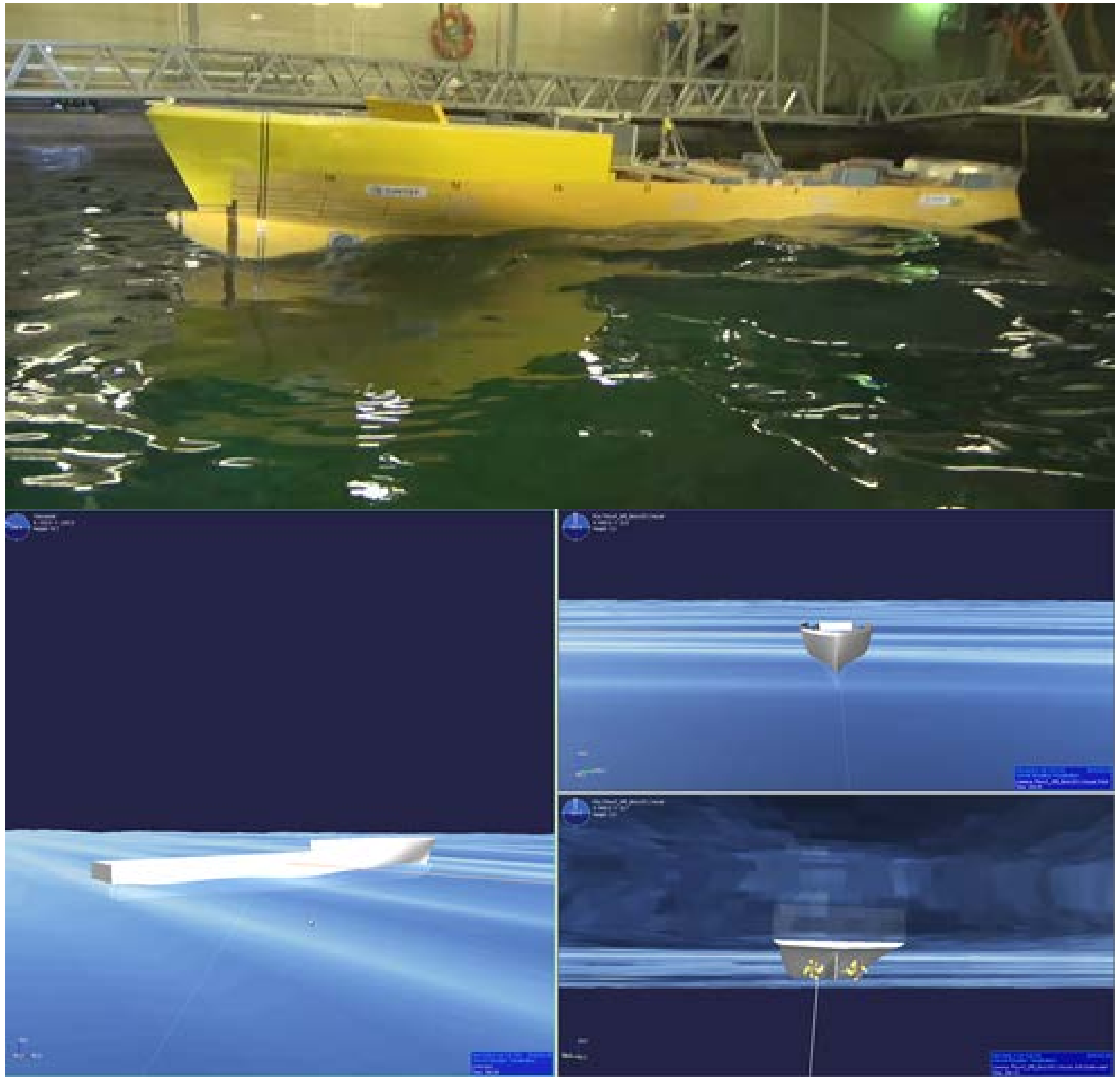
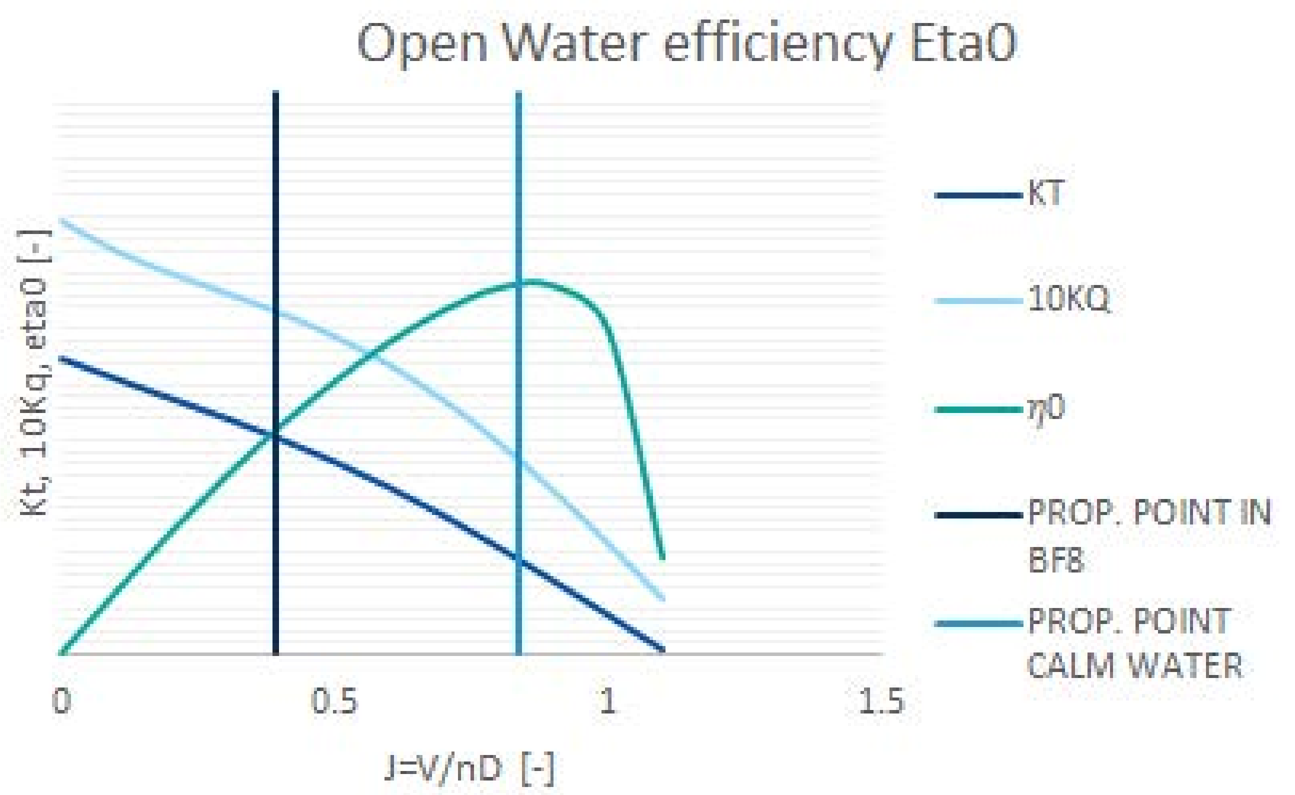


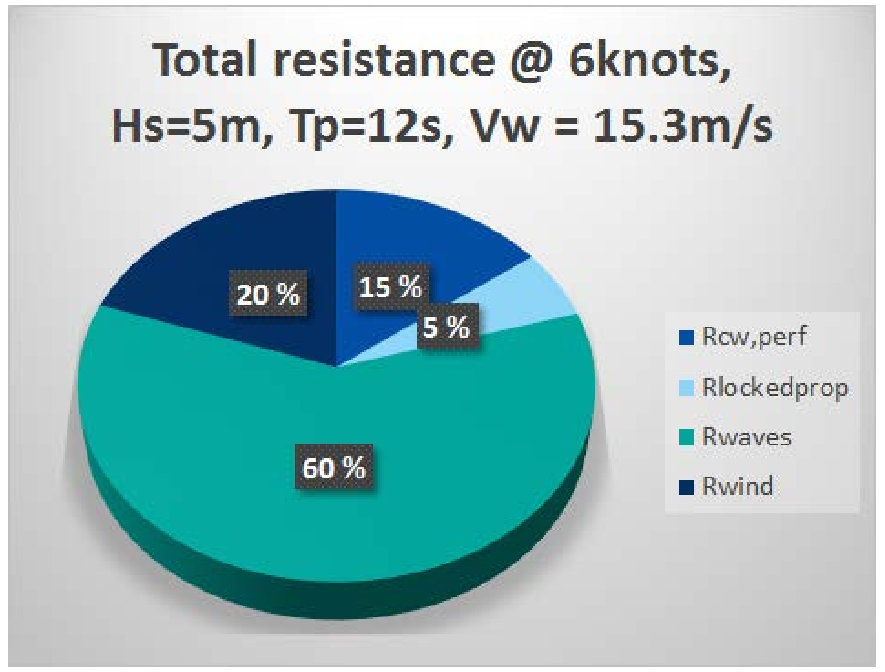
Figure 1: Model tests and numerical simulations of a cruise ship in BF8 sea conditions

Results from the study was presented to the SFI partners in a Webinar held in cooperation between SINTEF Ocean, NTNU and DNV-GL.

