DNV·GL

MARITIME

# Complex ship energy systems modelling, simulation and optimization

## Applications experience in various ship types

MOSES 2017 Workshop

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23 October 2017

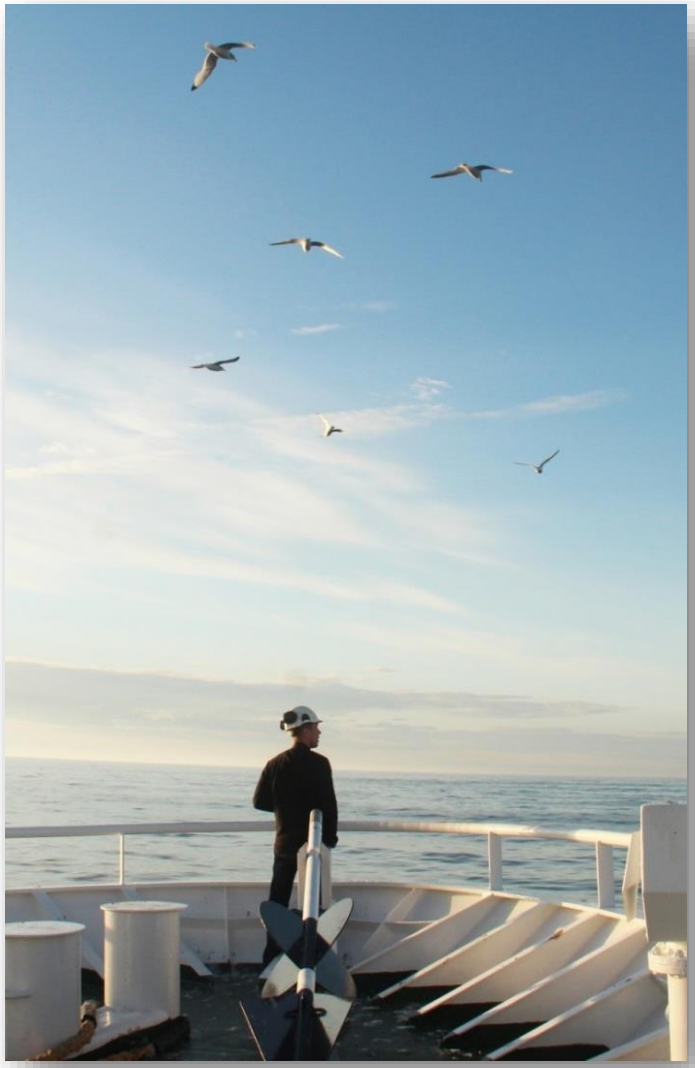
Maritime R&D and Advisory, Piraeus

# Introduction:

# Ship Energy systems & Need for Modelling and Simulation

# Ship Energy Systems: Features



- Isolated operation: resource constraints.
- Safe, redundant and uninterrupted operation.
- Time varying mission profiles.
- Environmental performance & compliance.
- Need for fuel economy.
- Commercial pressure.
- Complexity increases.
- Truly integrated systems.

- **Objective: Competitive Assets**

***Build and operate better ships in terms of safety, efficiency, costs, and environmental footprint.***

# Key driver: Digitalisation in Shipping and Maritime Operations


- Need for integration: vendors, service providers, designers, yards, operators
- Leverage of (big) data
- Systems Engineering: *the sum is more than its parts*
- Holistic approaches
- Improved analytics and quantification.

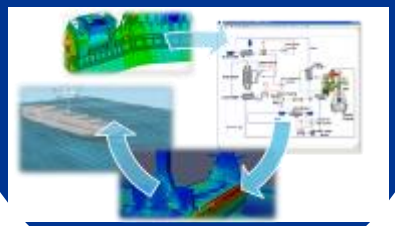
# Ship systems: the way forward

Increased Systems and Operation Complexity

Data & Connectivity

+

Modelling & Simulation



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Quantification

Useful insights implemented in practice

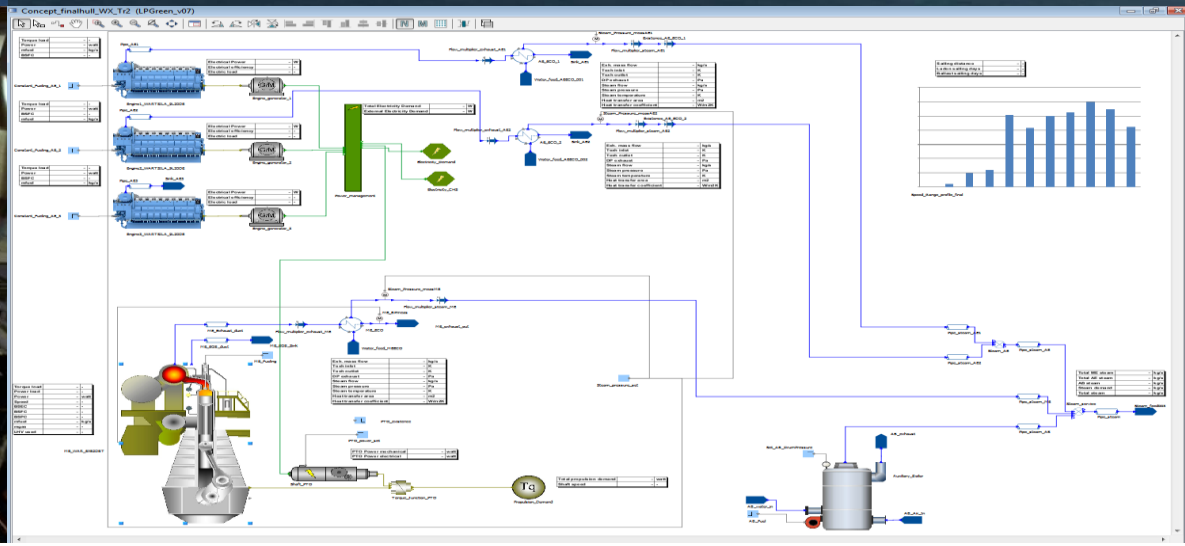
Actionable Knowledge!

# Modelling Simulation and Optimisation of Ship Energy Systems

@ DNV GL: COSSMOS

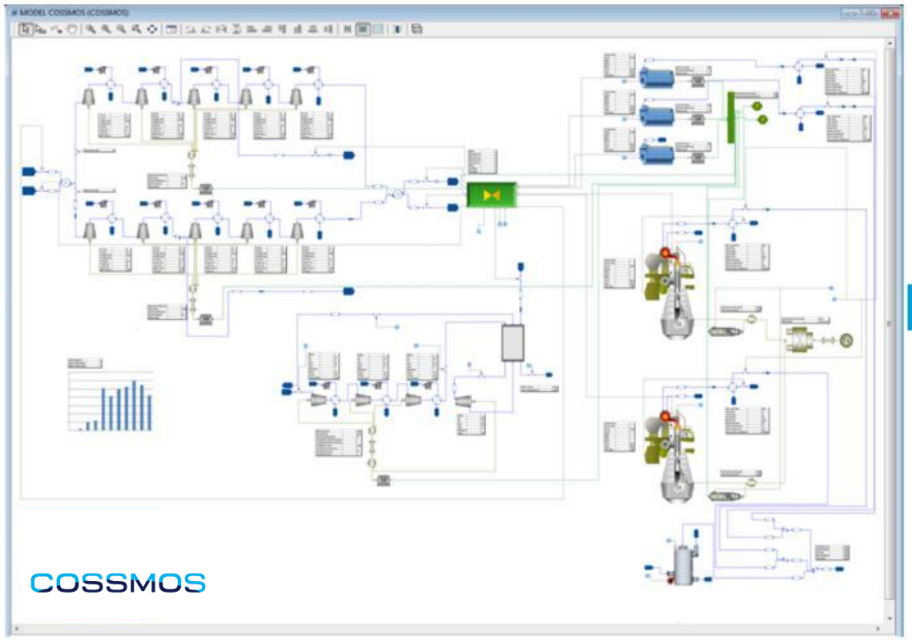
# Modelling & simulation of vessels and systems: building Digital Twins & Virtual Engine Rooms

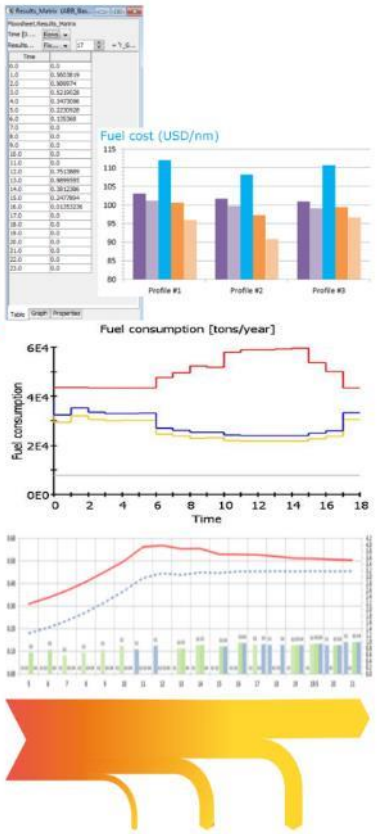
COSSMOS

# Building virtual integrated ship machinery systems

COSSMOS


GUI and modelling platform

Library of machinery component models

Steady-state / dynamic simulations, optimisation…

# COSSMOS current service examples

- COSSMOS New Buildings

  Techno-economic comparison of full machinery / propulsion configuration alternatives

  - Engines
  - Auxiliaries
  - Cargo handling systems
  - Waste heat recovery systems solutions
  - Economizers
  - Shaft generators
  - Steam/power turbine systems
  - VOC recovery systems optimal sizing
  - Scrubbers estimation of additional fuel consumption
  - Diesel electric propulsion
  - Hybrid battery propulsion systems.

Average:
10 projects /year

# COSSMOS current service examples

Average:
20+ ships /year

- COSSMOS Fleet in Service
  - Advanced performance monitoring & optimisation
  - Energy audit coupled with advanced thermodynamics.
  - Energy efficiency assessment of power management strategies in Diesel-electric vessels and improvement suggestions.
  - Trouble-shooting and root cause analysis.

- COSSMOS Retrofit & Conversion
  - Techno-economic comparison of solutions and optimisation.
  - Gas carriers reliquefaction plants: techno-economic comparison of vendors options and optimal sizing.
  - Waste heat recovery solutions e.g. economizers, etc.
  - Scrubbers retrofit techno-economic evaluation
  - Battery-hybrid systems.

# Applications in New Buildings, Retrofits & Concept Designs

# NB machinery configurations for modern LNGCs

## New ships and projects

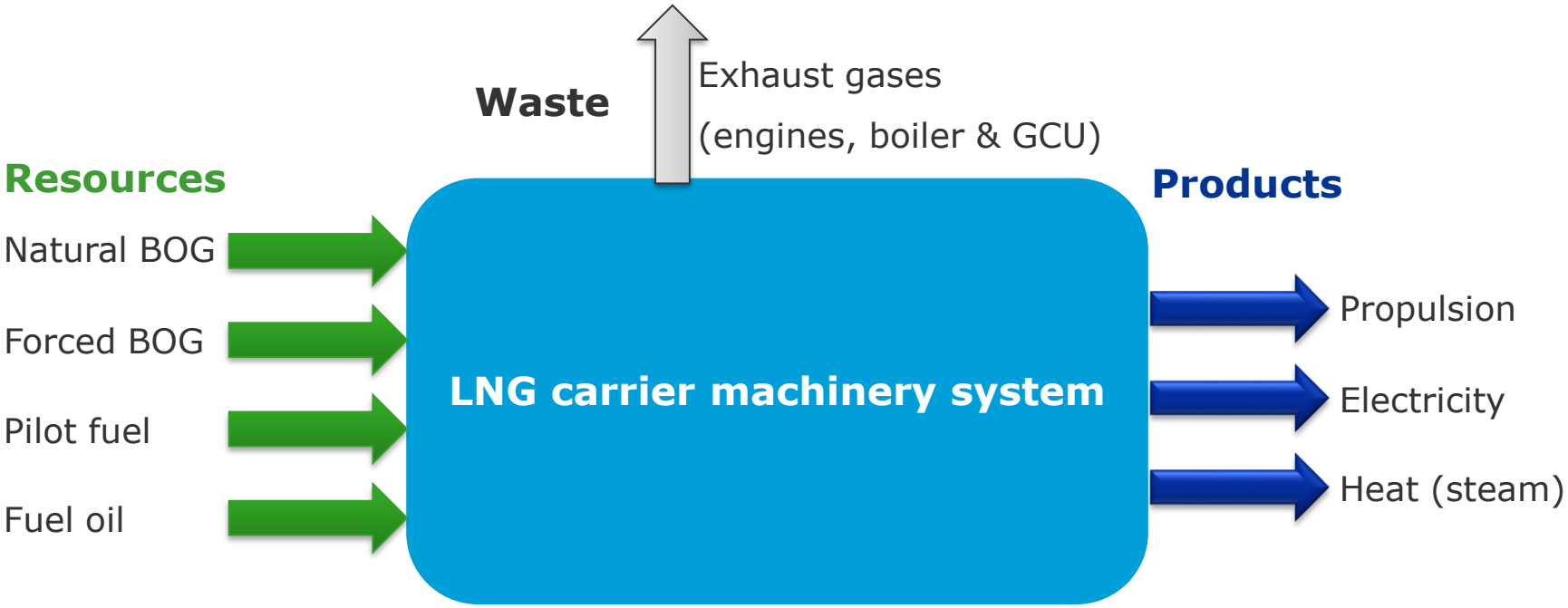
What is the best integrated machinery propulsion configuration for the vessel and project we want to build or bid?

i.e. what is the configuration that maximises the expected performance of our investment?

