Decarbonizing waterborne transport using fuel cells and DC grids

Dheeraj Gosala

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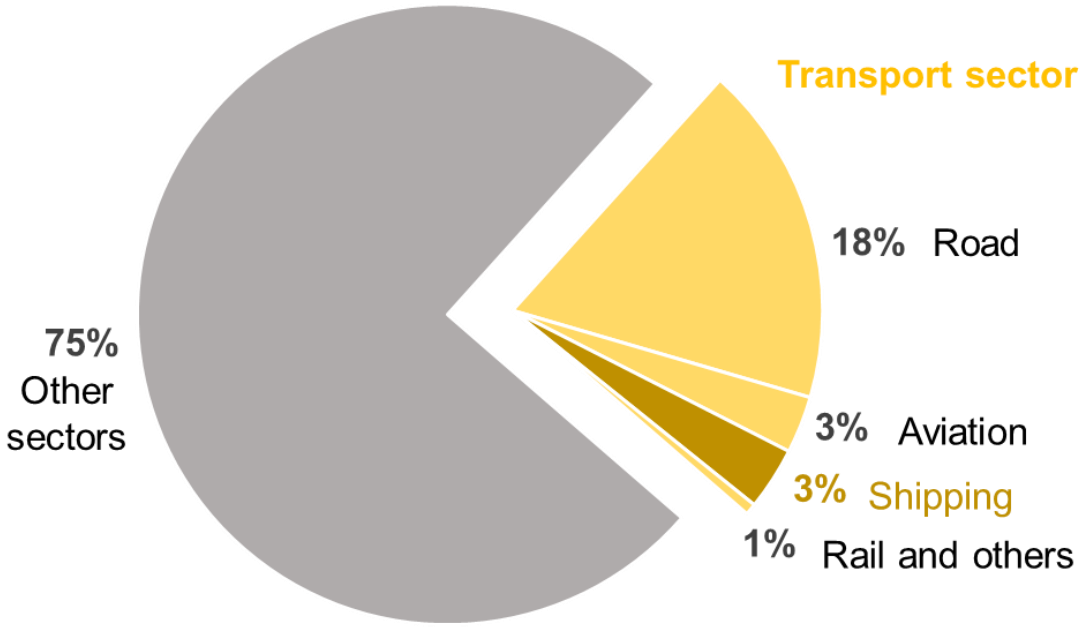
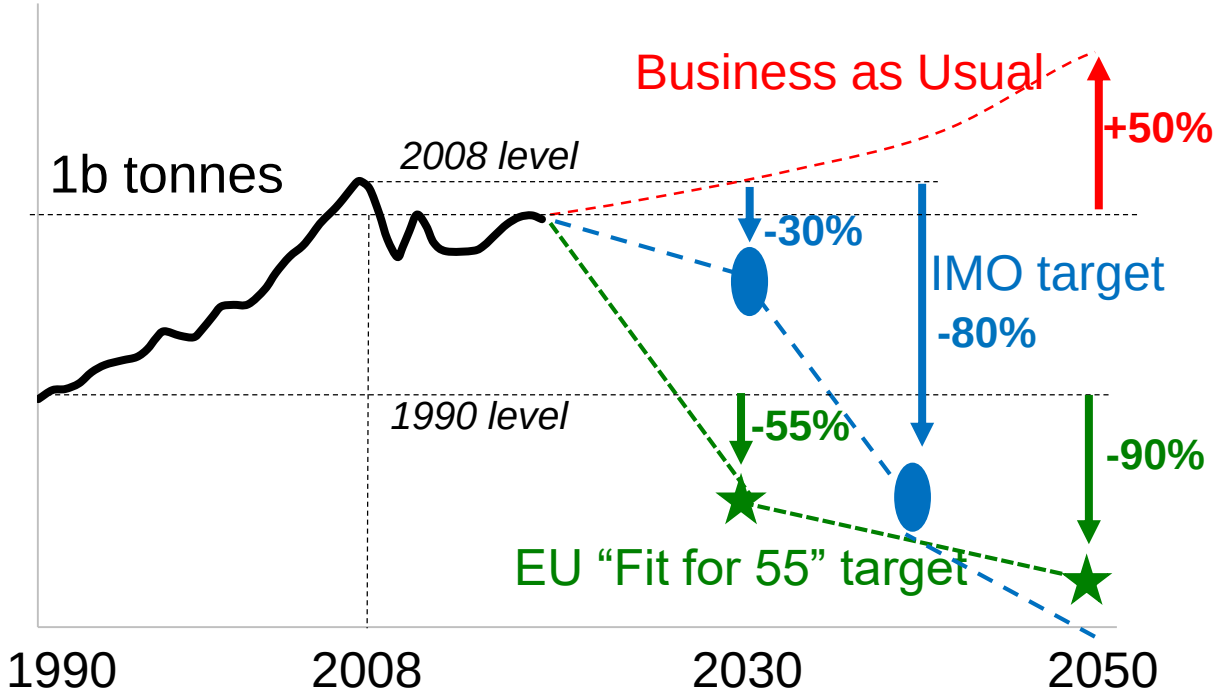
05.01.2024