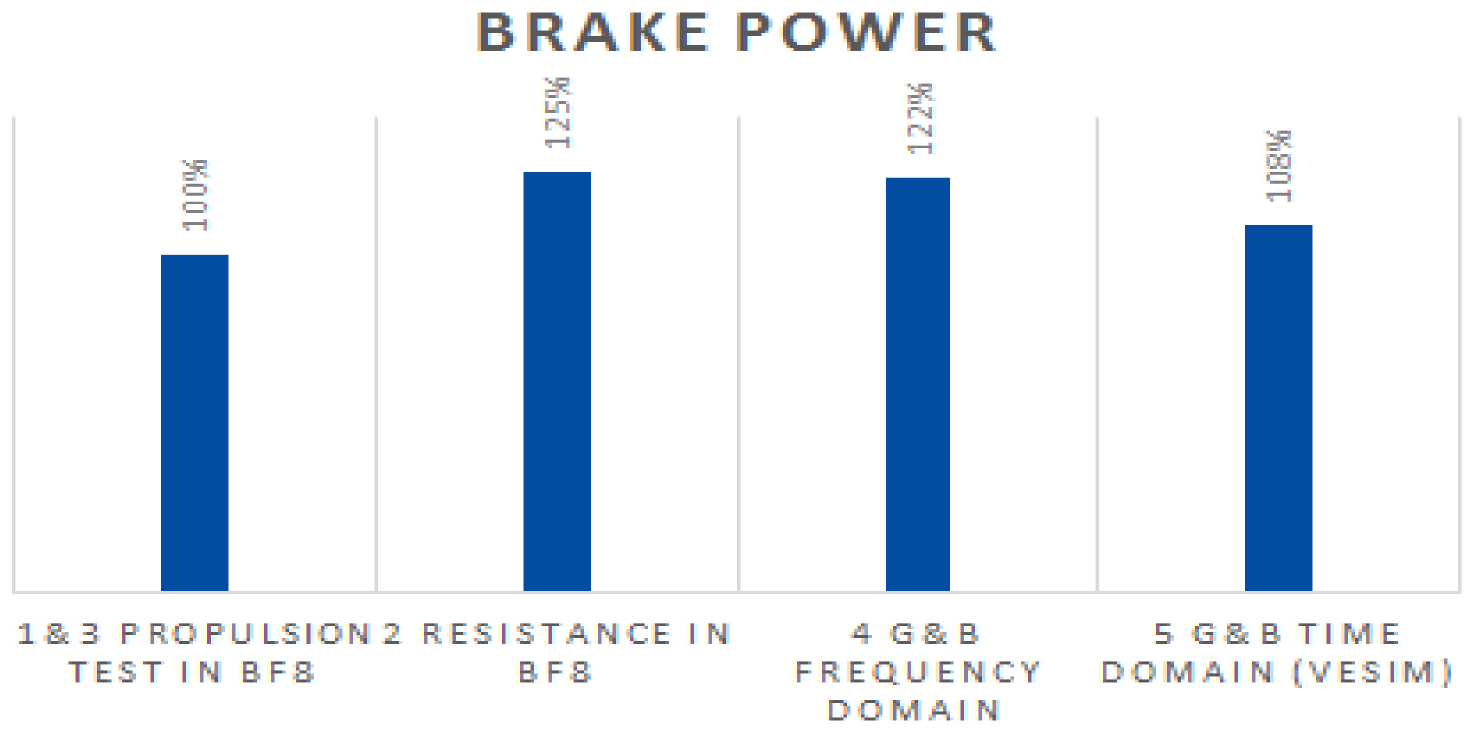
The results from the study indicate that the choice of method for deriving added resistance in waves has a significant impact on the predicted power required to comply with the regulations.

Propulsion analyses from model tests for the subject twin screw cruise ship case in SINTEF Ocean's large towing tank showed only minor losses of relative rotative efficiency and hull efficiency, but a significant loss in open water efficiency was seen due to increased resistance and the fact that only one working propeller (Safe Return to Port regulations require that operability is documented for the case of one dead propulsive line)




Distribution of resistance components for the ~140m cruise vessel in head seas, BF8 at 6 knots forward speed. Added resistance due to waves is by far the largest component. Drag from a dead propulsor is found to be around 5% in this case



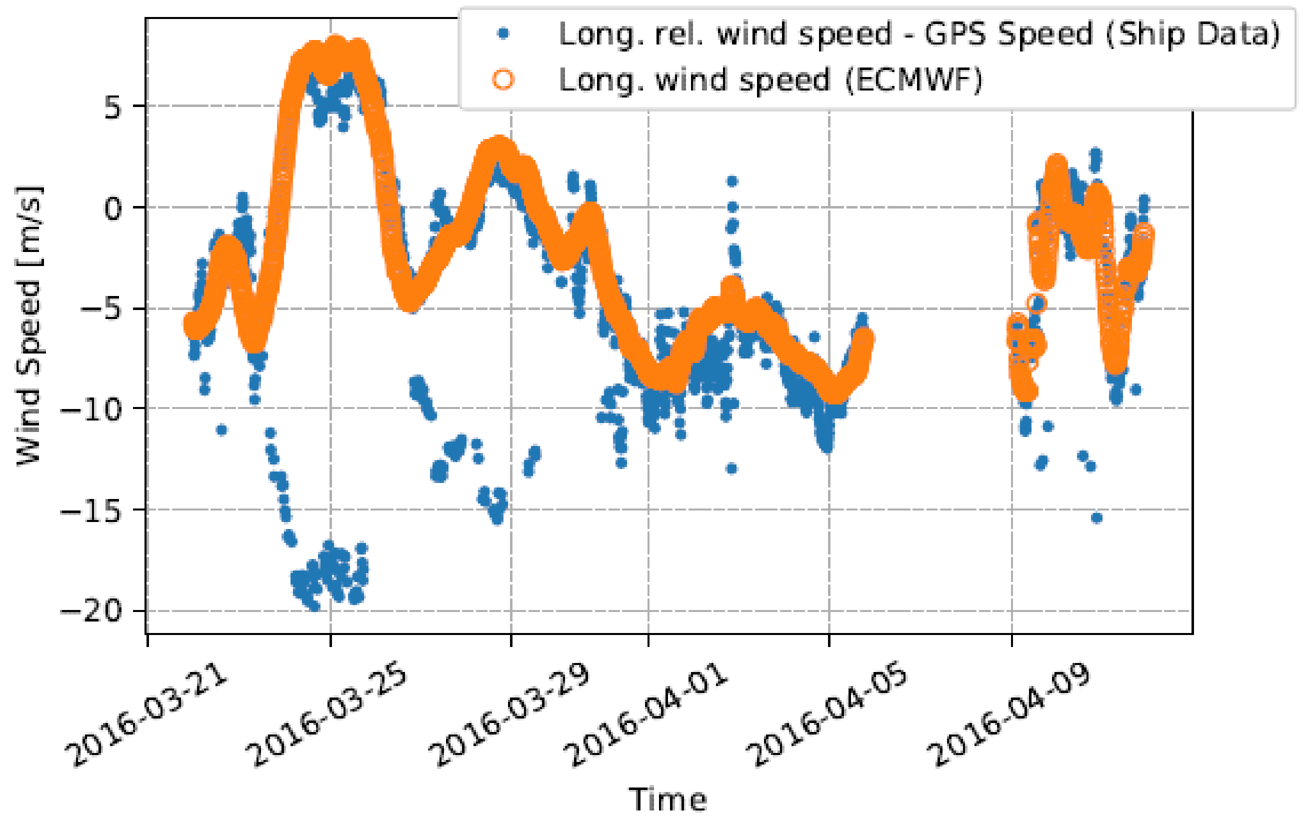

Power required to maintain 6knots in a BF8 sea condition for a ~120m cruise vessel as predicted by different numerical and experimental Methods. Relative differences between prediction methods are shown

## ANALYSIS OF IN-SERVICE DATA OF SHIP PERFORMANCE

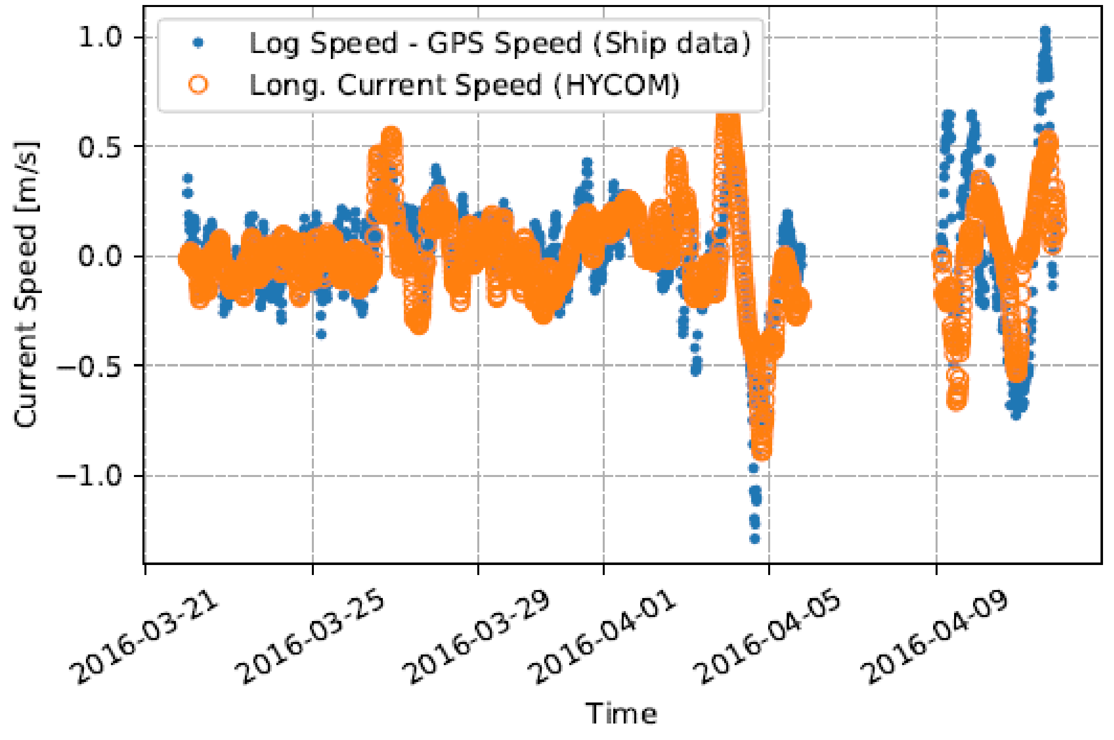
*Contact: Sverre Steen and Prateek Gupta, NTNU,*

The amount and quality of in-service collected data concerning ship performance is increasing rapidly. This data is potentially very valuable, and many uses is seen, like hull condition monitoring, machine-learning based performance prediction and ship routing, and performance optimization of various kinds. For scientists, this type of data represent a unique opportunity to get access to full scale data – until now one has mainly had to rely on model scale ship performance data. However, the full scale data sets are large, heterogeneous and of unknown and sometimes poor quality. Thus, data collection, data cleaning and data processing of this type of data are still areas of research and development. In SFI Smart Maritime, we've had a series of Msc thesis projects on processing and using in service data; Jens Gjølme and Anna Karina Magnussen in 2017 and currently ongoing projects by Jonas Munch Wahl and Kristian Ejdfors.

Prateek Gupta started his PhD in Smart Maritime in August 2018 on ship performance monitoring and optimization using in-service measurements and big data analysis methods. His first project has been to apply Principal Component Analysis (PCA) to process the high dimensional sensor data recorded onboard a ship during a sea voyage. Principal Component Analysis (PCA) was used to perform variable selection and detect potential outliers. The high dimensional dataset obtained from ship sensors and weather hindcast, representing the hydrodynamic performance of the ship, was greatly reduced in dimensions by PCA. The PCA model achieved upto 90% explained variance with only 4 Principal Components (PCs). Wind and sea current hindcast data, obtained from ECMWF and HYCOM respectively, was found to be in good agreement and, in some cases, more reliable than the in-service measurements recorded onboard the ship.