Use COSSMOS to compare in techno-economics alternative machinery / propulsion configurations to support improved decision making

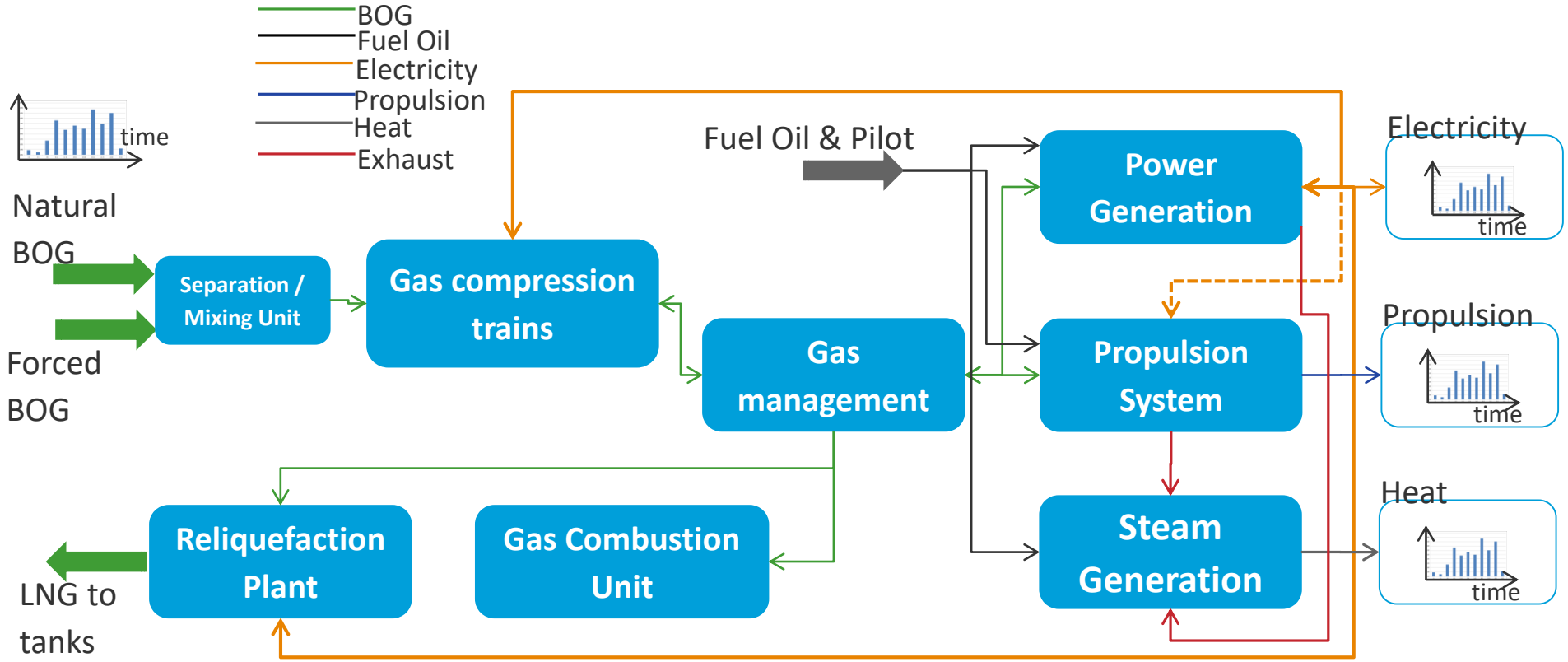
General Ship Applicability

# The LNG carrier integrated marine energy system



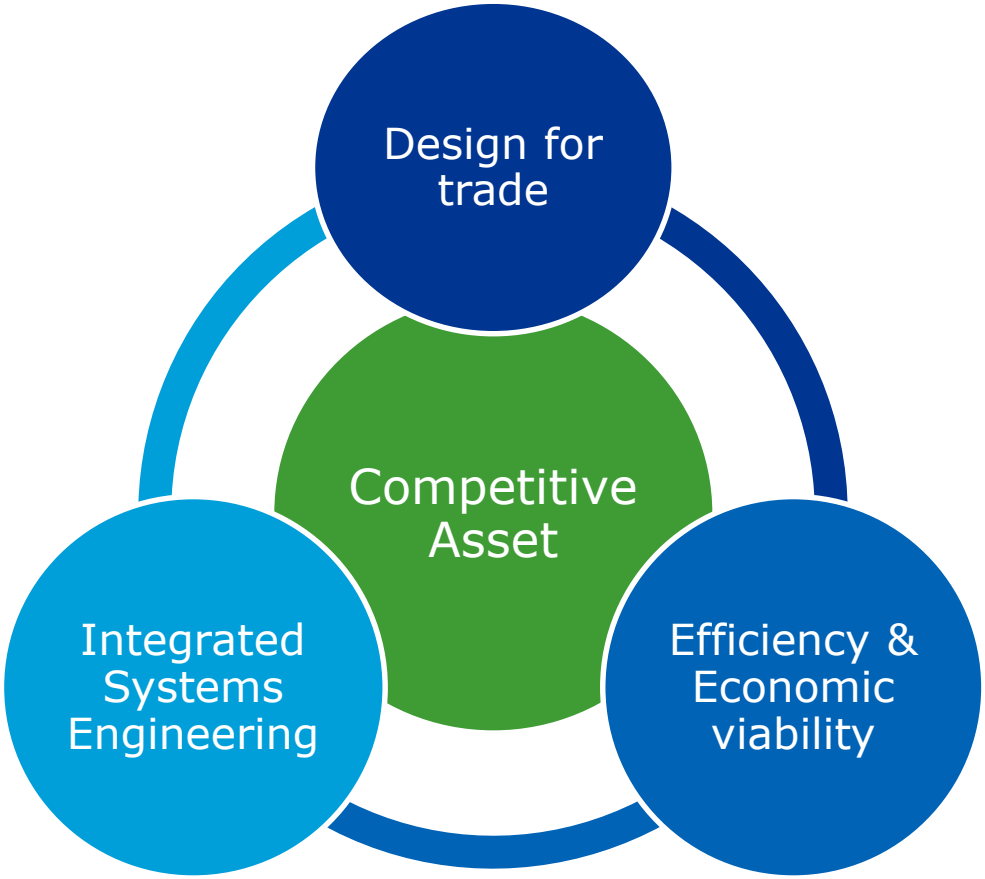

- *Multi-fuel / multi-product energy system*
- *LNG evaporation: natural Boil-Off Gas variable during voyage (**natural BOG**)*
- *Forced LNG vaporisation when natural is not enough (**forced BOG**)*
- *Gas combustion of surplus BOG … or*
- ***Reliquefaction** plant onboard*

# The LNG carrier integrated energy system – decomposed



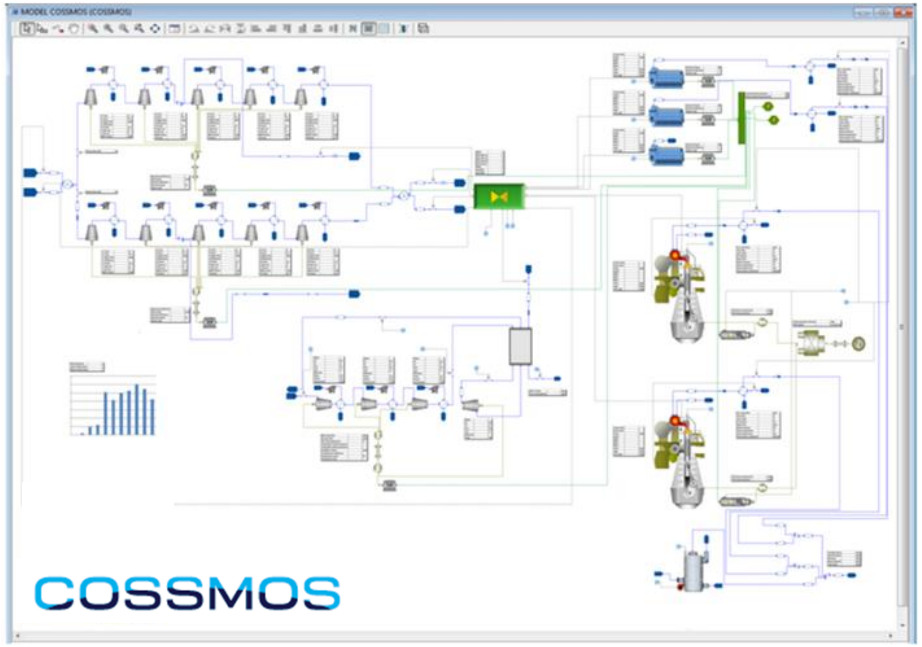

- Tightly integrated system (feedback loops)
- BOG composition and re-liquefaction affect gas quality to engines
- Time varying operational profile

# Adopt novel design approaches

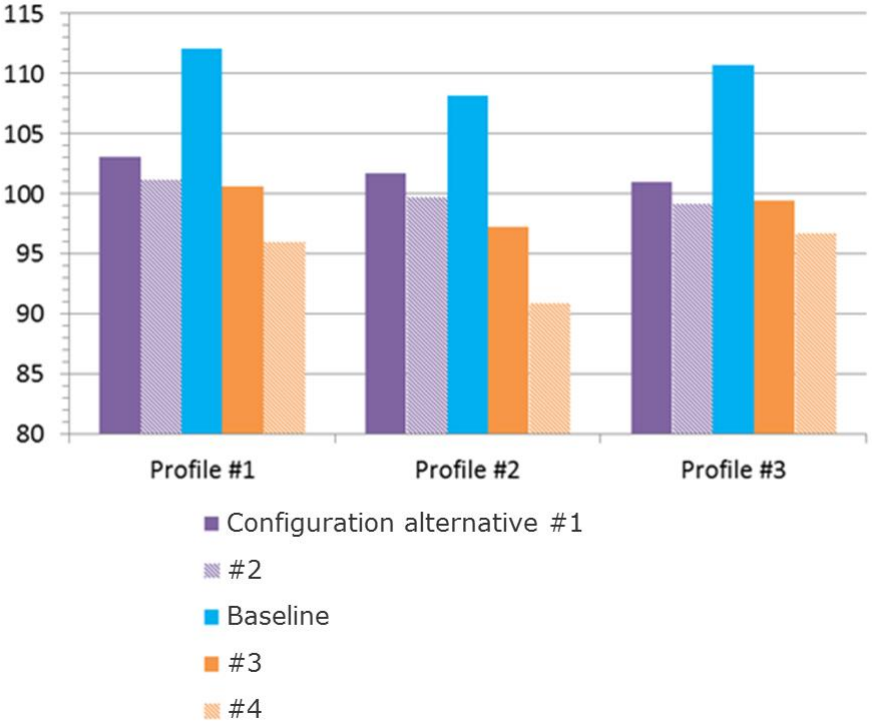


# Techno-economic comparison of alternative configurations in new buildings and retrofits

Build COSSMOS models, the ship's Digital Twin to sail virtual




Specific fuel cost (USD/nm)