Background

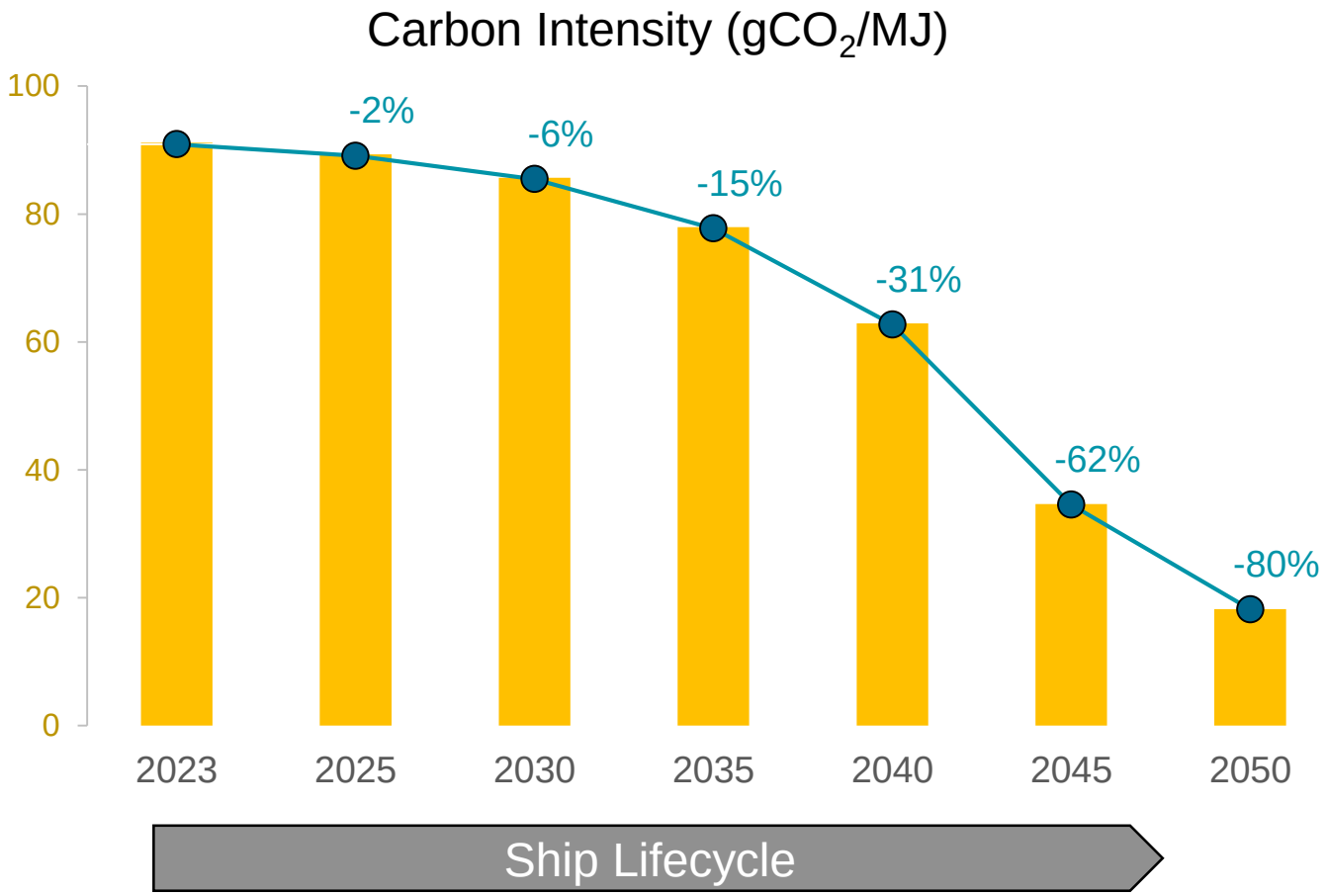
Global GHG Emissions (2018)