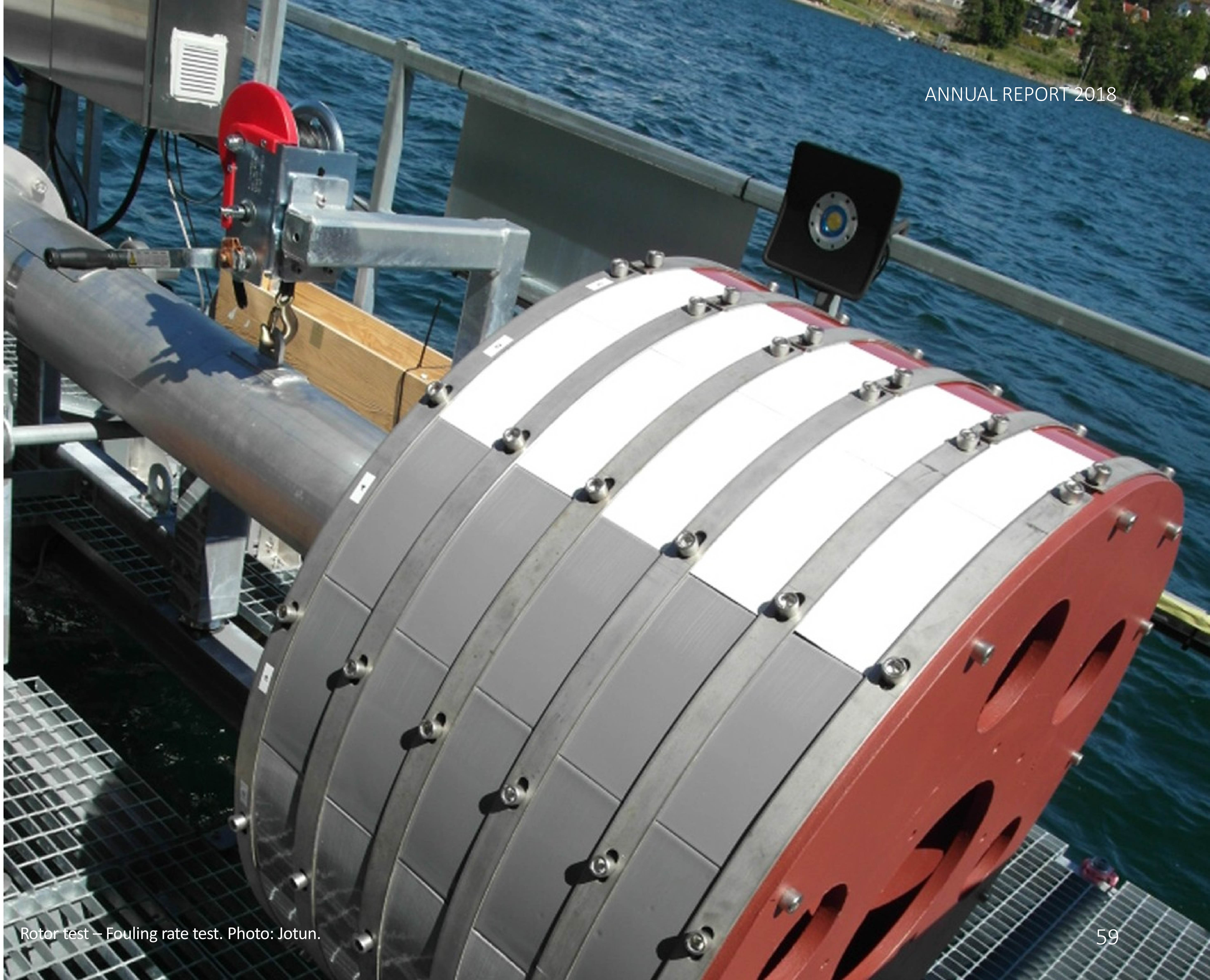



Comparison of wind from onboard measurements with hindcast data from ECMWF




Comparison of sea current derived from onboard measurements with hindcast data from HYCOM.

# COOPERATION



Rotor test – Fouling rate test. Photo: Jotun.

## NATIONAL COOPERATION

### Cross-SFI research cooperation

Research cooperation among PhD students from SFI Move (M. Gutsch) and Smart Maritime (E. Sandvik) has resulted in an additional journal article in 2018. Cooperation on simulation methods and tools among SFI Smart Maritime, MOVE and EXPOSED is also coordinated through the Joint Industry Project Open Simulation Platform launched in 2017.

### SFI Forum

SFI Smart Maritime partitipated at the SFI-forum organised by the Norwegian Research Council in April 2018, gathering 90 participants. The focus this year was on sharing information and experience in preparation of the midway evaluation process for SFI.

### Spin-off and associated projects

Additional funding is seeked every year by partners of Smart Maritime for further research or commercialisation activity. Funding sources include:

- Research projects (RCN, EU)
- Commercialisation: Innovation Norge, NTNU TTO

In 2018, based on active collaboration among the Centre partners, the following project applications were submitted, and after approval by the Norwegian Research Council they will be launched in **2019**.

- **CLIMMS** - Climate change mitigation in the maritime sector (MAROF, lead NTNU)
- **RuteSim** - Simuleringsbasert Ruteplanlegging (MAROFF, lead Grieg Star)
- **SMARTSHIPROUTING** - Selvlærende ruteoptimalisering for skip (MAROFF, lead Norwegian Control Systems)
- **Digital Twin Yard** - Ecosystem for maritime models and digital twin simulation (MAROFF, lead DNV GL)
- **FreeCO2ast** - Zero-Emission ROPAX (PILOT-E, lead Havyard)
- **Flying Foil** – Zero-emission fast ferry (PILOT-E, lead Flying Foil)

## 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. SINTEF Ocean is currently participating in 6 H2020 projects with relevance for Smart Maritime in terms of scientific activity or industrial challenges.

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### International conferences and forums

- Contribution to conferences: SNAME Maritime convention; IMDC International Marine Design Conference; SOME Ship operations, Management & Economics; IMSF International Maritime Statistics Forum;
- SNAME fellowship attributed to Dr Elizabeth Lindstad in 2017
- Membership in ESSF the European Sustainable Shipping Forum Dr Lindstad.

### Academic and research cooperation

- Scientific advisory committee, consisting of 5 Professors with expertise covering research area of the Centre. These are important knowledge partners. Through annual meeting, the Committee audits and advice on the research activity of the Centre.
- 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).

### International cooperation on policy making:

- Prof. A. H. Strømman (NTNU) designated as co-author of the IPCC's Sixth Assessment Report (chap. 10 Transport) due in 2022 together with researchers from 11 countries.
- Dialog and cooperation with Norwegian Shipowner Association and Sjøfartsdirektorat for contribution to IMO environmental strategy.

## ASSOCIATED PROJECTS - 2018

| Project name | Description | Synergi with Smart Maritime | Schedule & Funding |
| --- | --- | --- | --- |
| **HOLISHIP** - HOLIstic optimisation of SHIP design and operation for life cycle | Multi-objective, - disciplinary and multifidelity ship design and optimisation framework. | WP4, SP3<br>Virtual prototyping | 2016-2020<br>EU H2020<br>MG-4.3-2015 |
| **Hybrid testing** - Real-Time Hybrid Model Testing for Extreme Marine Environments | Focus on challenges in the model test in laboratory by replacing a substructure of the model by a numerical simulation running in parallel. WP4 works on the testing of a marine hybrid power plant with the simulation of the vessel motion and propulsion. | WP3 Power systems<br>WP4 Ship system integration | 2016-2020<br>RCN - MAROFF |
| **SATS** | Analytics for ship performance monitoring in autonomous vessel | WP1 Feasibility studies<br>WP4 Ship system integration | RCN - MAROFF<br>2018-2020 |
| **ARCTILOG**<br>Arctic Offshore Logistics | Concepts for Offshore Operations in Remote Areas: Ship design, ship operations, and offshore supply logistics. | | 2015 – 2018 |
| **STORSKALA LABORATORIEOPPGRADERING** | Model tests campaign, carried out with an open ship model in the Tower Tank at SINTEF Ocean. | WP2 Hull and propeller optimization | 2018 |
| **FUEL CELLS FOR MAIN PROPULSION** | Testing the viability of fuel cells as an energy source for main ship propulsion | WP3 Power systems | From 2018<br>ABB & SINTEF Ocean |

# RECRUITEMENT

Smart Maritime is a scientific and industrial network of 100 people. The research team consists of over 20 research scientists from two institutions NTNU and SINTEF Ocean, including 1 Postdoc and 6 PhD students financed by the Centre in 2018.


Ponant Icebreaker. Photo: Vard and Sterling Design.

SMART MARITIME

## PHD AND POSTDOC RESEARCH PROJECTS

Research training:

The doctoral education programme combines academics with methodological schooling and hands on experience. A PhD programme is composed of one semester of coursework / research training, and 2.5 years of dissertation work and research. The supervisor assists in preparing the project plan, training component, plan for internationalization and an application for admission. The faculty is responsible for the required coursework and academic training based on the supervisor's recommendation and offers training in research ethics and scientific methods.

Entrepreneurship training:

Ocean School of Innovation (OSI) is an additional program og courses and seminars offered to all PhD students in SFI ad SFF at the NTNU Department of Marine Technology, aiming at increasing innovation and value creation of the centres through improved awareness and competence on innovation and entrepreneurship among PhD students. Smart Maritime cooperates with SFF AMOS, SFI EXPOSED, MOVE and SAMCoT through OSI.