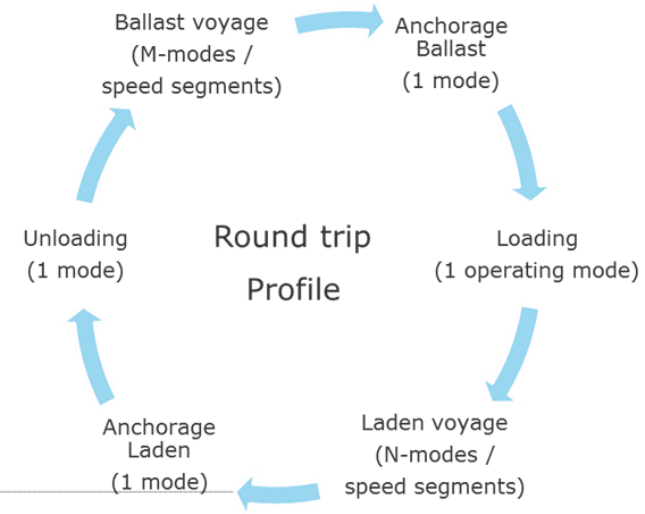


# Overall fuel consumption per mode of operation

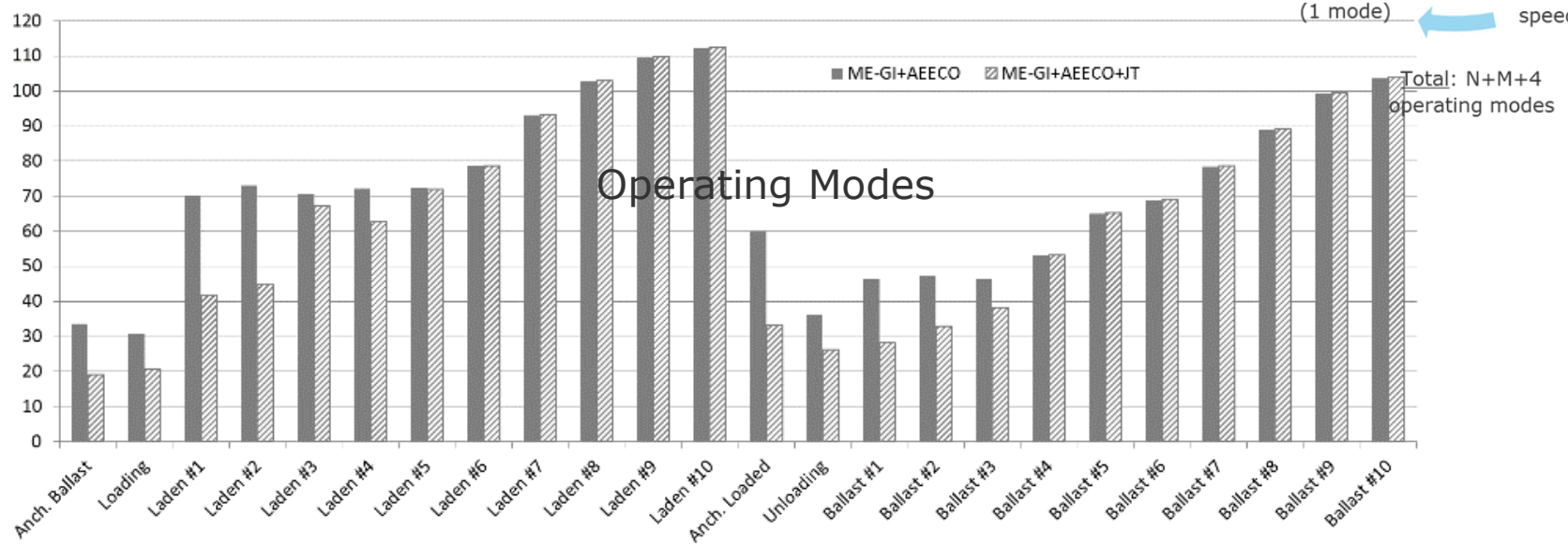
**Trade route**

**+**

**Operating Profile**



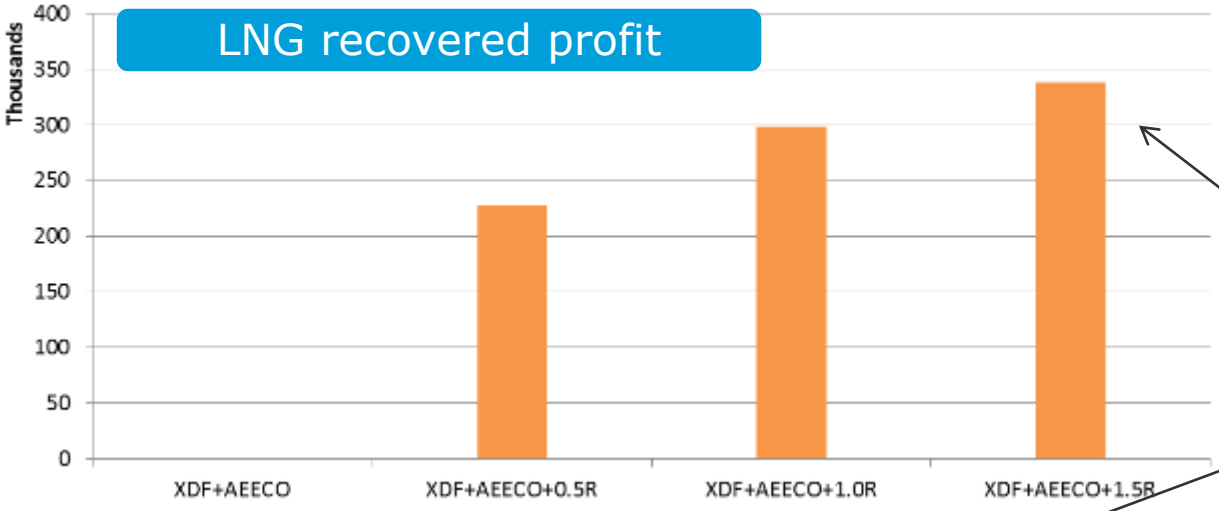

Equivalent HFO, tonnes / day

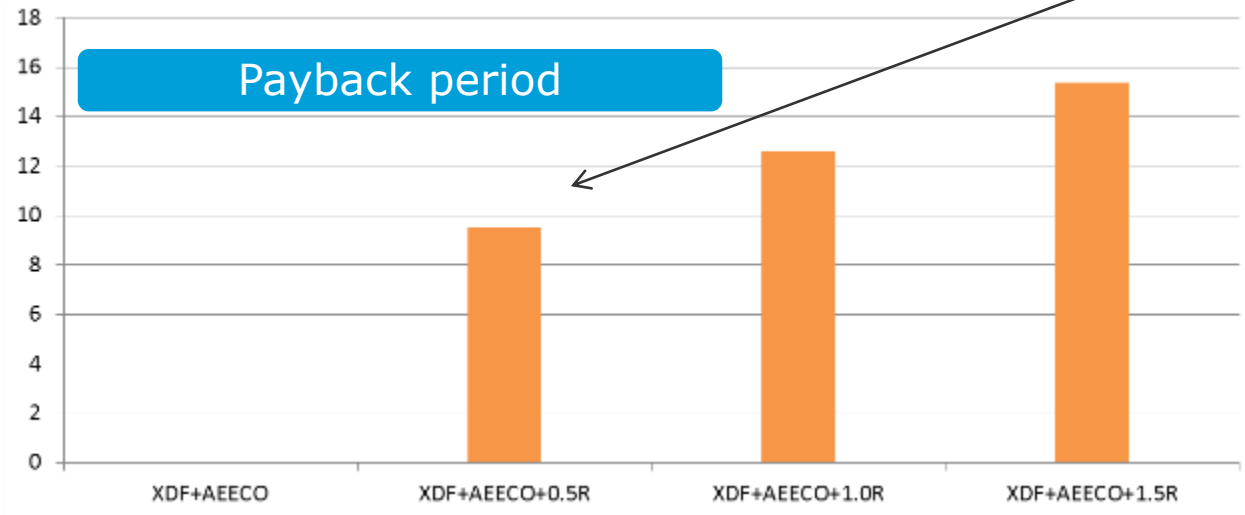



Total: N+M+4 operating modes

# Techno-economic appraisal & Payback time calculations
# Reliquefaction systems in LNGC NB

kUSD / year



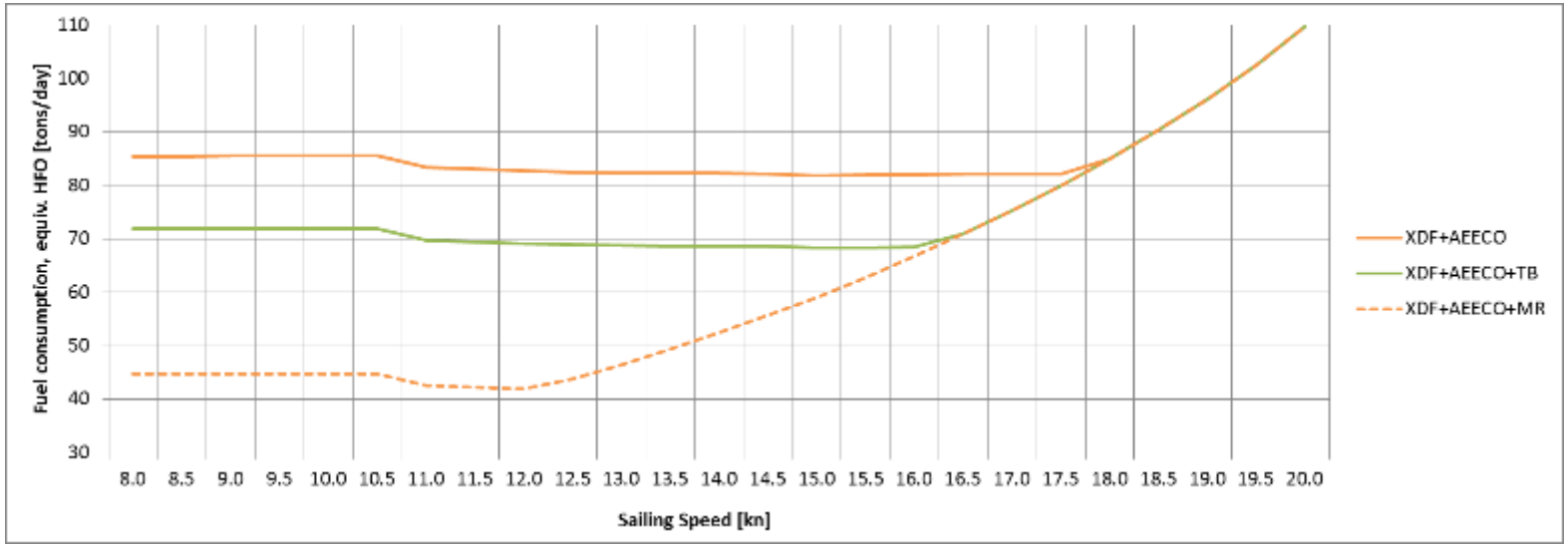



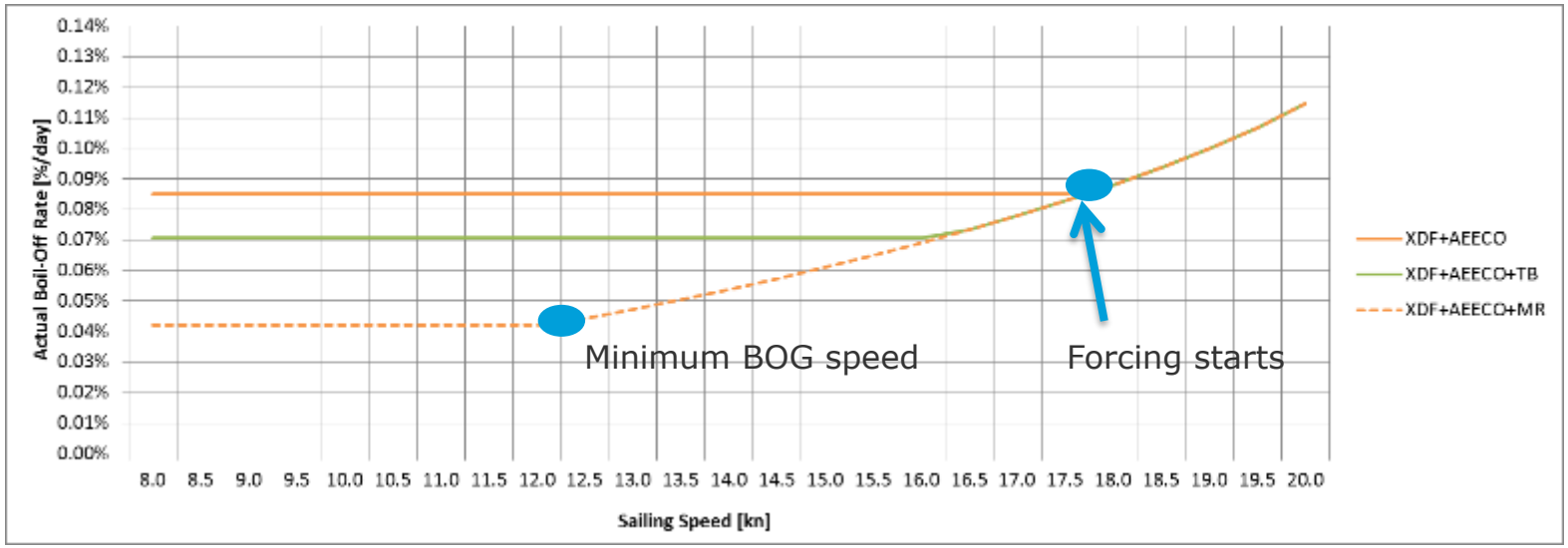

Higher efficiency

But…

More economically attractive

# Overall Fuel Consumption and actual Boil-off Rates, entire speed range simulations



# Concept Designs

## LPG carriers: design and operation

# Integrated system approaches

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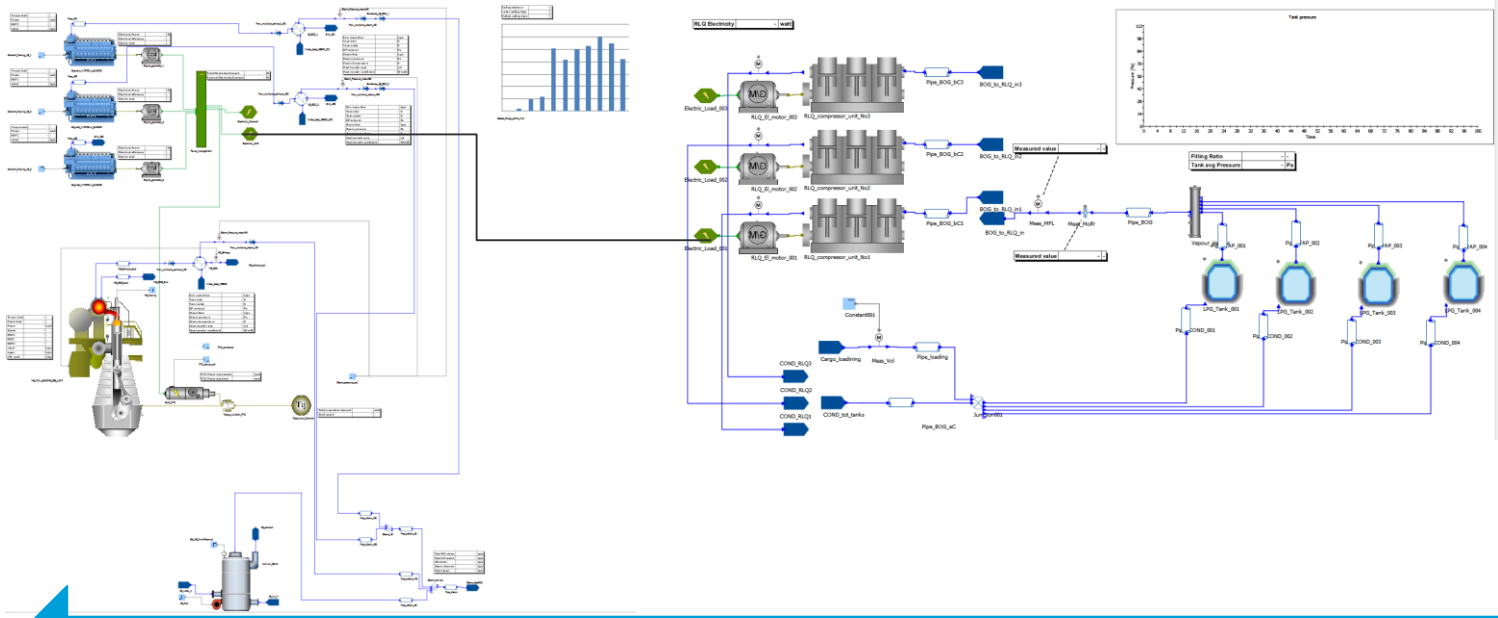
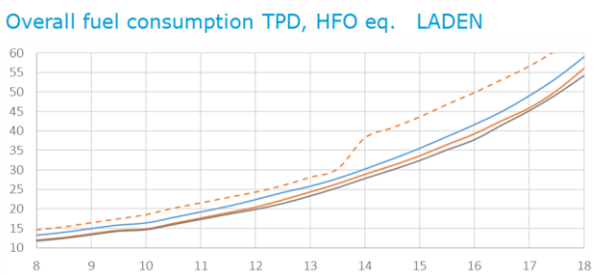