GHG Emissions from Shipping



Fuel EU Maritime Initiative



Reduce GHG intensity of fuels by up to 80% by 2050

Obligation ships to use **on-shore power supply or zero-emission technology** at ports

Zero-emission technology:

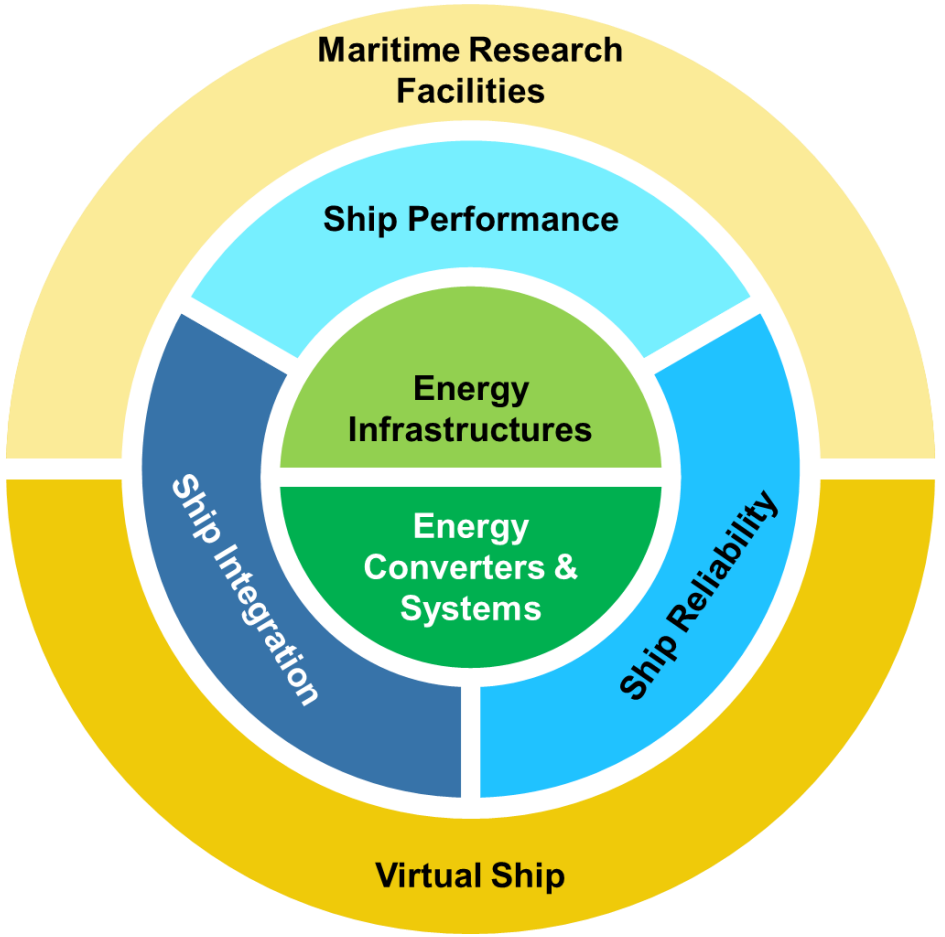
- Fuel cells
- Batteries
- PV/Wind energy