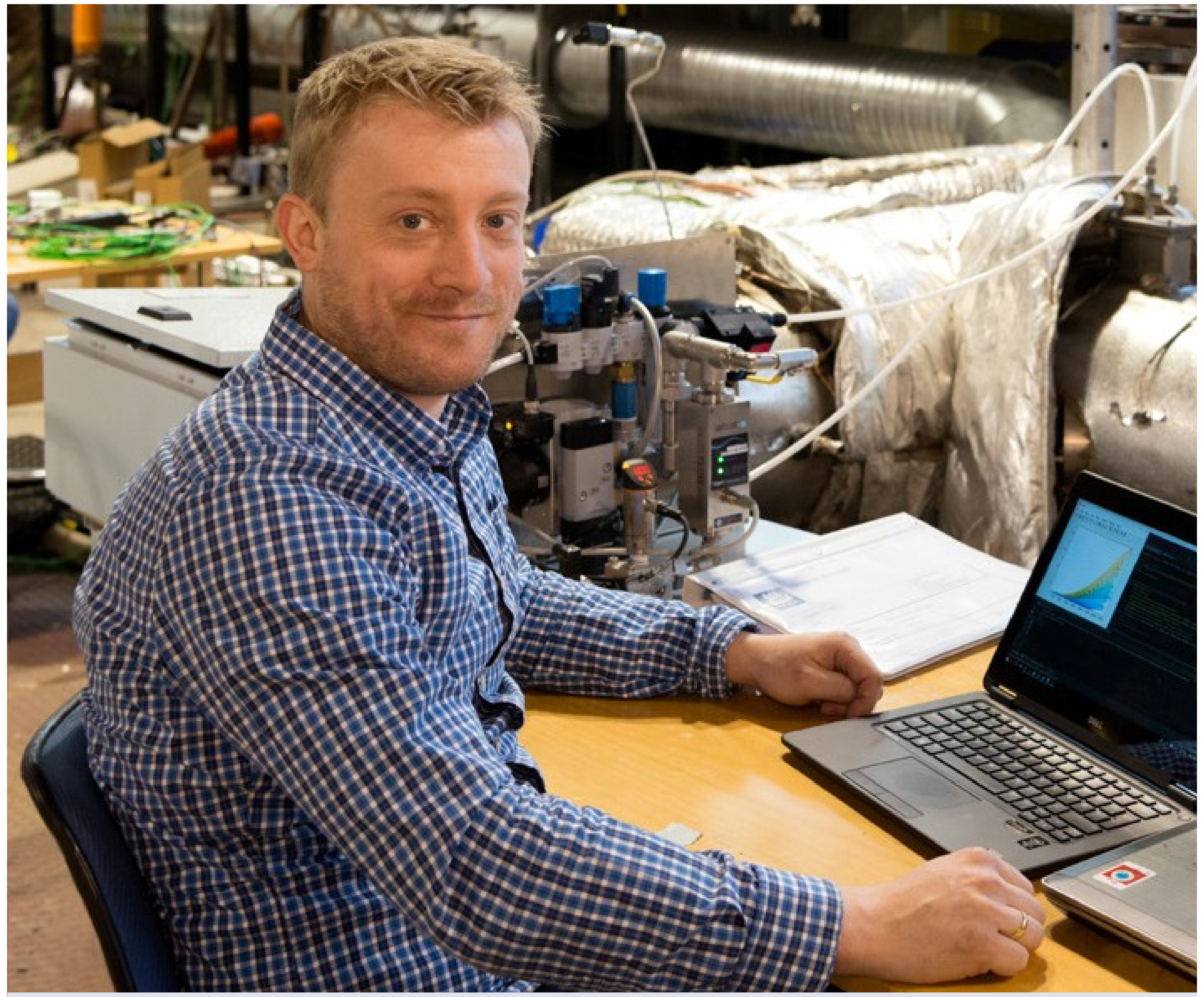


Photo: Maria A. L. Gulaker.

**Jørgen Nielsen**

*PhD Student WP3/WP4 (2015–2018)*

***Virtual Prototyping of Complex Marine Power Systems***

**Foreseen innovation**

Improved methods for assembly and evaluation of system models relevant for modelling marine power plants.

**Supervisor**

Eilif Pedersen (IMT, NTNU)

**Research goal and strategy**

The maritime industry is facing significant changes in how marine power plants have to be designed due to stricter regulation on emission of air pollutants and greenhouse gases and the need for increased energy efficiency. Designing compliant and efficient marine power plants depends on developing and implementing new technology and new technical solutions. This is a significant change for the deep sea sector where the current marine power plant concepts have changed little since the introduction of the turbocharged heavy fuel oil burning large two stroke marine diesel engine, while for the offshore sector additional technical solutions and systems adds additional complexity to already advanced systems. Due to the geographic application of regulation, there are reasons to believe that a more diverse set of system solutions will appear suited to fit the trade, operation profile and area of operation. Moving from a standardised design to selecting between multiple viable designs or developing custom designs, poses a significant challenge for marine power plant designers. Designers need methods for evaluating suggested designs and for building confidence in novel systems before system realization. System modelling and simulation is considered an important methodology for our ability to develop these novel systems. Successful use of system modelling and simulation increases our ability to tackle systems related problems such as complexity due interaction between components and sub-systems and provides designers with an methodology to evaluate concepts using virtual prototyping. Although a promising method for virtual prototyping, system modelling and simulation faces challenges such as:

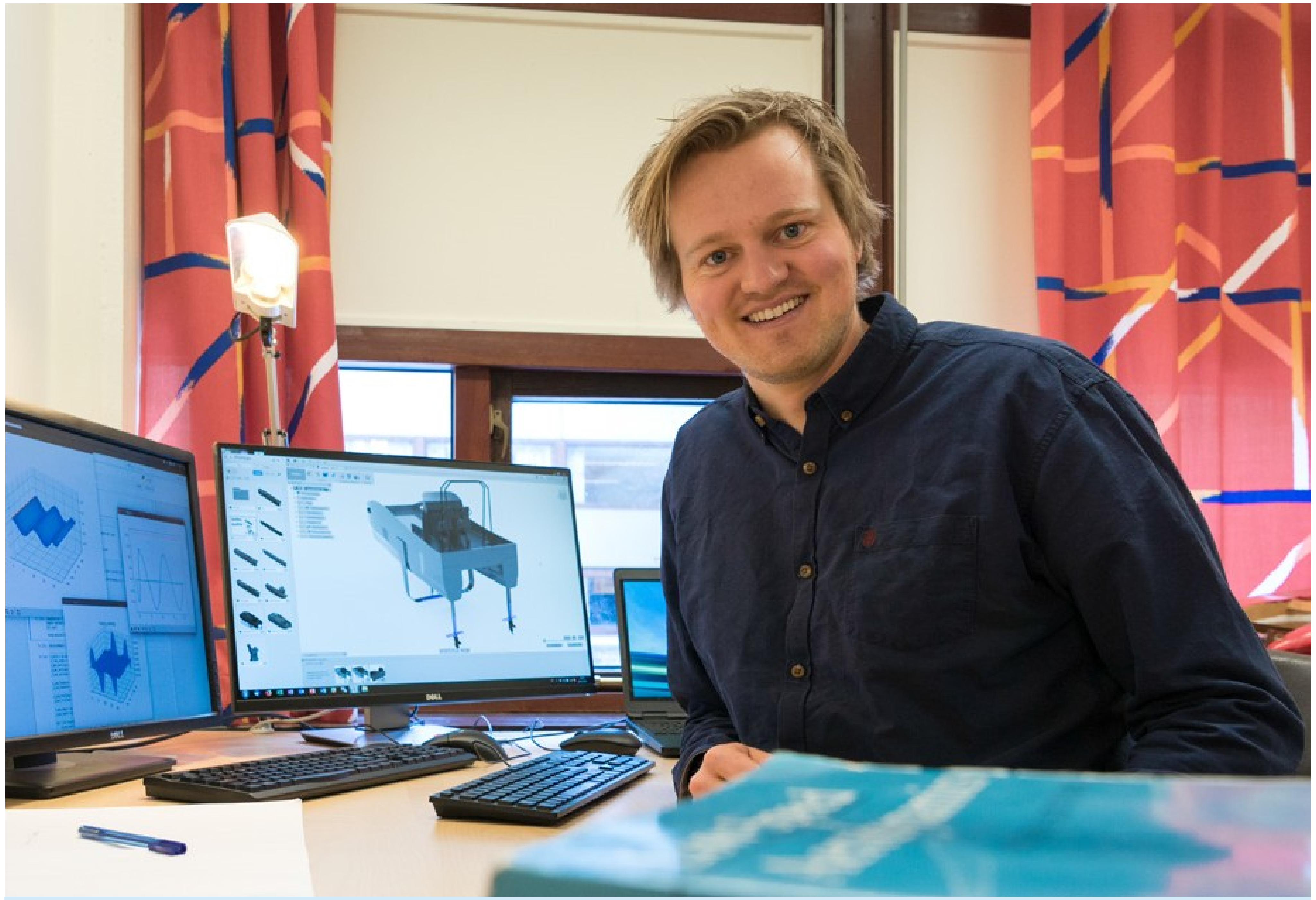
- how to identify the relevant problem and represent the relevant physical phenomena using mathematics?
- how to gather required data needed to make a model represent a physical component or system?
- how to ensure that the model developed is able to answer the question being asked?
- how to assemble models into total system models?
- how to develop models that have equation structures for which we have efficient numerical solvers?
- how to extract understanding and knowledge from simulation results?
- how to make decisions based on simulation results?

These challenges combined with the ones facing the maritime industry lead to the overall research goal of this thesis: *Improve the methods for system modelling and simulation in the maritime industry, increasing our ability to evaluate energy efficient system concepts for reducing emission of air pollution and CO2*

**Main achievements 2018**

Submission of two papers

- A system approach to modelling heat exchanger and heat exchanger network dynamics using bond graphs.
- A system approach to Selective Catalyst Reduction DeNOx monolithic reactor modelling using bond graphs.