Cargo tanks

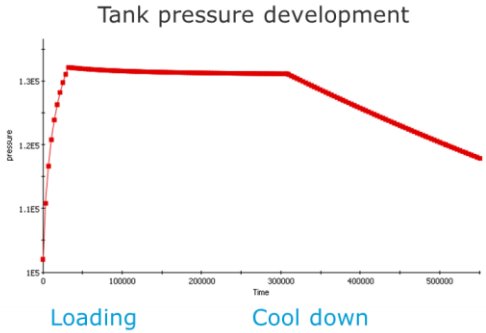
Integrated machinery: propulsion + power generation + cargo handling

Machinery & energy recovery




Cargo ops:

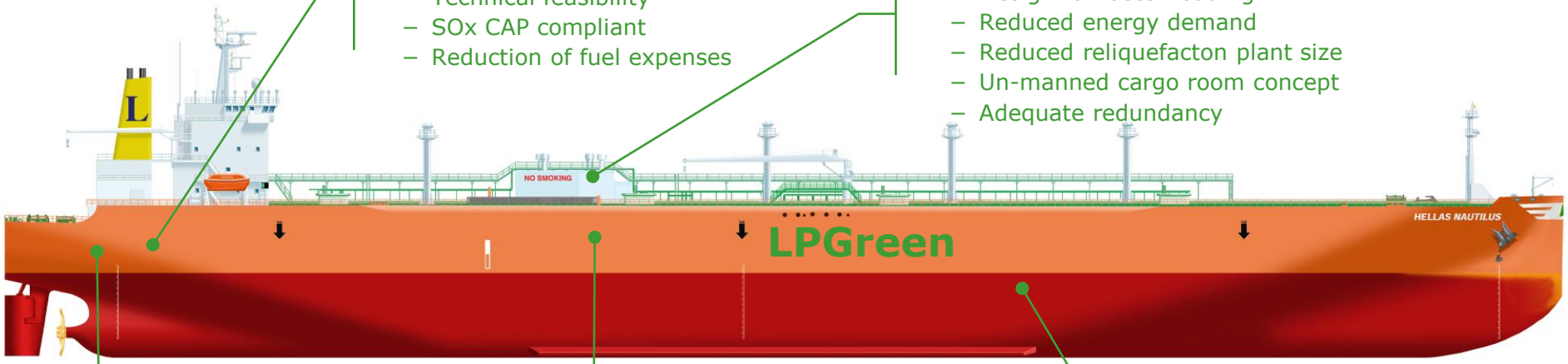
Loading, Pressure keeping



# LPGreen concept VLGC: Final concept appraisal

LPG as fuel
- Technical feasibility
- SOx CAP compliant
- Reduction of fuel expenses

Cargo handling:
- Design for faster loading
- Reduced energy demand
- Reduced reliquefacton plant size
- Un-manned cargo room concept
- Adequate redundancy




Machinery configurations:
- Improved overall efficiency
- Conventional and LPG as a fuel
- Energy recovery technologies
- IMO Tier III compliant

Tank design
- New IGC code / IMO Tier 3 compliant
- Higher tank design pressure

Hull and propeller
- Optimised for both calm water and waves
- Multiple speeds and loading conditions
- Energy saving devices

**6-9%**
**Overall Efficiency Improvement**

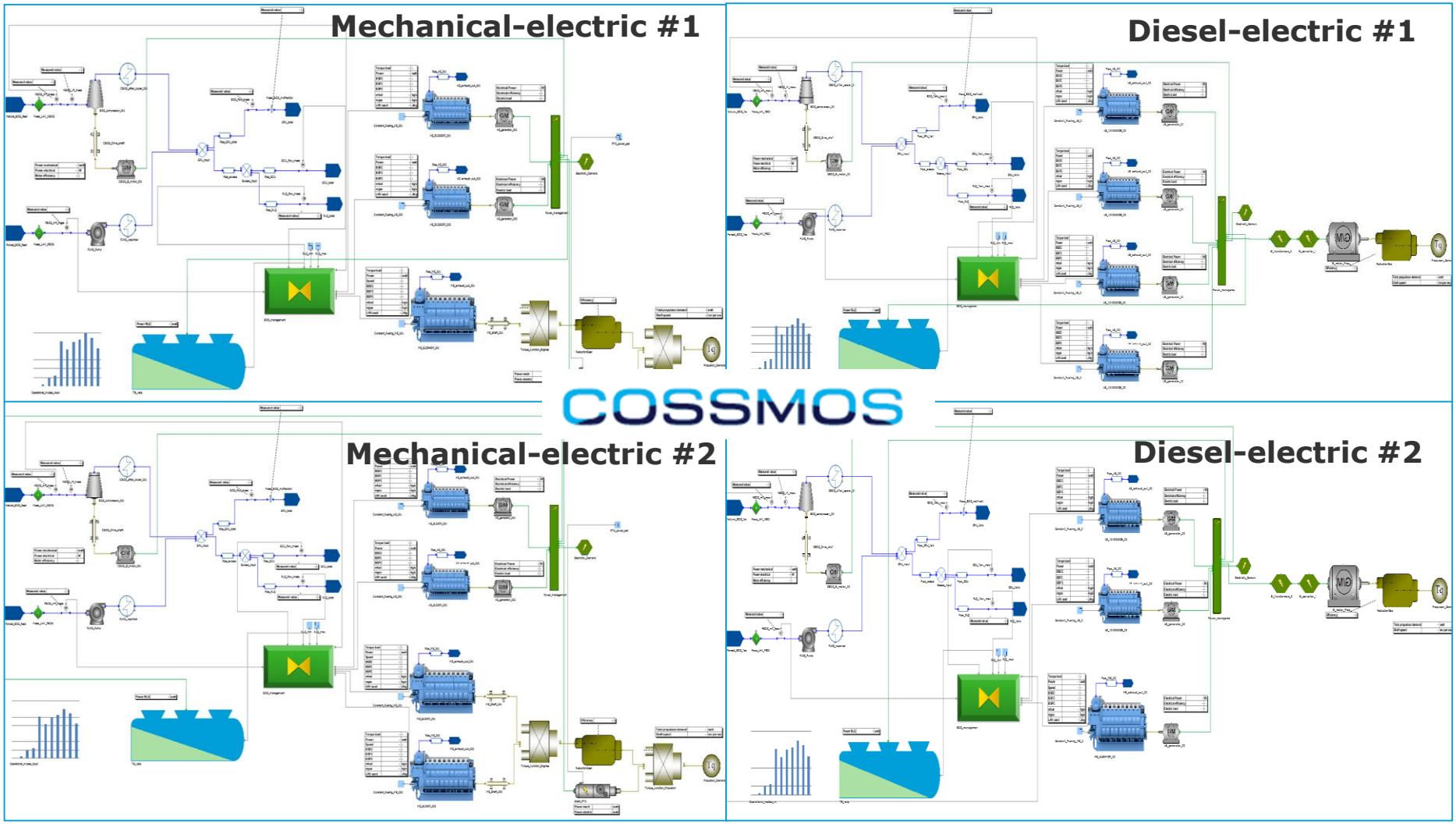
**LPG**
**as fuel,**
**technically feasible**

Up to
**30%**
**Reduction of Fuel Expenses**

Up to
**30%**
**Reduction of Loading time**

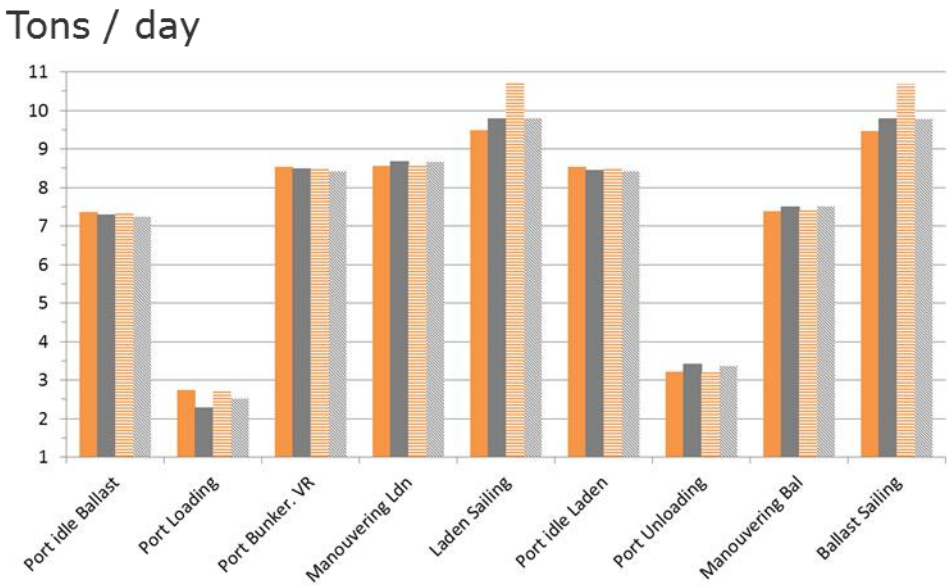
# NB machinery configurations for a small-scale LNGC, 7.5k m3

# Analysis of different machinery options for various operating profiles

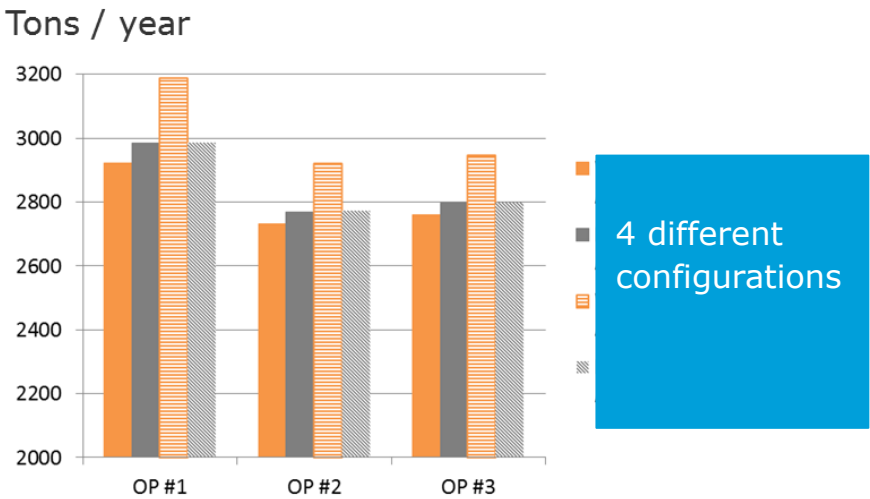


# Assessing the fuel consumption of the various configuration alternatives

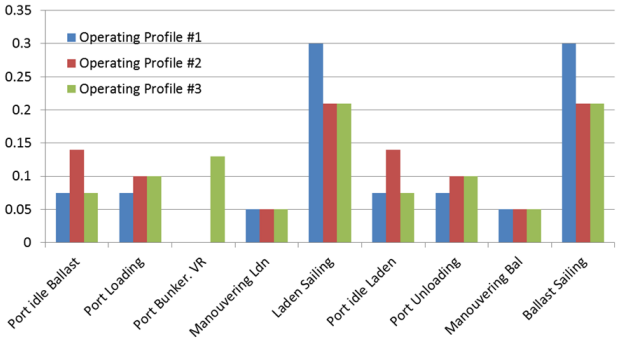
## Fuel consumption per operating mode and configuration




## Annual fuel OPEX under different scenarios



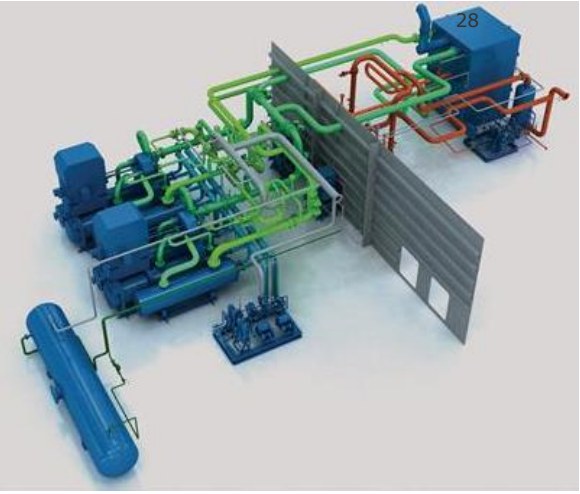

3 operating profiles considered:




**Fast evaluation of alternatives: total project support <5 days !!!**

# Reliquefaction plants: NB and Retrofitting of existing LNGCs

# Reliquefaction systems assessment



## COSSMOS techno-economic studies by DNVGL

determining reliquefaction
systems suitability to Owner and market needs

## Applications:

- Retrofitting on existing vessels of various technologies
- New buildings according to charterers requirements

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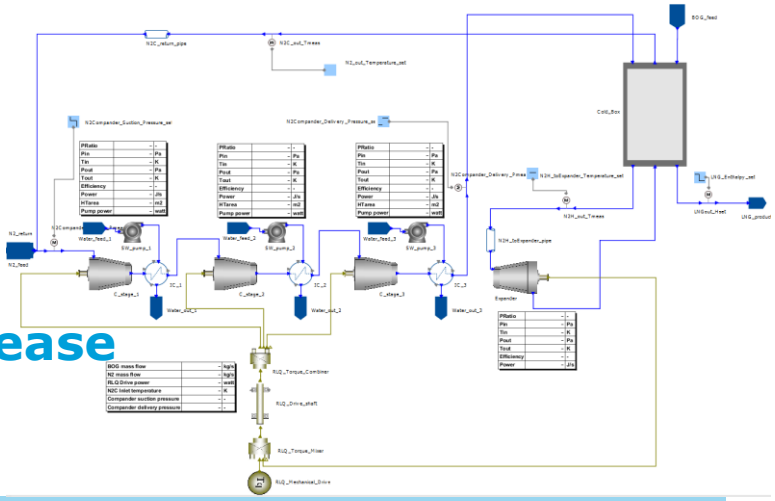
## Systems under consideration (recent projects):