**John Martin Kleven Godø** *PhD student WP2 (2015–2018)*

***Hydrodynamics of hydrofoil vessels***

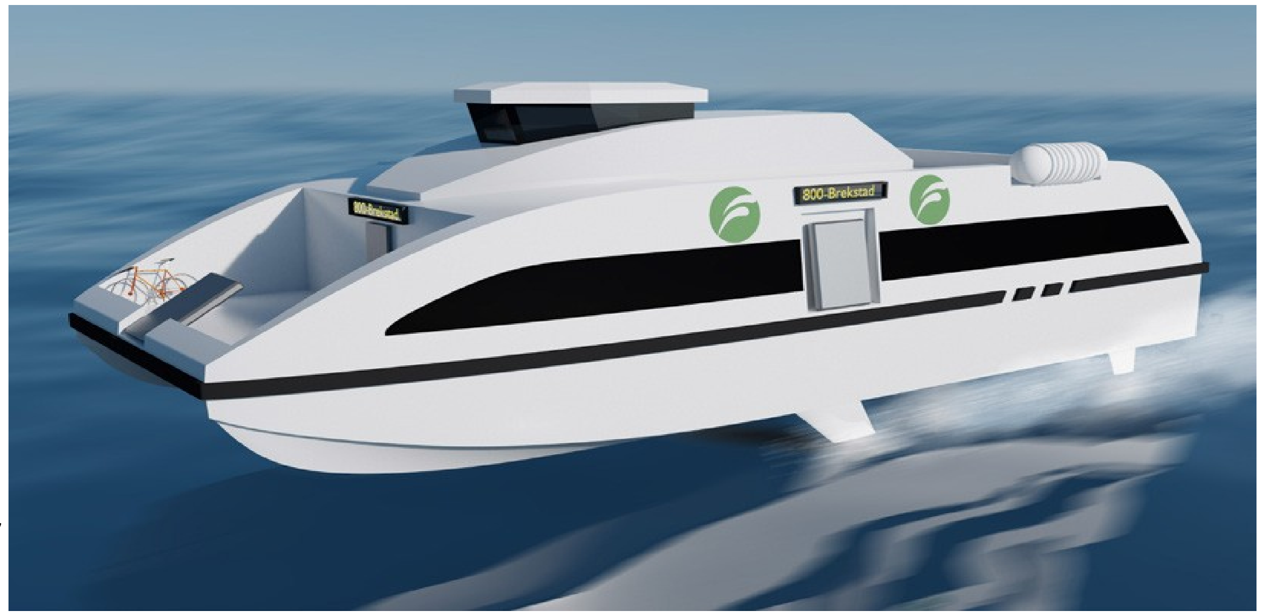
**From PhD student to entrepreneur**

John Martin is on leave from my PhD studies to focus on the product development and commercialization part of the *Flying Foil project.*

Flying Foil is a start-up project aiming to develop and commercialize a new generation of hydrofoil vessels for use in passenger transport. The principle of lifting a vessel on hydrofoil has great potential, and current calculations indicate that it might be possible to reduce the energy requirement of a 35 knot fast ferry by more than 30% as compared to the best conventional vessels of today. This translates to more lightweight machinery and energy storage and thereby a positive design loop yielding further reductions of power requirement.

In 2017, Flying Foil has established a collaboration with Norway's leading fast ferry shipyard, Brødrene Aa, with the aim of building a fully electric 7 meter prototype vessel of our current hydrofoil design. This prototype project is supported by Norges Forskningsråd FORNY-grant.

In 2018, Flying Foil received further support through PILOT-E program.



Copiright: Flying Foil / Jarle Kramer.

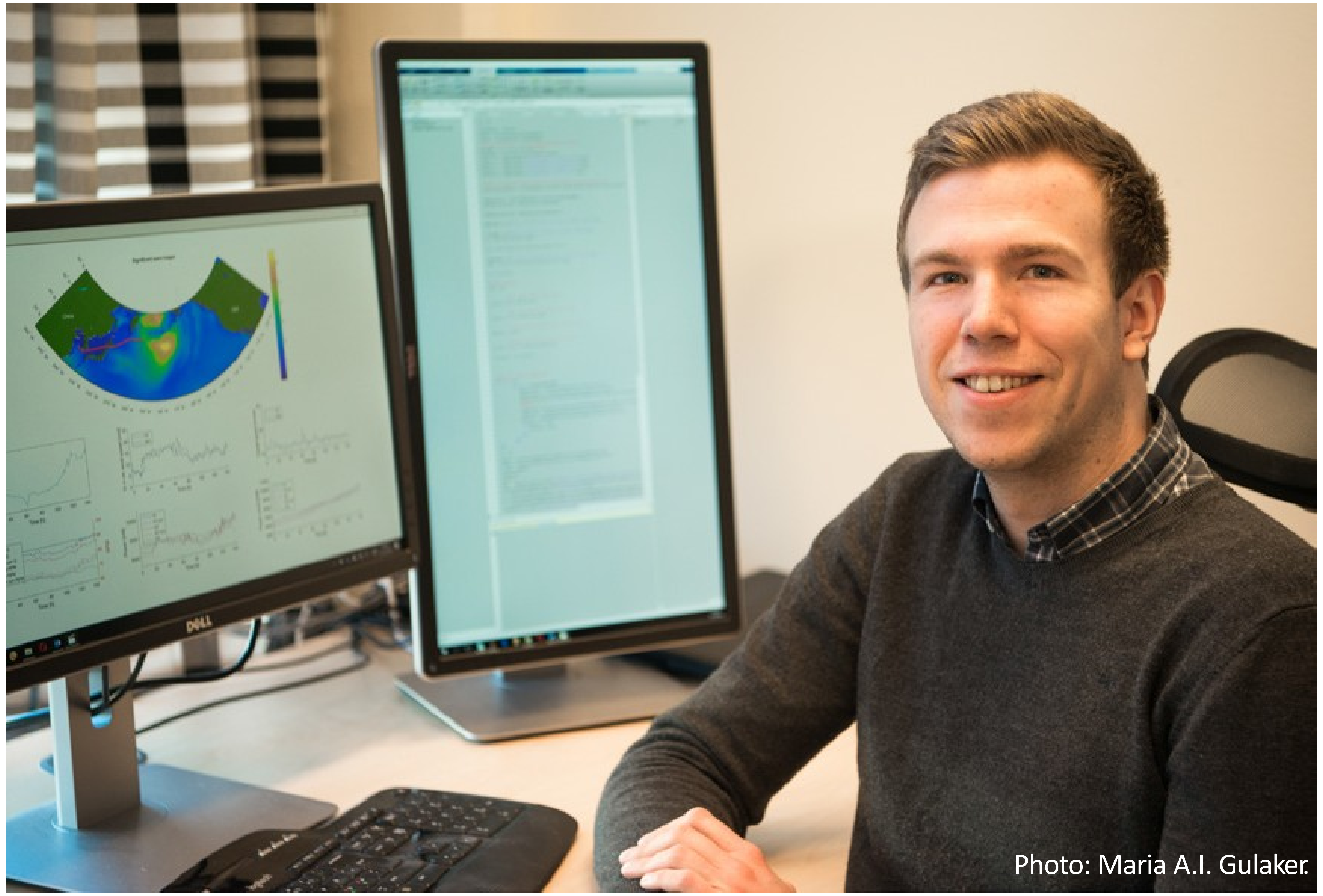


Photo: Maria A.I. Gulaker.

## Endre Sandvik

*PhD student WP4 (2016–2019)*

***Simulation Based Design of Ships With Regards to System Performance***

**Research topics**

The purpose of the PhD research is to provide knowledge regarding the validity of simulation models for application in ship design. The research focuses on how simulation is applied to virtually test designs in operational scenarios.

**Industrial goals**

Knowledge that supports energy efficient design and operation of ships using simulation-based methods. The research focuses on techniques for implementing relevant operational scenarios for virtual testing of design concepts. Scenarios are created taking the operational decisions of ship owner and the ship master into account, thus making the research relevant for both ship owners and designers.

**Achievements**

A validation study towards estimation of fuel consumption and operational profile using GYMIR was conducted in 2017. The methodology and results are presented in a conference paper for the International Marine Design Conference in Helsinki June 2018.

Two papers have recently been submitted for review:

1. *Operational sea passage scenario generation for virtual testing of ships using an optimization for simulation approach*. E. Sandvik, J.B. Nielsen, B.E. Asbjørnslett, E. Pedersen, K. Fagerholt
2. *Impact of simulation model fidelity on ship system evaluation in sea passage scenarios*. J.B. Nielsen, E. Sandvik, B.E. Asbjørnslett, E. Pedersen, K. Fagerholt

**Supervisors**

Main supervisor:

- Professor Bjørn Egil Asbjørnslett, NTNU IMT

Co-supervisors:

- Professor Sverre Steen, NTNU IMT
- Professor 2 Stein Ove Erikstad, IMT (FEDEM)
- Associate professor Eilif Pedersen, NTNU IMT

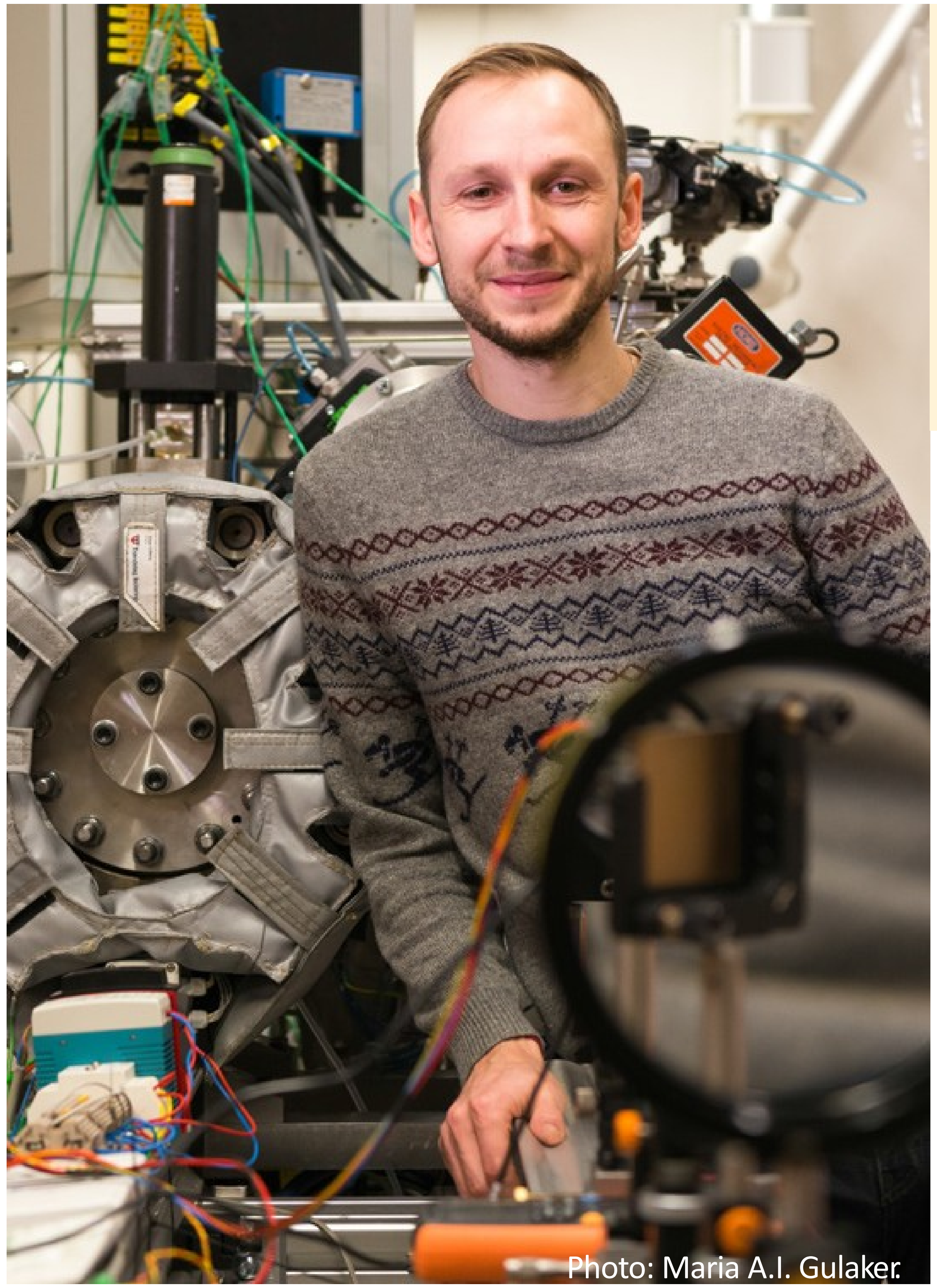


Photo: Maria A.I. Gulaker.

# Vladimir Krivopolianskii

*PhD student WP3 (2015–2018)*

***Development of a constant volume combustion rig for experimental investigation of combustion and emission characteristics of alternative fuels***

**Research topics**

Environmental regulations to reduce emissions from ships are creating a strong impulse for the development of new technological and operational solutions. Utilization of alternative fuels such as biodiesel, natural gas and hydrogen instead of conventional fuels in marine engines can potentially reduce emissions and hence satisfy the environmental requirements.

For fundamental study of the emission from alternative fuels' combustion, this project is to develop an experimental setup that resembles a combustion chamber environment in a marine diesel/natural gas engine.

In order to ensure an application of non-intrusive measuring techniques, the experimental setup is equipped with optical windows for detail study of combustion phenomena. For case studies, the research on biodiesel and natural gas + hydrogen blends combustion was chosen.

**Industrial goals:**

To develop a facility and experimental research methods for testing the performance of marine engine injection valves and for investigation of combustion process of both liquid and gaseous fuels.

**Supervisors**

| | |
|---|---|
| Supervisor: | Sergey Ushakov (IMT, NTNU) |
| Co-supervisor: | Eilif Pedersen (IMT, NTNU) |

## Jon Coll Mossige

*PhD student WP2*
*(2017–2020)*

***Added resistance on ships due to hull roughness***

### Research topics

The research will initially be focused on a numerical investigation of roughness effects on the turbulent boundary layer for a flat plate. A challenge here is to find a parametrization for the roughness found on hulls in typical conditions. This includes everything from heavily fouled to freshly painted hulls.

Further research may include a study of the impact on the roughness effects by plate curvature and/or presence of waves, as well as an investigation of new coating designs in cooperation with JOTUN.

### Industrial goal

- Improve prediction methods for power requirement and fuel consumption of full scale ships.
- Design of new hull coating technologies with better performance, both when it comes to resistance and anti- fouling capabilities.

### Scientific questions

To which level do we understand the effect of roughness on fluid flowing past a wall?

Which parameters are necessary in order to describe the roughness on a typical hull plate?

What is the impact of flow perturbations and plate curvature on the added resistance due to roughness?

### Work 2018

- A 1D time marching solver for boundary layer flow.
- A simulation tool for:
  - early design phase resistance prediction
  - estimates of added roughness given a ship's fouling conition.

### Cooperating company

JOTUN

### Supervisors

Supervisor: Lars Erik Holmedal (NTNU)
Co-supervisor: Kourosh Koushan (NTNU, SINTEF)

## Prateek Gupta

*PhD student WP2*
*(2018–2021)*

***Ship performance monitoring and optimization using in-service measurements and big data analysis methods***

**Main achievements 2018**

- Developed a data-driven mathematical model based on Principal Component Analysis (PCA) to model the hydrodynamic behavior of a ship during a sea voyage. The model accuracy was evaluated based on the in-service data recorded onboard a sea going ship.
- Performed dimensionality reduction of high dimensional data recorded onboard a ship using the correlation between various recorded parameters.
- Various statistical methods were used to detect outliers for cleaning the given dataset for quality assurance and ensuring data integrity.

**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 NorKyst800 and ECMWF 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 frictional resistance of the ship from total engine power consumption and ship motions using in-service measurements.
- Estimation of added wave resistance using weather hind-cast data, ship motions and total engine power consumption during voyage.

**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 identify the frictional resistance from the measured total engine power consumption?
- How to estimate sea state and speed-through-water in real time?

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


Photo: Maria A.I. Gulaker.

## Torstein Ingebrigtsen Bø

*Postdoc WP3 (2015-2018)*

***Hybrid propulsion, integrating new power sources for marine power plants***

### Research topics

The purpose of the Postdoc is to provide models of marine electric power plants suitable for design and optimisation of propulsion systems. This also includes measurements of losses of real equipment in addition to control studies.

### Industrial goals

The goal of the study is to establish models of the marine electric power plants. Today there exist multiple models for powerplants. However, their use case is often either to investigate dynamics or losses. The models should be complex enough to capture the most important dynamics of the system, while simple enough to be efficient in an early design phase. Loss models of marine power plants are either very complex (finite element method) or just a fixed efficiency. The aim of the development is to bridge the gap between these two model types.

### Foreseen innovation

The models of the power plant can be useful in further design of marine power plants. It has been shown that using fixed efficiency of equipment is not sufficient for DP vessels, as the power demand is often very low. These models can therefore help further optimization of the powerplant for more economic and environmentally friendly operations.

### Cooperation with industry partners

ABB has helped with testing of losses in the joint hybrid power lab, Rolls Royce has contributed with load profiles and models of components in marine power plants.

### Main achievements / milepæler

- Models for marine power plants, including main losses
- Estimation of losses for supply vessel
- An MPC based controller for gas engines and batteries

### Faculty / Supervisor

Associate professor Eilif Pedersen, NTNU IMT


Photo: SINTEF Ocean.

## Lokukaluge Prasad Perera

*Postdoc WP2/WP3 (2015–2017)*

***Data handling framework for ship performance and navigation monitoring***

**Summary of Postdoc project**

L.P. Perera has developed a machine learning based data handling framework with various data analytics to over-come the respective challenges in ship performance and navigation monitoring. There are various industrial challenges encountered in large-scale data handling situations among vessels and shore based data centers.

The proposed data handling framework consists of pre and post-process sections as onboard and onshore applications, respectively. The pre-process as a part of ship IoT consists of the data analytics with data anomaly detection and parameter reduction/data anomaly compression facilitated by data driven models, i.e. digital models.

The pre-processed data communicate through onboard data transmitters in much smaller improved data sets and that are obtained by shore based data centers through data receivers. The post-process as a part of onshore data centers consists of the data analytics with parameter expansion/data anomaly recovery, integrity verification & regression and data visualization & decision support facilitated by the same digital models.

These data analytics has special features of self-learning (i.e. data clusters and the structure of each data cluster), self-cleaning (i.e. sensor and DAQ fault removal and compression, data recovery, data regression & integrity verification), self-compression & expansion (i.e. parameter reduction and expansion).

Furthermore, that has a multi-purpose structure that can be used for both ship energy efficiency and system reliability applications.

Photo: Pål Leraand.

**Renato Skejic**

*Postdoc WP2 (2016–2018)*

## *Computation of added resistance due to waves*

**Summary of Postdoc project**

Ship behavior and operational patterns in a seaway are strongly affected by the presence of added resistance in a seaway. In order to ensure optimized and economically justified short, medium and/or long time duration voyages of the ship in realistic irregular wave field scenarios, the added resistance needs to be investigated from both, the theoretical and/or experimental point of view.

Post doc Renato Skejic has worked on development of medium-fidelity computational methods for added resistance due to waves.

Focus has been on investigating of several approaches to develop a reliable and robust prediction algorithm for the added resistance in waves with the accuracy within the common engineering practice. One of the main goals was to understand and develop the methodologies which will lead to the formulation of the state-of-the-art medium resource demanding application within the potential fluid flow theory based on the Boundary Element Method (BEM) in comparison to Computational Fluid Dynamics (CFD) methods such is Volume Of Fluid (VOF) method.

The methodology towards prediction of added resistance in waves was based in the frequency domain. This means that any kind of the transition time depended (unsteady) effects are disregarded and the steady-state formulation is adopted.

The post doc project has implemented improved versions of the Salvesen (1974) and Maruo (1960, 1963) methods to calculate the added resistance based on the framework of the STF linear strip theory.

The post doc project has laid a foundation for implementing improved practical computational methods for computing added resistance due to waves.

It can be expected that the developed methodology will contribute to better understanding of the physical phenomena affecting the added resistance. The current approach removes some of the boundaries of the methods for blunt ship forms while maintaining the mathematical rigorousness.

The applicability of the developed methodology will be demonstrated through publication of papers in the upcoming PRADS conference in Japan and a journal paper aimed for Journal of Ship Research.

SMART MARITIME

# PEOPLE




Photo: Havyard Group.

## INDUSTRY NETWORK

| ABB | Bergen Engines | DNV GL | Grieg Star |
|---|---|---|---|
| Børre Gundersen<br>Jan-Fredrik Hansen*<br>Matko Basiric | Jan Eikefet<br>Leif Arne Skarbø*<br>Erlend Vaktskjold | Hendrik Brinks*<br>Christos Chryssakis<br>Hans Anton Tvete | Roar Fanebust<br>Jan Øivind Svardal*<br>Henry Svendsen<br>Svenn Sørstrand |

| Havyard Group | Jotun | Kristian Gerhard Jebsen Skipsrederi |
|---|---|---|
| Daniel Aaro<br>Kay Lorgen<br>Arve Nedreberg<br>Ole Rorhus<br>Kristian V. Steinsvik*<br>Rolf Arild Topphol<br>Kåre Nerland | Lennard Bosh<br>Angelika Brink*<br>Stein Kjølberg<br>Andreas Krapp<br>Geir Axel Oftedahl | Jan Berntzen<br>Ole-Johan Haahjem*<br>Øyvind Monsen |

| Kystrederiene | Norwegian Electric Systems | Rolls-Royce Marine |
|---|---|---|
| Tor Arne Borge* | Stein Ruben Larsen*<br>Torbjørn Haugland<br>Johannes Tveit | Martijn de Jongh<br>Hans Martin Hjørungnes<br>Per Ingeberg*<br>Kristen Jomås<br>Sverre Torben<br>Leif Vartdal<br>Bjørnar Vik |

| Norges Rederiforbund | Siemens | Sjøfartsdirektoratet |
|---|---|---|
| Gunnar Malm Gamlem*<br>Tor Christian Sletner<br>Jahn Viggo Rønningen | Lars Barstad<br>Arne-Gunnar Brandvold<br>Vemund Kårstad<br>Odd Moen<br>Kenneth Presttun Tjong<br>Stig-Olav Settemsdal* | Lasse Karlsen*<br>John Malvin Økland |

| Solvang | Vard Design | Wallenius Wilhelmsen Logistics | Wärtsilä Moss |
|---|---|---|---|
| Jone Ask<br>Tor Øyvind Ask*<br>Alexander Grødeland | Tim Mak<br>Kjell Morten Urke* | Håvard Abusdal<br>Lars Dessen* | Stian Aakre<br>Sigurd Jenssen* |