- Nitrogen-loop, inverse Brayton cycle
- Mixed refrigerants (MR) cycle
- Joule Thomson Valve effect cycle



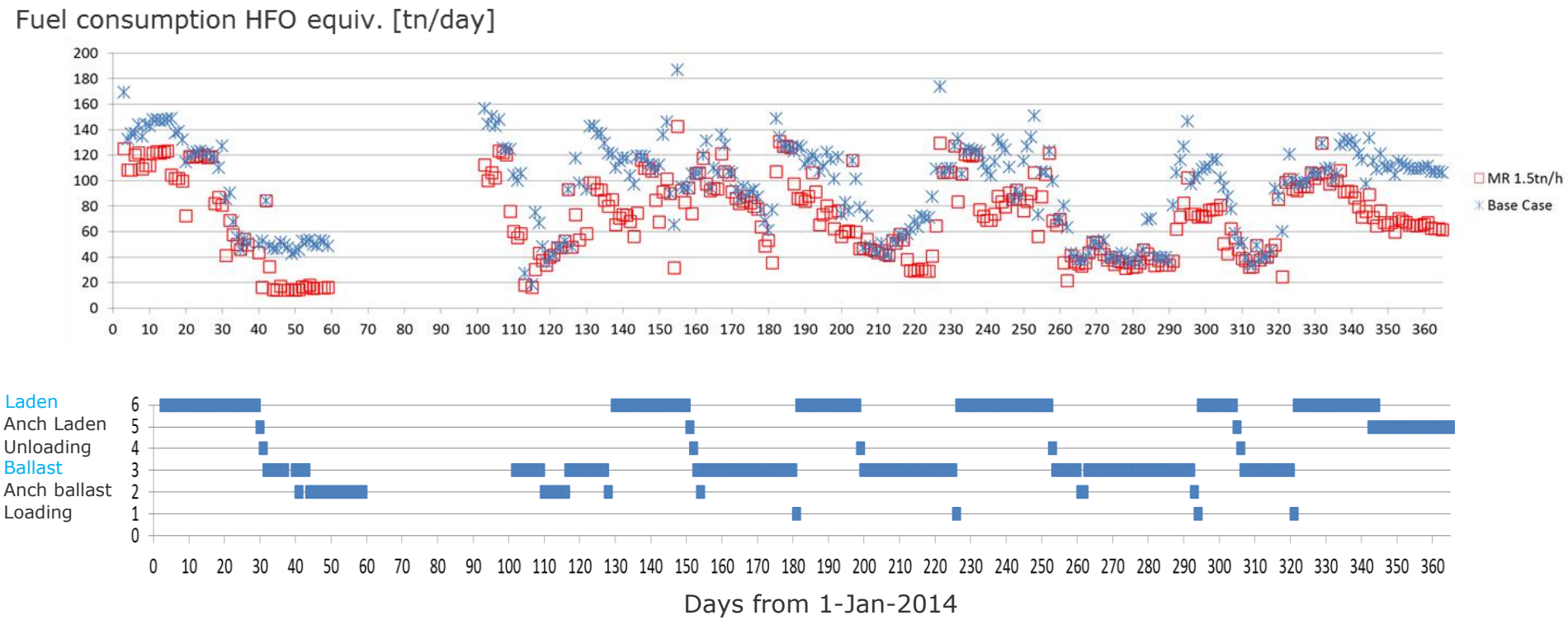
## Leverage ship / operational data to increase value of analysis

# Reliquefaction virtual retrofitting based on real operational data

## COSSMOS simulation for a year of sailing, historic data

**Blue**: Vessel as is – without reliquefaction

**Red**: Vessel with MR reliquefaction 1.5tn/h



# Reliquefaction virtual retrofitting based on real operational data

## Based on voyage / noon reports:

- 5700 tons / year, Reliquefied BOG quantity
- 1.35 mil. USD reliquefied BOG value (@ 5 $/mmBTU)
- X% reduction of GCU usage
- Y% reduction of annual fuel consumption
- 3.6 years, simple payback period

**Decision to retrofit gotten!**

**Benefits**:

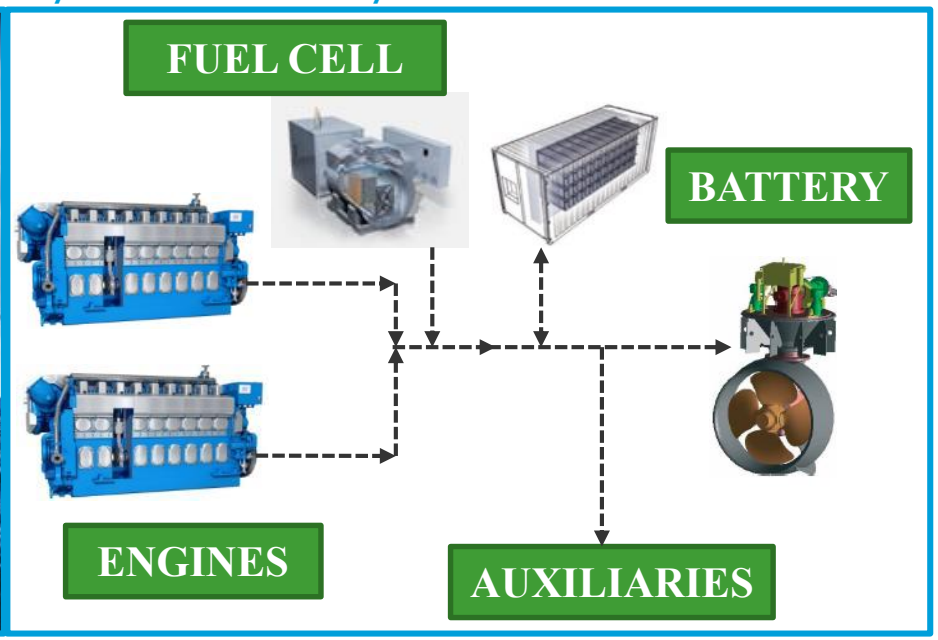
- Increased attractiveness of existing vessels
- Lifetime / charter party extensions
- Trade route / cargo flexibility
- Cost-effectiveness / increased competitiveness

# Battery Hybrids NB or Retrofits

# Hybrid-electric propulsion assessment case

## Viking Lady OSV


## Hybrid-electric systems




On-board measurements

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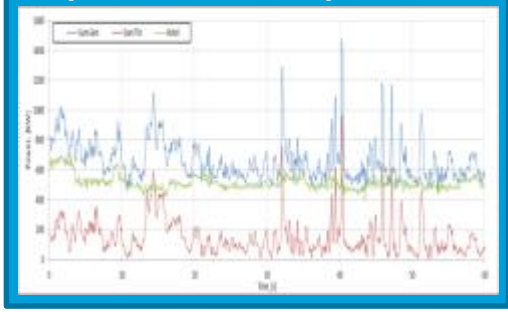
→

Optimal power management

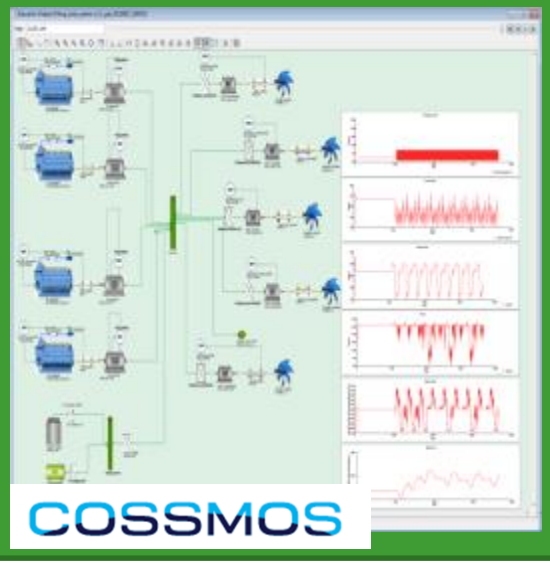
# *Example*
# Use of modelling and simulation techniques to derive the best power management strategy

## Measurements of operational profile

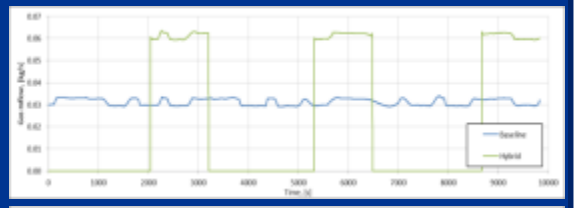


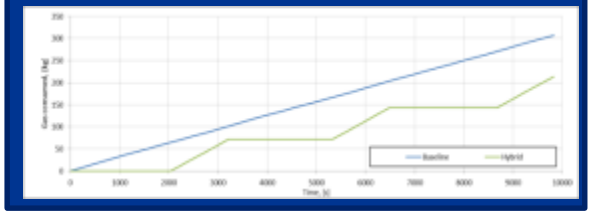
## Proposed power management strategies

## Modelling of different control strategies

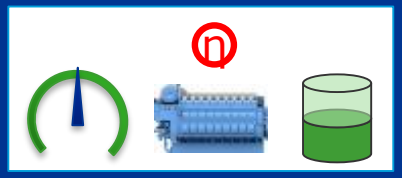


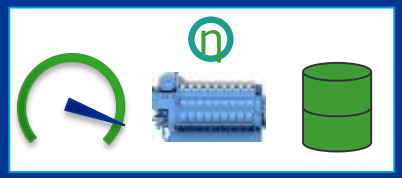

## Quantification of fuel savings





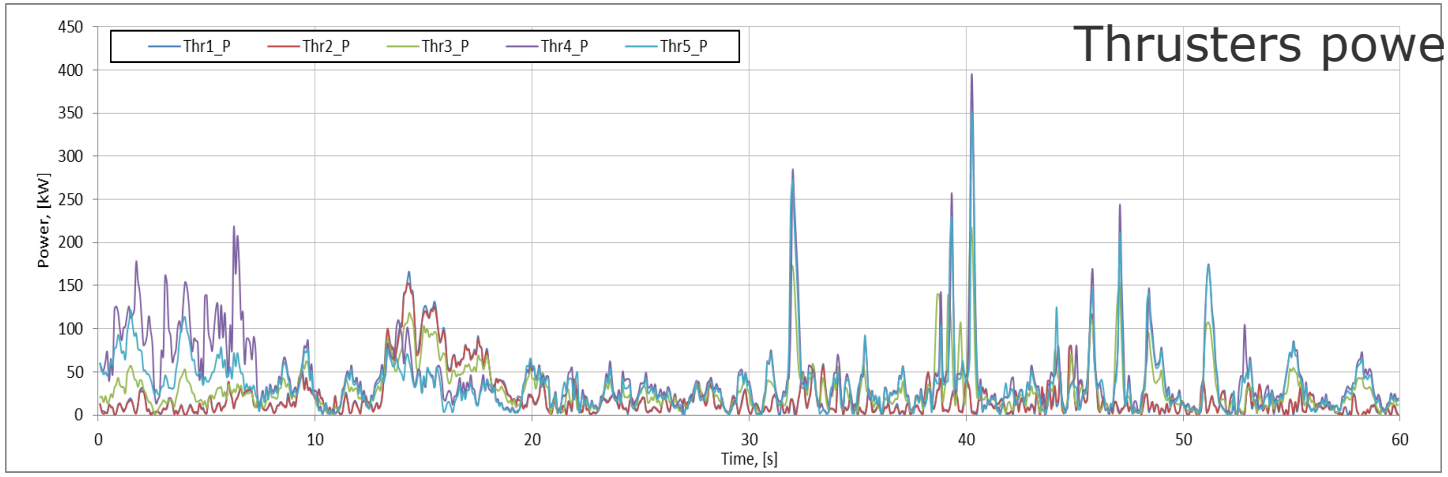
## Comparison of alternatives

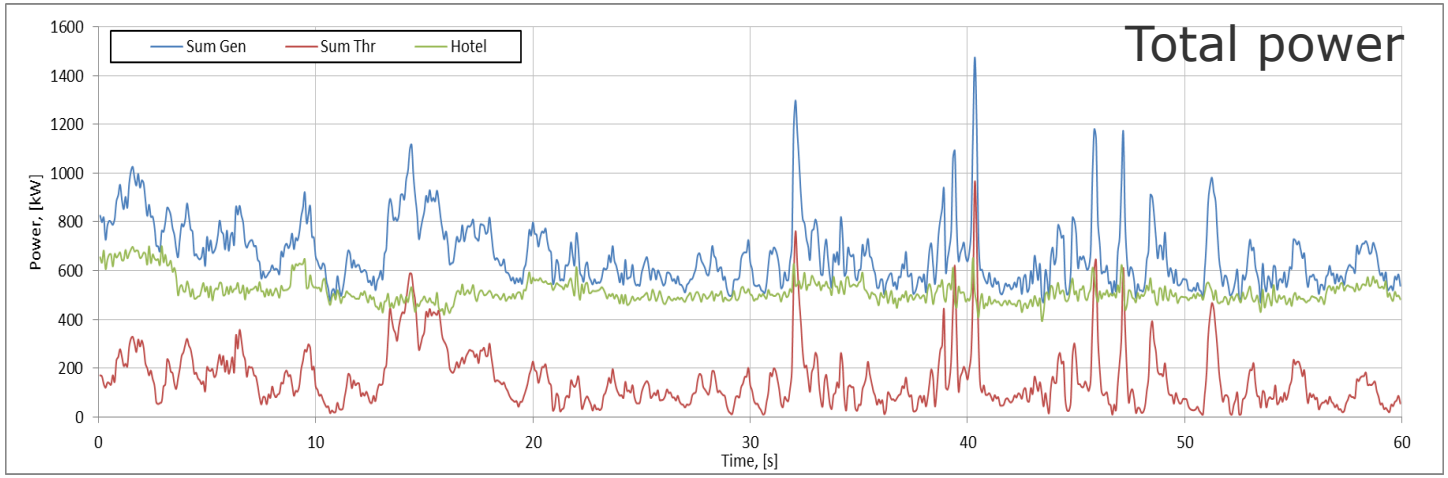




# DP mode : measured profile

→ Used data from the measurements to set-up simulations




<u>Scenario</u>
DP- mode
(average load)

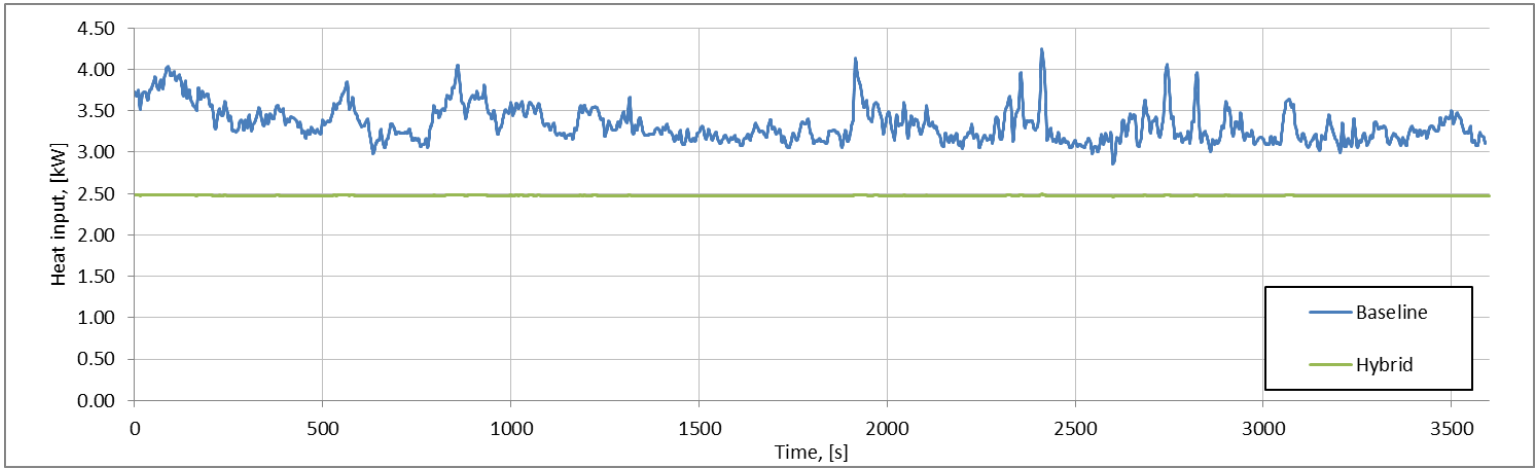
Avg. power:0.8 MW

7 May 2012
10:00-11:00

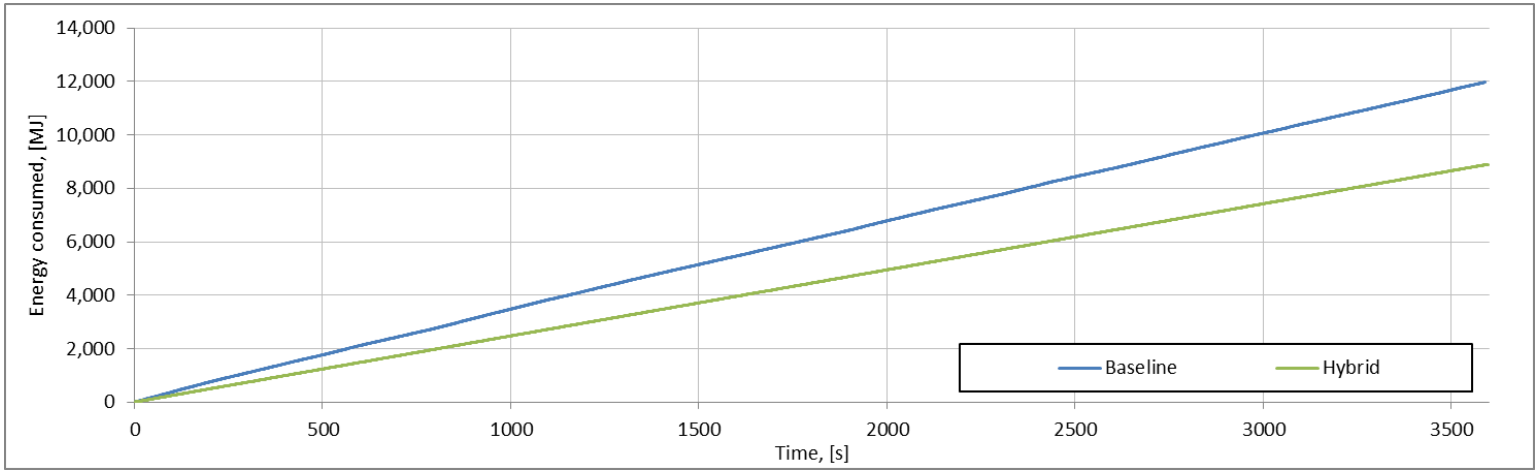
Exact operational conditions never o be repeated !!!

# DP mode : Peak-shaving strategy fuel consumption

## Instantaneous fuel consumption




## Cumulative fuel consumption



# Viking Lady operational modes energy cost

| Energy cost MJ/kWh | | | |
|---|---|---|---|
| Operational mode | Baseline | Optimal | Difference |
| DP Low | 11.84 | 8.73 | -26.26% |
| DP High | 10.21 | - | - |
| Transit 12kn | 7.99 | - | - |
| Transit 9kn* | 10.64 | 7.99 | -25% |
| Transit 6kn | 8.89 | - | - |
| Harbour | 11.89 | 8.99 | -24.40% |
| Stand-by | 11.23 | 8.79 | -21.74% |

# Applications in Ships in Operation

# Optimum Power management Strategies

# DFDE LNGCs in operation

- Is there potential for efficiency gains through power management optimisation for DFDE LNGCs in operation.
- How can we assess performance using COSSMOS?
- Study:
  - Testing of proposed PMS via simulations on historical operational data of a given ship in operation
  - On board implementation from ship-owner in collaboration with DNV GL.

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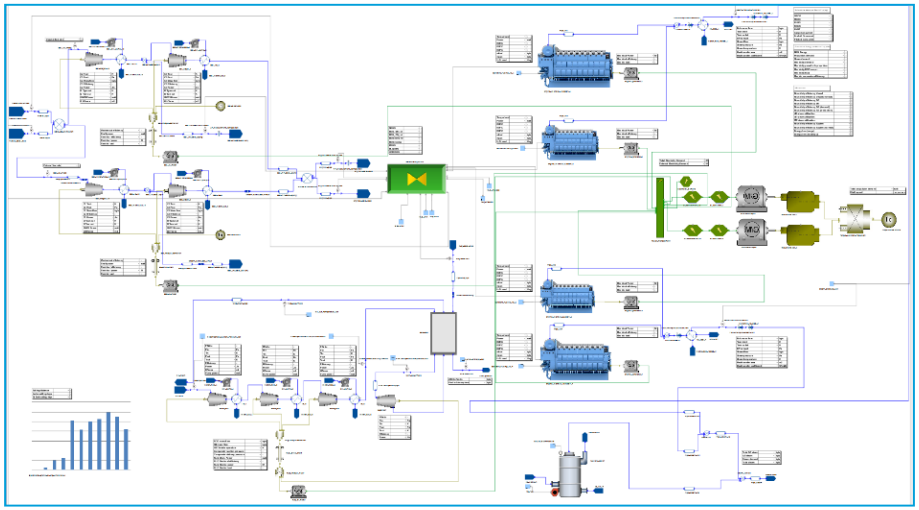
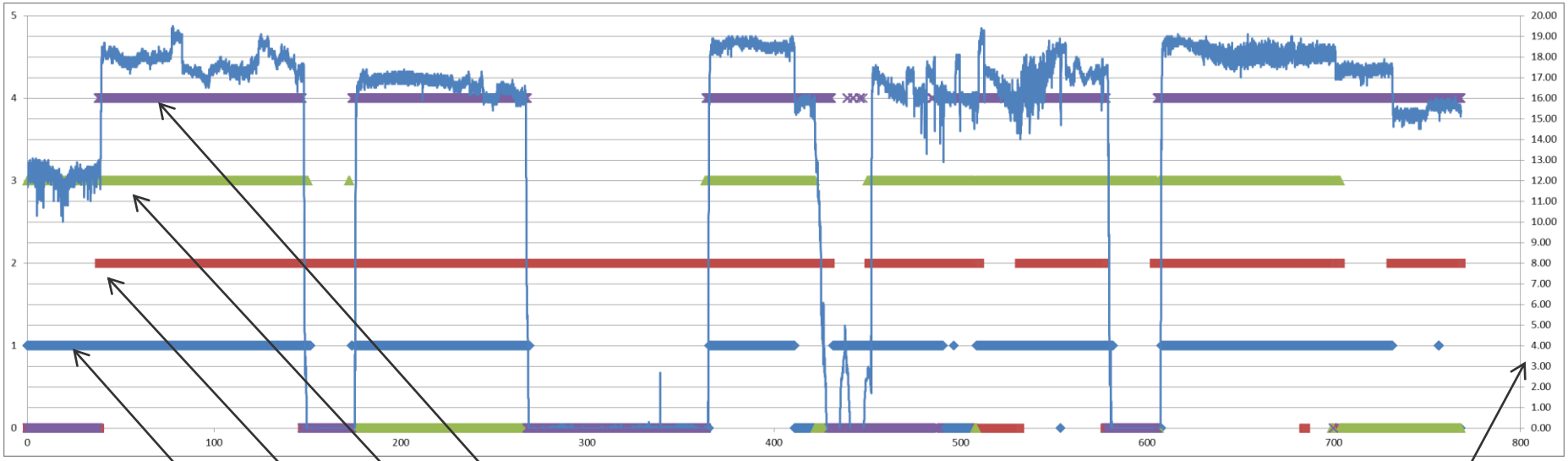


*DFDE integrated machinery system, Z LNG carrier*

# Operational data measurements from DFDE LNGC in operation




Engine #4 in operation

Engine #3 in operation

Engine #2 in operation

Engine #1 in operation

Vessel speed

# Simulation-based power management assessment in Diesel electric vessels

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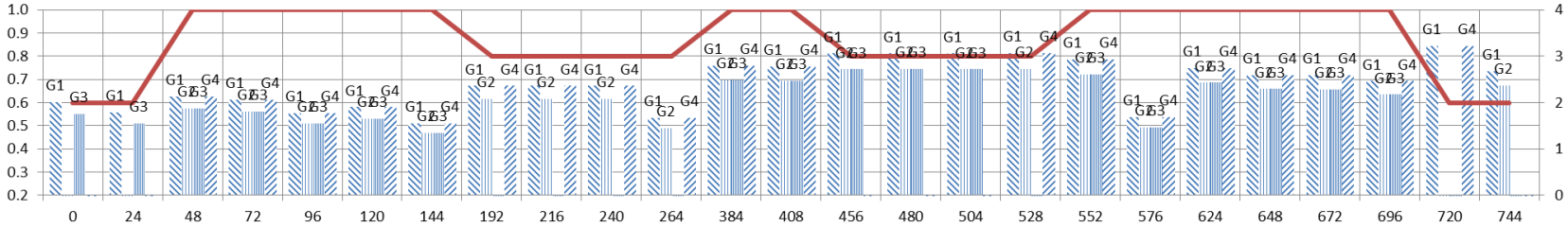
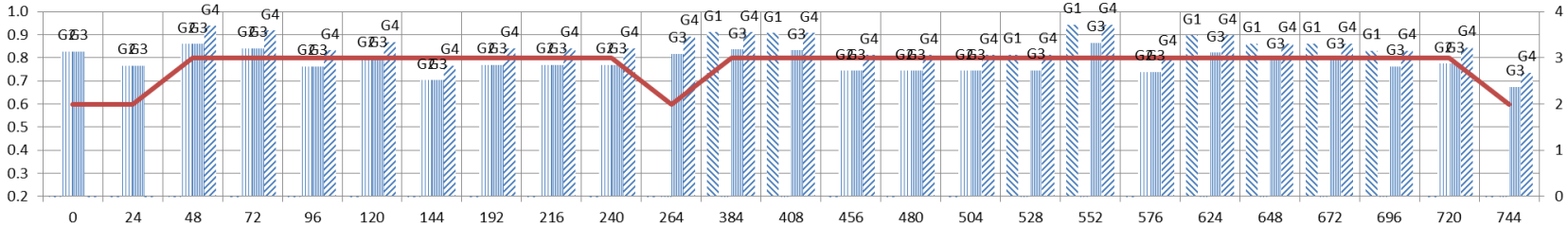
Load (-) **As recorded from onboard operation** # Engines run