* Primary contacts

## PARTNERS PRIMARY CONTACTS

**ABB**
Jan-Fredrik Hansen

**Bergen Engines**
Leif Arne Skarbø

**DNV GL**
Hendrik Brinks

**Grieg Star**
Jan Øivind Svardal

**Havyard Group**
Kristian V. Steinsvik

**Jotun**
Angelika Brink

**Kristian Gerhard Jebsen Skipsrederi**
Ole-Johan Haahjem

**Kystrederiene**
Tor Arne Borge

**Norwegian Electric Systems**
Stein Ruben Larsen

**Rolls-Royce Marine**
Per Ingeberg

**Norges Rederiforbund**
Gunnar Malm Gamlem

**Siemens**
Stig-Olav Settemsdal

**Sjøfartsdirektoratet**
Lasse Karlsen

**Solvang**
Tor Øyvind Ask

**Vard Design**
Kjell Morten Urke

**Wallenius Wilhelmsen Logistics**
Lars Dessen

**Wärtsilä Moss**
Sigurd Jenssen

Road Fanabust, Grieg Star
**Coordinator of Technical Advisory Committee**

## RESEARCH TEAM

| Name | Company | Position | Expertise area | Contribution to Smart Maritime |
|---|---|---|---|---|
| **Sverre Anders Alterskjær** | SINTEF Ocean | Research Scientist | Hull and propeller performance | WP2 |
| **Torstein Ingebrigtsen Bø** | SINTEF Ocean | Research Scientist | Hybrid propulsion | WP2, WP1 |
| **Jon Schonhovd Dæhlen** | SINTEF Ocean | Research Scientist | Simulation-based concept design | WP4 leader (from Nov. 2018) |
| **Per Magne Einang** | SINTEF Ocean | SINTEF Ocean | Power systems and fuel | Centre director (until Oct. 2018) |
| **Dariusz Fathi** | SINTEF Ocean | Research Manager | Data simulations and optimization | WP4 |
| **Trond Johnsen** | SINTEF Ocean | Research Manager | Maritime logistics | WP4, Centre director (from Nov. 2018) |
| **Kourosh Koushan** | SINTEF Ocean | Senior Advisor | Hull and propeller performance | WP2 |
| **Kevin Koosup Yum** | SINTEF Ocean | Research Scientist | Simulation, Machinery | WP3 |
| **Elizabeth Lindstad** | SINTEF Ocean | Senior Research Scientist | Environment-friendly shipping | WP1 leader |
| **Andrew Ross** | SINTEF Ocean | Research Scientist | Hydrodynamics | WP2 |
| **Dag Stenersen** | SINTEF Ocean | Senior Engineer | Power systems and fuel | WP3 |
| **Ole Thonstad** | SINTEF Ocean | Senior Engineer | Full scale data harvesting | WP3 |
| **Anders Valland** | SINTEF Ocean | Research Manager | Hybrid propulsion | WP3 |
| **Ingebrigt Valberg** | SINTEF Ocean | Senior Engineer | systems and fuel | WP3 |
| **Henning Borgen** | SINTEF Ålesund | CEO | Simulation based design | WP4 |
| **Bjørn Egil Asbjørnslett** | NTNU Marine Technology | Professor | Ship design | WP4 |
| **Stein Ove Erikstad** | NTNU Marine Technology | Professor | Hull and propeller hydrodynamics Data | WP4 |
| **Helene Muri** | NTNU Indusrial Ecology | Researcher | Climate and environmental impact | WP5, WP1 |
| **Sverre Steen** | NTNU Marine Technology | Professor | Hydrodynamics | WP2 leader |
| **Anders H. Strømman** | NTNU Indusrial Ecology | Professor | Climate and environmental impact | WP5 leader |
| **Sergey Ushakov** | NTNU Marine Technology | Professor | Exhaust emissions | WP3 leader |
| **Vilmar Æsøy** | NTNU Ålesund | Professor | Power systems and fuel | WP3 |

## RESEARCH TEAM - SINTEF OCEAN


Sverre Anders Alterskjær


Torstein Ingebrigtsen Bø


Jon Schonhovd Dæhlen


Per Magne Einang


Dariusz Fathi


Trond Johnsen


Kourosh Koushan


Kevin Koosup Yum


Elizabeth Lindstad


Andrew Ross


Dag Stenersen


Ole Thonstad


Anders Valland


Ingebrigt Valberg


Henning Borgen
**SINTEF Ålesund**

## RESEARCH TEAM - NTNU


Bjørn Egil Asbjørnslett


Stein Ove Erikstad


Helene Muri


Sverre Steen


Anders H. Strømman


Sergey Ushakov


Vilmar Æsøy

## PHD STUDENTS AND POSTDOCTORAL RESEARCHERS - 2018

| Name | Funding source | Nationality | Period | Topic |
|---|---|---|---|---|
| ***Postdoctoral researchers*** | | | | |
| Renato Skejic | SFI Smart Maritime WP2 | HR | 2016–2018 | Computation of added resistance due to waves |
| Torstein Ingebrigtsen Bø | SFI Smart Maritime WP3 | NO | 2015–2018 | Hybrid propulsion, integrating new power sources for marine power plants |
| ***PhD students*** | | | | |
| Prateek Gupta | SFI Smart Maritime WP2 | IN | 2018–2021 | Ship performance monitoring and optimization using in-service measurements and big data analysis methods |
| Jon Coll Mossige | SFI Smart Maritime WP2 | NO | 2017–2020 | Added resistance on ships due to hull roughness |
| John Martin Godø | NTNU in-kind to Smart Maritime | NO | 2015–2018 | Hydrodynamics of hydrofoil vessels |
| Espen Krogh | NTNU in-kind to Smart Maritime | NO | 2018–2020 | Hybrid propulsion machinery optimisation |
| Jørgen B. Nielsen | SFI Smart Maritime WP3/4 | NO | 2015–2018 | Simulation of complex high efficiency maritime power systems |
| Vladimir Krivopolianskii | SFI Smart Maritime WP3 | UA | 2015–2018 | Fuel injection and combustion |
| Endre Sandvik | SFI Smart Maritime WP4 | NO | 2016–2019 | Simulation Based Design of Ships With Regards to System Performance |
| ***Other funding*** | | | | |
| Sadi Tavakoli | Cotutelle NTNU / DTU | IR | 2017–2020 | Marine machinery |
| Simone Saettone | Cotutelle NTNU / DTU | IT | 2017–2020 | Hydrodynamics |
| Øyvind Øksnes Dahlheim | Rolls-Royce UTC | NO | 2015–2018 | Hydrodynamics |
| Anna Swider | Rolls-Royce Ind. PhD | PL | 2015–2018 | Hydrodynamics |
| Jarle Kramer | KPN LEEDS | NO | 2013–2018 | Hydrodynamics |


Renato Skejic


Torstein Ingebrigtsen Bø


Prateek Gupta


Jon C. Mossige


John Martin Godø


Espen Krogh


Jørgen Nielsen


Endre Sandvik


Vladimir Krivopolianskii

# MASTER STUDENTS - 2018

## MSc THESES

| MSc students | University, Department | Topic MSc thesis |
|---|---|---|
| **Joakim Tveiten Vigsnes** | NTNU, Marine Technology | Comparison of seakeeping analyses |
| **Jens Kristian Myhrer Bredahl** | NTNU, Marine Technology | Experimental Study of High-Pressure Gas Injection Using Optical Methods |
| **Ole JJohan Jørgensen Lønnum** | NTNU, Marine Technology | Deep Learning Metocean Simulation |
| **Jens Berg Ildstad** | NTNU, Marine Technology | Use of turbulence stimulation on ship models |
| **Even Wollebæk Førrisdal** | NTNU, Marine Technology | Empirical prediction of resistance of fast catamarans |
| **Benjamin Vist Hagen** | NTNU, Marine Technology | Influence of a wavefoil on the wave pattern resistance of a ship |
| **Mario Delgado** | NTNU, Industrial Ecology | Reconciling Big Data on Trade Statistics and Ship Traffic |

## SUMMER INTERSHIP

| MSc students | University, Department | Project |
|---|---|---|
| **Astrid Vamråk Solheim** | NTNU, Marine Technology | Influence of different weather data sources on evaluation of hydrodynamic performance from numerical routing approaches (Gymir). |