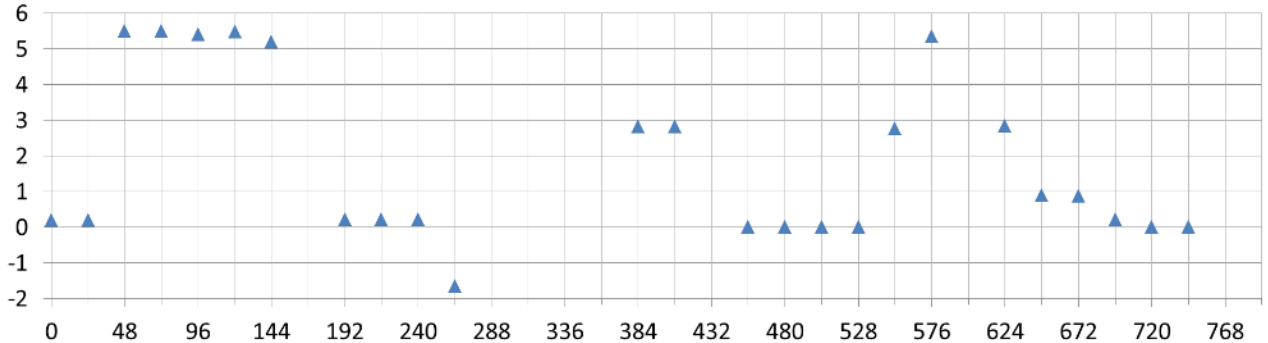

Hours from start of month

Load (-) **As selected by COSSMOS optimal Power Management** # Engines run



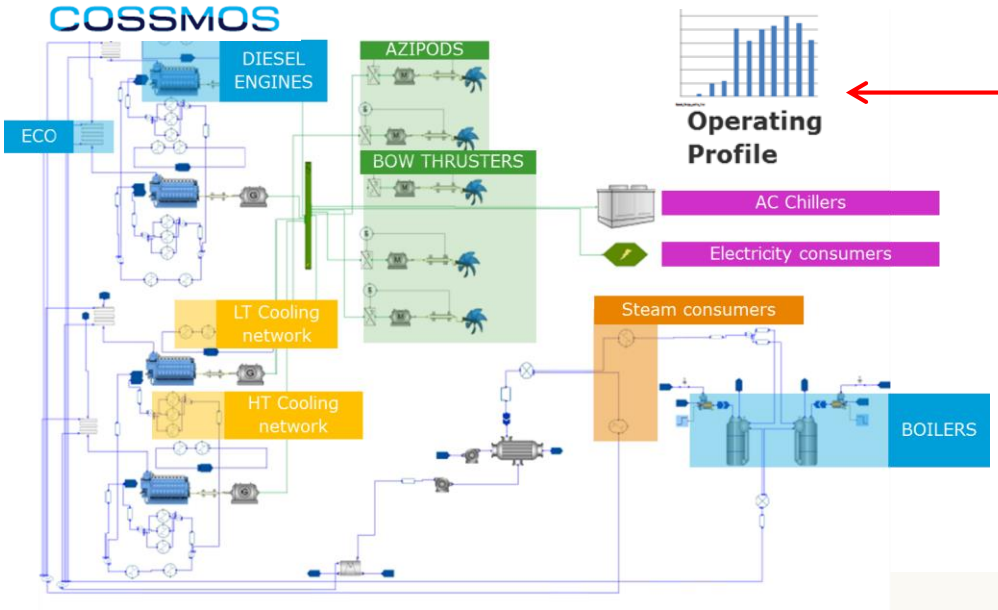

Hours from start of month

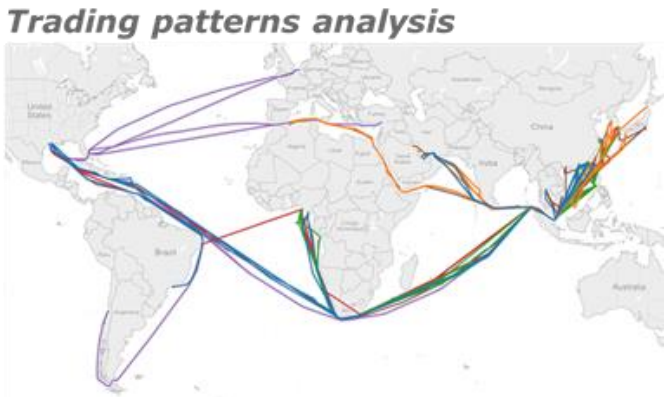
## Estimated equivalent fuel savings (tons-LNG/day)

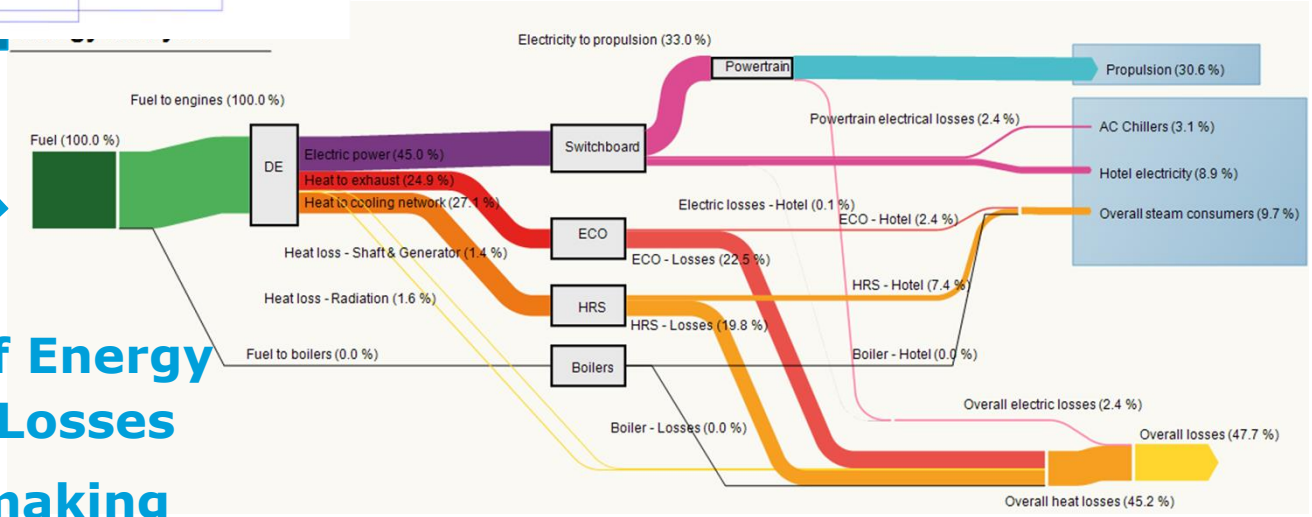


# Integrated system energy flow mapping

# DATA (design and operational) + computer MODELS



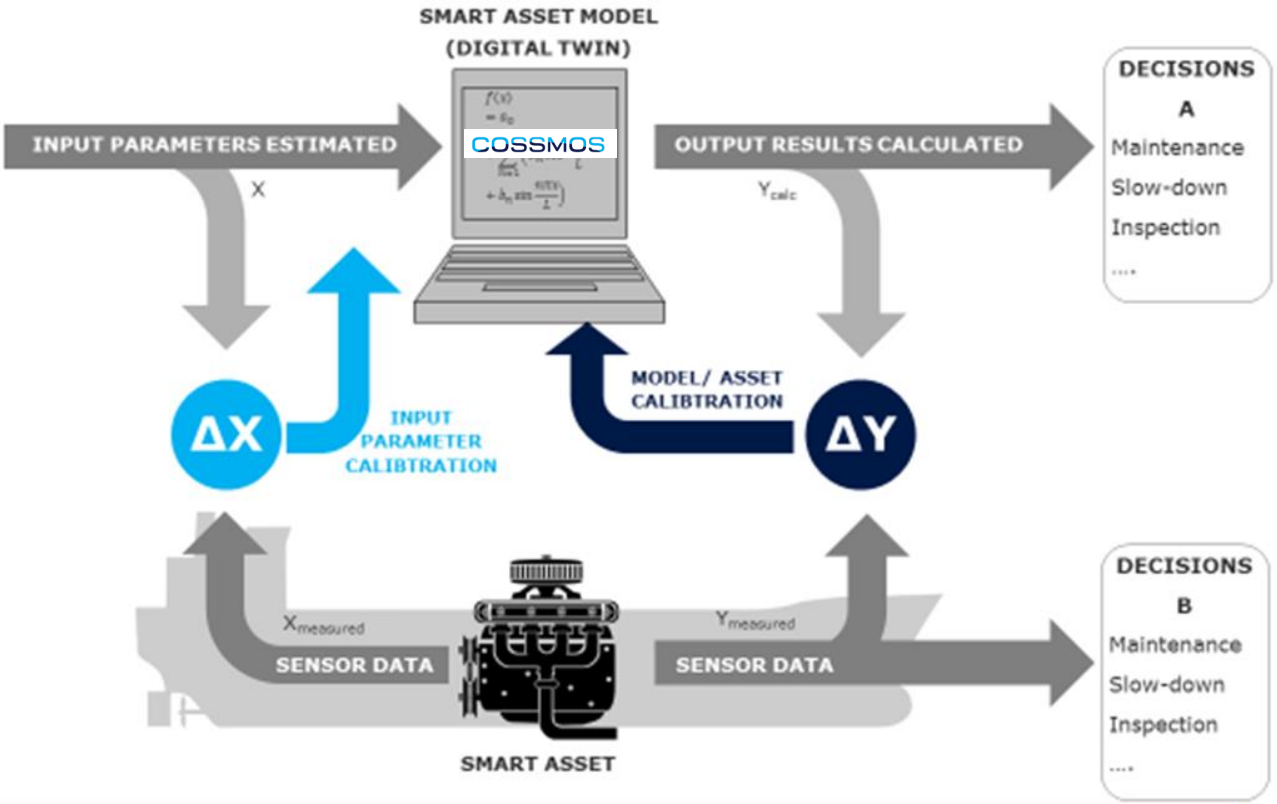




**Accurate mapping of Energy flow, Efficiency and Losses**

**Improved decision making**

# Ambition: Model-based data driven asset management (near) Real time support




Build / adapt / expand COSSMOS models

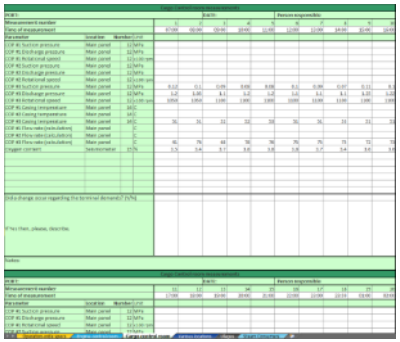
Availability of an extended set of sensor signals

**COSSMOS model simulates the conversion of energy across the vessel's power train and compares with on board data**

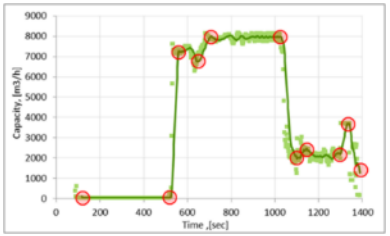
# Performance assessment and improvement of tanker cargo operations

# Boiler / Steam turbine-driven pumping station onboard
# Compare operational with simulated performance

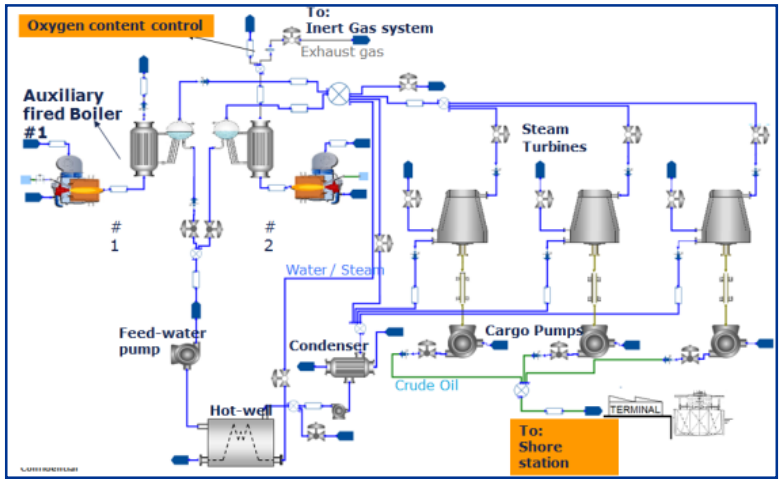
## Data acquisition



## Data processing




## Ship-specific COSSMOS model



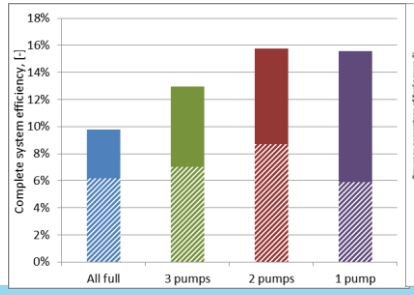

**Assessment**

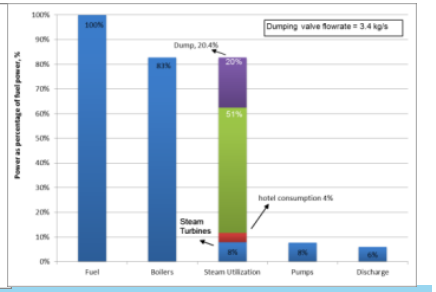
**Understanding**

**Best practices**

**Efficiency gains**

**Simulations, analysis and optimisation**

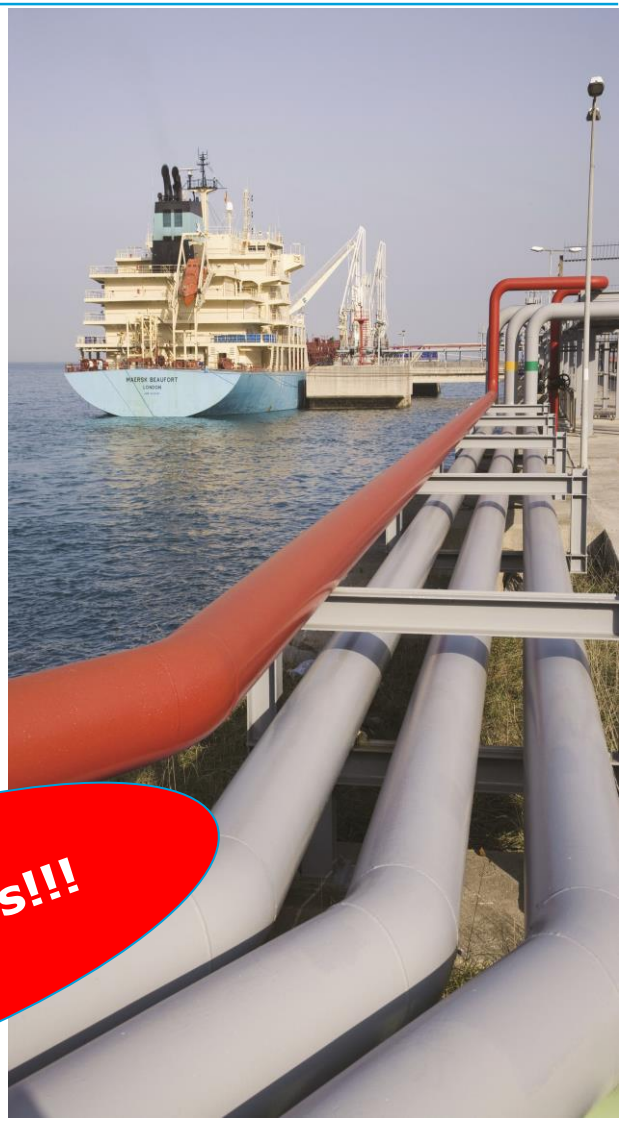


## Crude oil tankers cargo operations

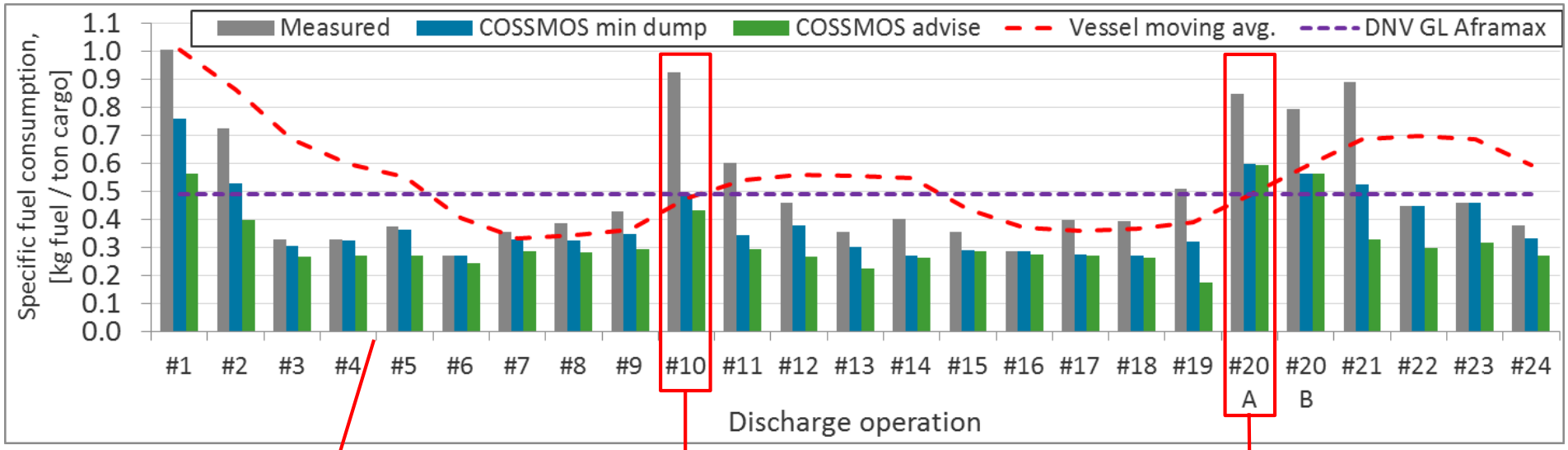
Complex systems, ship & terminal operations, crew functioning, inefficiencies.

How to assess energy efficiency of the operations quantitatively & improve them in practice.



**Charterers focus!!!**

# COSSMOS performance assessment & improvement
# Fleet in service




Crew training and best practices adoption

Crew change

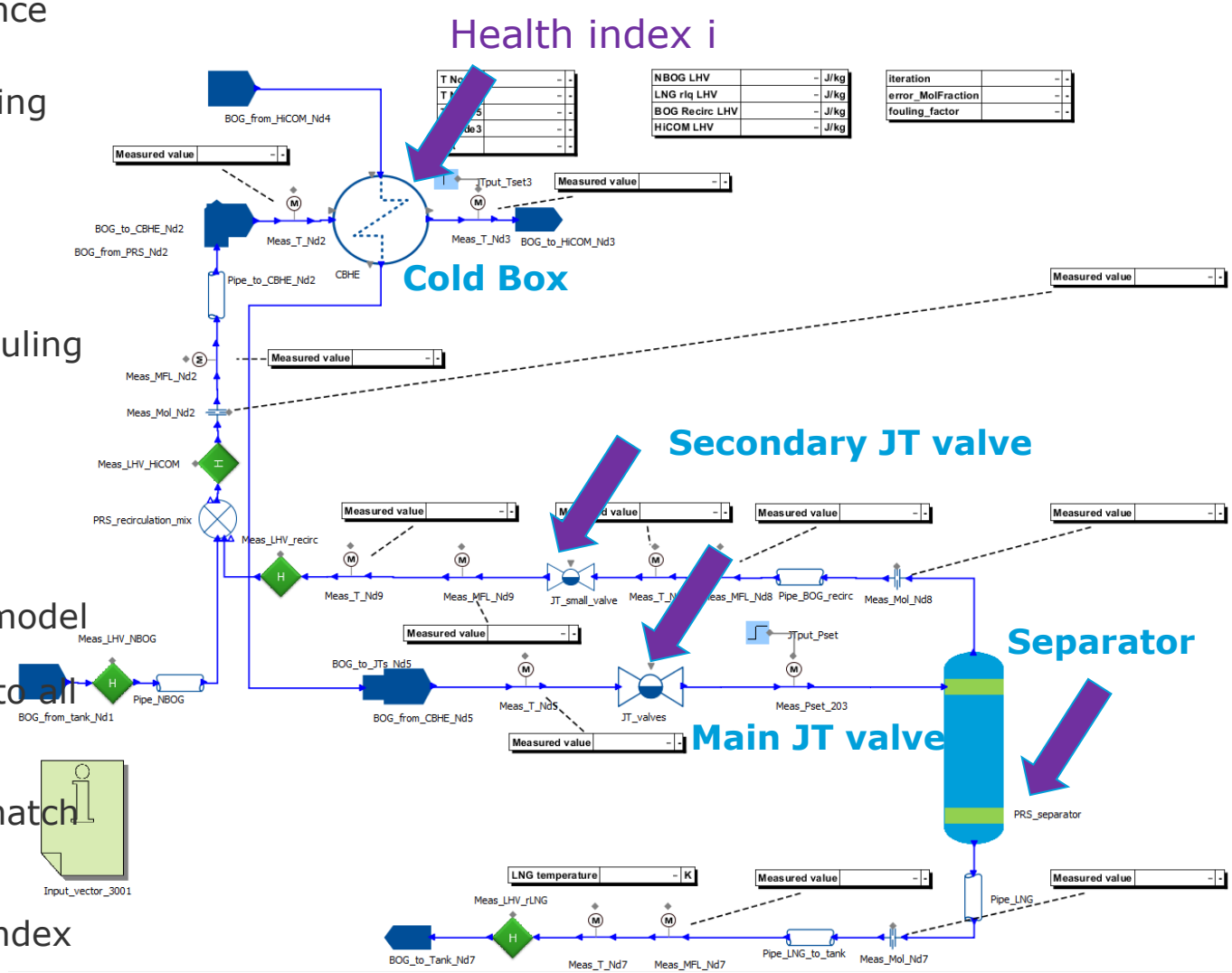
Crew change

# Using COSSMOS for cargo / BOG systems assessment, improvement and troubleshooting

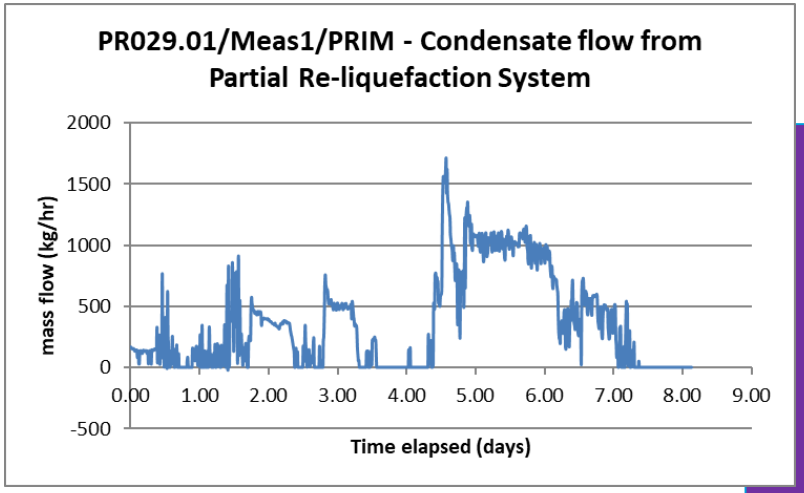
# Model-based troubleshooting of a BOG/LNG re-liquefaction system

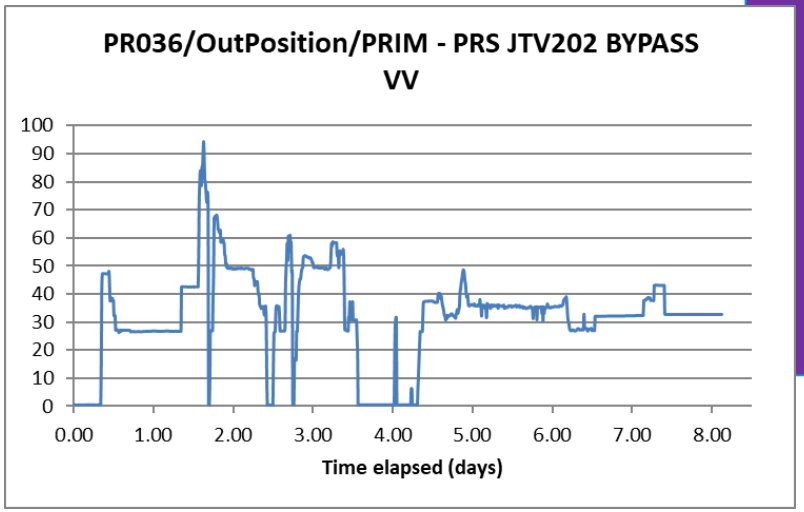
- Problem: poor performance and low re-liquefaction quantities (observed during whole voyage(s))
- Complex process many potential causes
- Complex control & scheduling strategies.

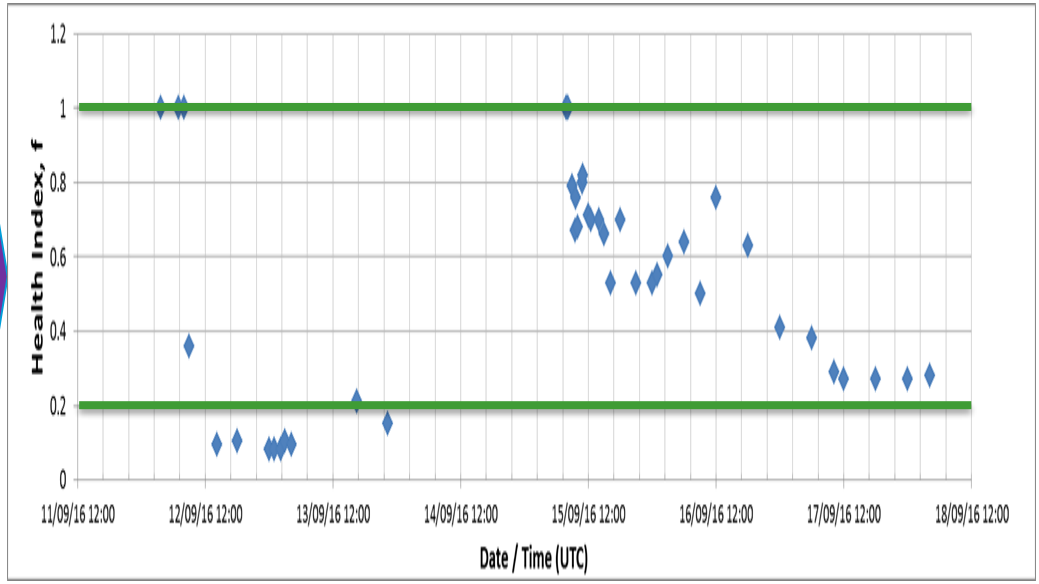
- Start for a design basis model
- Assign "Health indexes" to all major components.
- Vary Health indexes to match observed performance.
- Search for large health index variations.



# Health index of "Cold box" heat exchanger



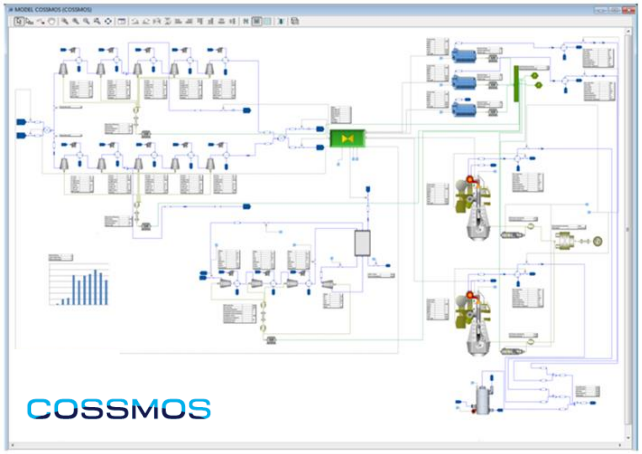




- **Excessive fouling due to oil contamination of surfaces after ~2-3 hrs of operation**
- **Purging, Inerting, Gas-freeing and Warming-up clean the oil deposits when open for inspection!**
- **Modelling was the strongest indicator!**

# Summarizing

# Model-based Approaches for Ships

- Advanced model-based methods that manage complexity in practice: DNV GL COSSMOS
- Robust decision making: Asset competitiveness
- Improve attractiveness of maritime assets
  - New bids and tenders: optimum configurations
  - Operations optimisation
  - New trades / charter extension
  - Retrofitting
  - Trouble-shouting
- Quantification and allocation of investments
- **Practical today's problems → Answered via Modelling, Simulation & Optimsation**



# DNV·GL

*advantage through innovation*

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