# COMMUNICATION AND DISSEMINATION



Photo: Grieg Star

## 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.

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### e-mail newsletters

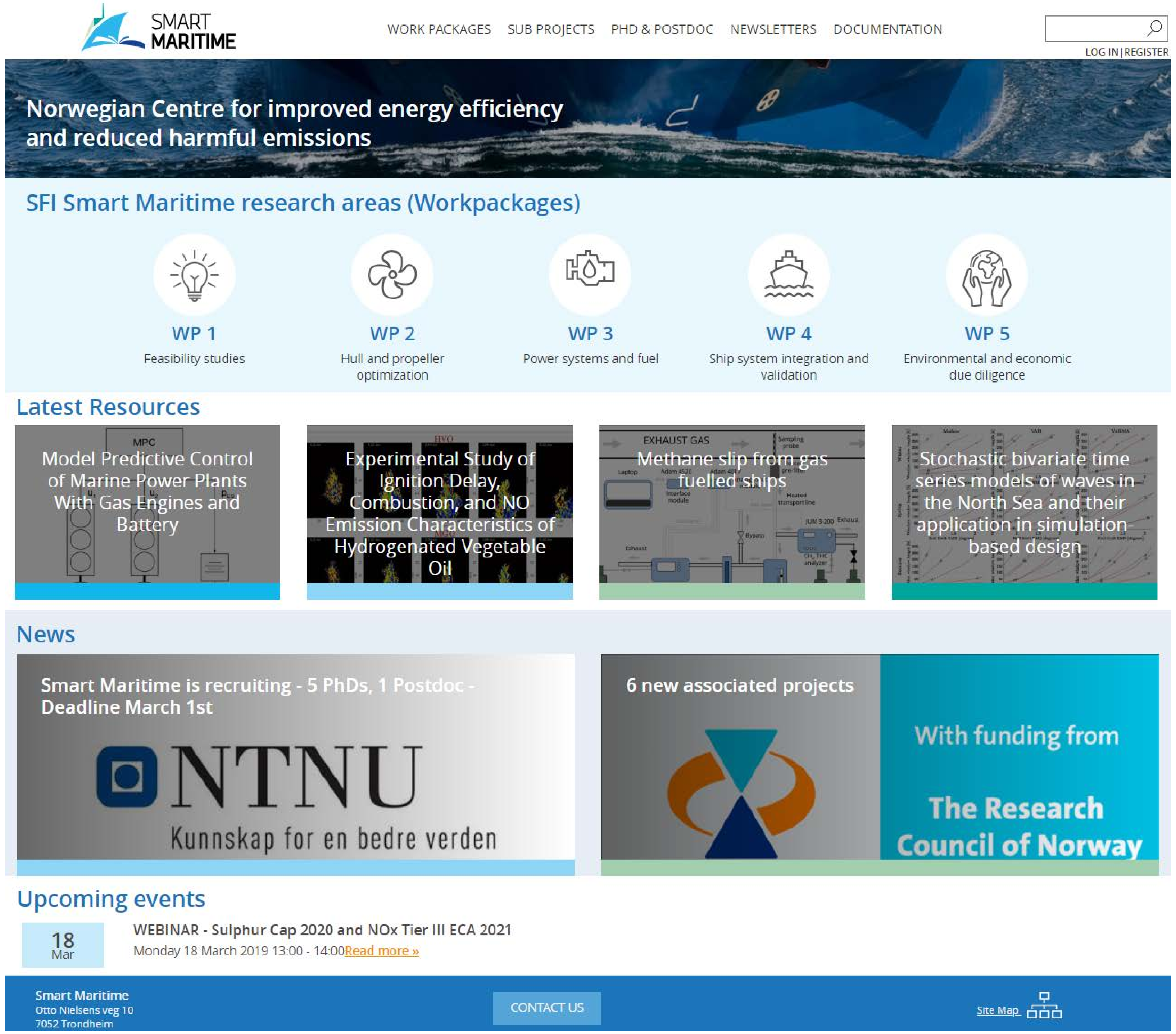
sent to Smart Maritime participants, with information about the research progress, achievements, upcoming events.

### Workshops

Technical workshops and Bi-annual network meetings.

### Webinars

Smart Maritime offers Webinars that contribute to more scientific discussion between research team and industry partners and a wider network.



## PUBLICATIONS AND REPRESENTATIONS

### *Scientific Journal Articles*

LAWRENCE, M. G., SCHÆFER, S., MURI, H., SCOTT, V., OSCHLIES, A., VAUGHAN, N. E., BOUCHER SCHMIDT, H., HAYWOOD, J. M. & SCHEFFRAN, J. R. 2018. Evaluating climate geoengineering proposals in the context of the Paris Agreement temperature goals. *Nature Communications* 2018 ;Volum 9:3734. s. 1-19

LINDSTAD, E. & Bø, T. I. 2018. Potential power setups, fuels and hull designs capable of satisfying future EEDI requirements. *Transportation Research Part D: Transport and Environment,* 63**,** 276-290.

KRIVOPOLIANSKII, V., VALBERG, I., STENERSEN, D., USHAKOV, S. & ’S›Y, V. 2018. Control of the combustion process and emission formation in marine gas engines. *Journal of Marine Science and Technology***,** 1-19.

NIELSEN, J. R. B. & PEDERSEN, E. 2018. A system approach to selective catalytic reduction deNOx monolithic reactor modelling using bond graphs. *Journal of Engineering for the Maritime Environment* (Part M) 2018 (1475-0902)

PERERA, L. P. & MO, B. 2018. Ship Performance and Navigation Data Compression and Communication under Autoencoder System Architecture. *Journal of Ocean Engineering and Science,* 3**,** 133-143.

SANDVIK, E., GUTSCH, M. & ASBJØRNSLETT, B. R. E. 2018c. A simulation-based ship design methodology for evaluating susceptibility to weather-induced delays during marine operations. *Ship Technology Research,* 65**,** 137-152.





## PUBLICATIONS AND REPRESENTATIONS

### *Conference presentation*

ESKELAND, G., LINDSTAD, E. & STRANDENES, S. P. 2018. New source bias: environmental policy risks raising emissions in maritime shipping - SMC-070-2018, *SNAME maritime Convention - 2018*; 2018-10-24/27

LINDSTAD, E. 2018b. Alternative Fuels versus Traditional Fuels in Shipping; *SOME 2018. Ship operations, Management & Economics*; 2018-03-20/21

LINDSTAD, E. 2018. Batteries in Offshore Support vessels; Advantages with focus on Pollution, Climate impact and Economics. WATTS UP conference,; 2018-03-07/08

LINDSTAD, E. 2018. Cleaner Fuels in shipping or are Climate and Cost better off with HFO & Scrubbers. *IMSF - 2018 : International Maritime Statistics Forum*; 2018-04-17/19

SANDVIK, E., ASBJØRNSLETT, B. R. E., STEEN, S. & JOHNSEN, T. A. V. 2018. Estimation of fuel consumption using discrete-event simulation - a validation study. International Marine Design Conference (IMDC); 2018-06-11/14

### *Conference paper – article in conference proceedings*

LINDSTAD, E., Bø, T. I. & ESKELAND, G. 2018. Reducing GHG emissions in Shipping - measures and options. *Marine Design XIII(2018).* Taylor & Francis ISBN 978-1-138-54187-0. p. 923-930

SANDVIK, E., ASBJØRNSLETT, B. R. E., STEEN, S. & JOHNSEN, T. A. V. 2018b. Estimation of fuel consumption using discrete-event simulation - a validation study. *Marine Design XIII, Volume 2: Proceedings of the 13th International Marine Design Conference (IMDC 2018), June 10-14, 2018, Helsinki, Finland.* CRC Press ISBN 9781138340763


## PUBLICATIONS AND REPRESENTATIONS

### *Lecture & Presentation at seminars and workshops*

BØ, T. I. 2018. Potential for GHG reduction from shipping. *Energy efficient and environment–friendly shipping*; 2018-05-23

BØ, T. I. 2018. Summary of Postdoctoral work. Webinar on Hybrid Propulsion - *Smart Maritime*; 2018-03-13

LINDSTAD, E. 2018. Advantages of Hybridisation with respect to LCA, EEDI, EEOI. *CIMAC 2018 Årsmøte*; 2018-01-24

LINDSTAD, E. 2018. Reducing fuel consumption, emissions and GHG impact of maritime transport; Measures and Options. *OCIMF MTSC 37 / CO2 Task Force*; 2018-09-18/20

MURI, H. 2018. Dare to be aware: Alternative ways to save us from global warming? *Klimadagen 2018*; 2018-03-14

MURI, H. 2018. Earth system modelling practices and conventions. *SRMGI-TWAS DECIMALS workshop*; 2018-11-13 - 2018-11-15

MURI, H. 2018. Forklaring på karbonbudsjett, negative utslipp og mulig betydning av ulike utslippsbaner. *FNs klimapanels rapport om 1,5 graders global oppvarming seminar* 2018, 2018-09-27

MURI, H. 2018. Hovedfunn fra IPCCs spesialrapport om 1.5C oppvarming. *SFI Smart Maritime Network meeting* 2018, 2018-10-16

MURI, H. 2018. The relevance of short lived climate forcers in the transport sector. The relevance of short lived climate forcers in the transport sector. *The future transport system,* 2018-03-02

MURI, H. 2018. Recent developments of the MariTEAM model. *NTNU seminar*, 2018-10-26

RIALLAND, A. I. 2018. SFI Smart Maritime, Centre organisation and strategy and the Norwegian Research Council's SFI scheme. *Energy efficient and environment–friendly shipping*; 2018-05-23.

### *Media contribution*

LINDSTAD, E. & JONATHAN, R. 2018. Slow steaming not necessarily a sulphur cap savior. *Slow steaming not necessarily a sulphur cap savior.* Fairplay Magazine, Vol 391, Issue 6940, page 24- 26 [Journal] 2018-09-13

LINDSTAD, E. & ROBINS, J. 2018. Majority of vessels could see 2020 fuel bills double. *Majority of vessels could see 2020 fuel bills double.* Fairplay Magazine [Internet] 2018-09-28

MURI, H. 2018. Alternativ til utslippskutt monner ikke. *Dagens næringsliv.*

MURI, H. 2018. Bare kutt i utslipp monner Iikke. *Dagens næringsliv* 2018

MURI, H. 2018. Brent jord III. Dagbladet [Internet] 2018-10-07

MURI, H. 2018. FNs siste klimarapport: Klimautslipp må halveres innen 2030. Dagens Perspektiv [Avis] 2018-10-08

MURI, H. 2018. Klimaarbeid på norsk. Nationen [Internett] 2018-10-09

MURI, H. 2018. Når tipper det over? Energi og Klima [Internett] 2018-10-29

### *Reports*

ALTERSKJÆR, SVERRE ANDERS. 2018. Model tests campaign 2018 - Added resistance amplitude dependency. Smart Maritime Presentation

HOFF, JAN. 2018. 3D Seakeeping Calculations of a Body with Forward Speed in Waves. SINTEF Ocean Report.

LINDSTAD, E. 2018. *2020 Sulphur Cap options, Executive summary*. Smart Maritime memo.

## STATEMENT OF ACCOUNTS 2018

| | Funding | | Cost | |
|---|---|---|---|---|
| Research council | 14 073 | (50 %) | | |
| The Host Institution (SINTEF ocean) | 168 | (0,6 %) | 10 050 | (36 %) |
| Research Partner (NTNU) | 4 363 | (15,7 %) | 9 560 | (35 %) |
| Industry partners | 9 078 | (33,7 %) | 7 736 | (28 %) |
| Equipment | | | 336 | (1 %) |
| Total NOK '000 | 27 682 | | 27 682 | |

Photo: Sjøfartsdirektoratet.

SMART MARITIME

## SMART MARITIME IN BRIEF

- Norwegian centre for improved energy efficiency and reduced harmful emissions from the maritime sector
- Centre for research-based innovation (SFI) granted by the research council (SFI-III)
- Main goals:
  - Improve energy efficiency
  - Reduce harmful emissions
  - Strengthen the competitiveness of the Norwegian maritime industry
- 22 research scientists
- 60 industry professionals
- 10 laboratories
- Duration: 2015–2023
- Budget: 24 mnok/year
- Financing:
  - 50 % research council of Norway
  - 25 % industry partners
  - 25 % research partners

sfi Senter for forskningsdrevet innovasjon

Norges forskningsråd

www.forskningsradet.no



Hurtigruten – Hybrid Propulsion. Photo: Rolls-Royce plc.

Senter for forskningsdrevet innovasjon

SMART MARITIME

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