DLR Institute of Maritime Energy Systems

- **Founded in May 2021**
- **Headquartered in Geesthacht, testing infrastructure in Kiel**

Research Themes:

- Low- and zero-emission and renewable energy converters and systems
- Onboard energy storage, distribution, bunkering, and transportation of alternative fuels
- Optimization of ship performance in various sea states
- Design methods for ship integration and reliability assessment of new energy systems
- Digital twins



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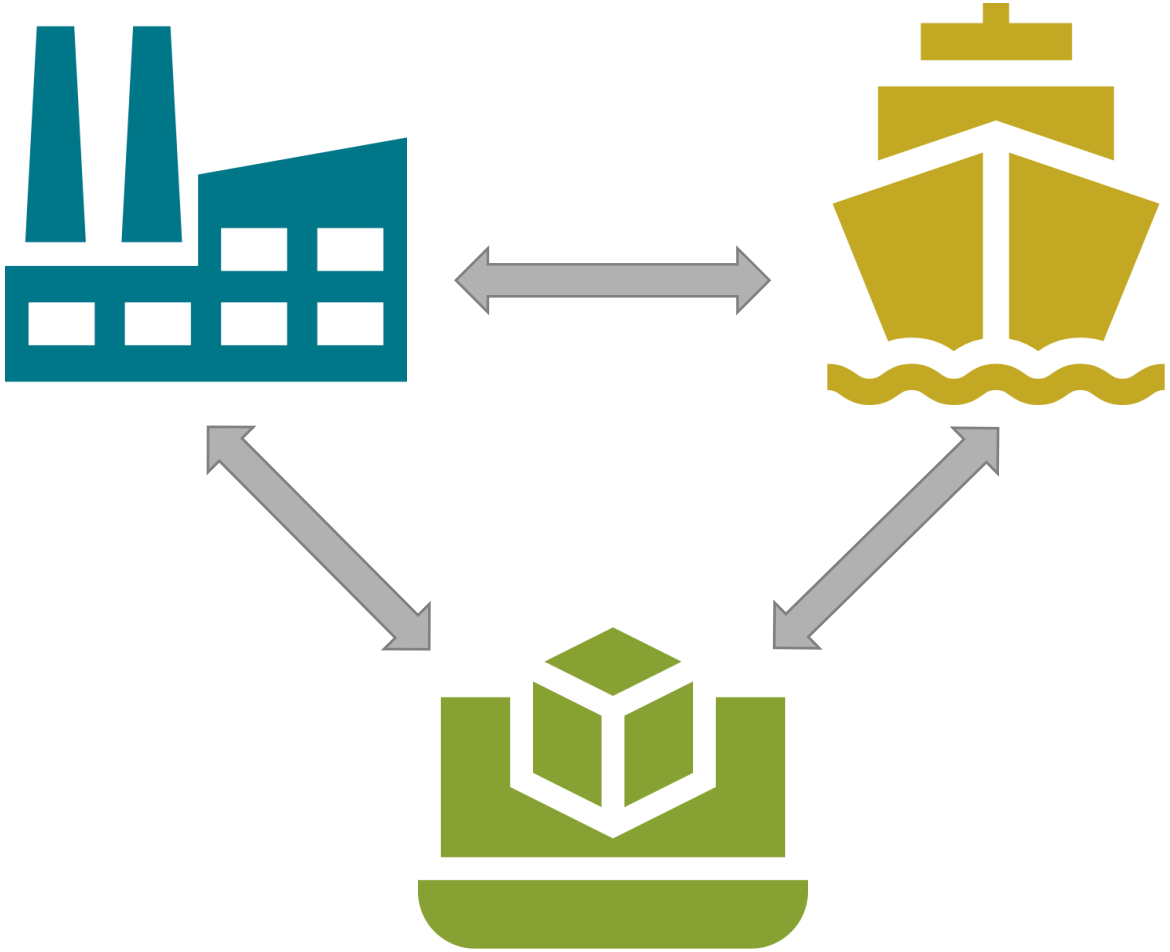
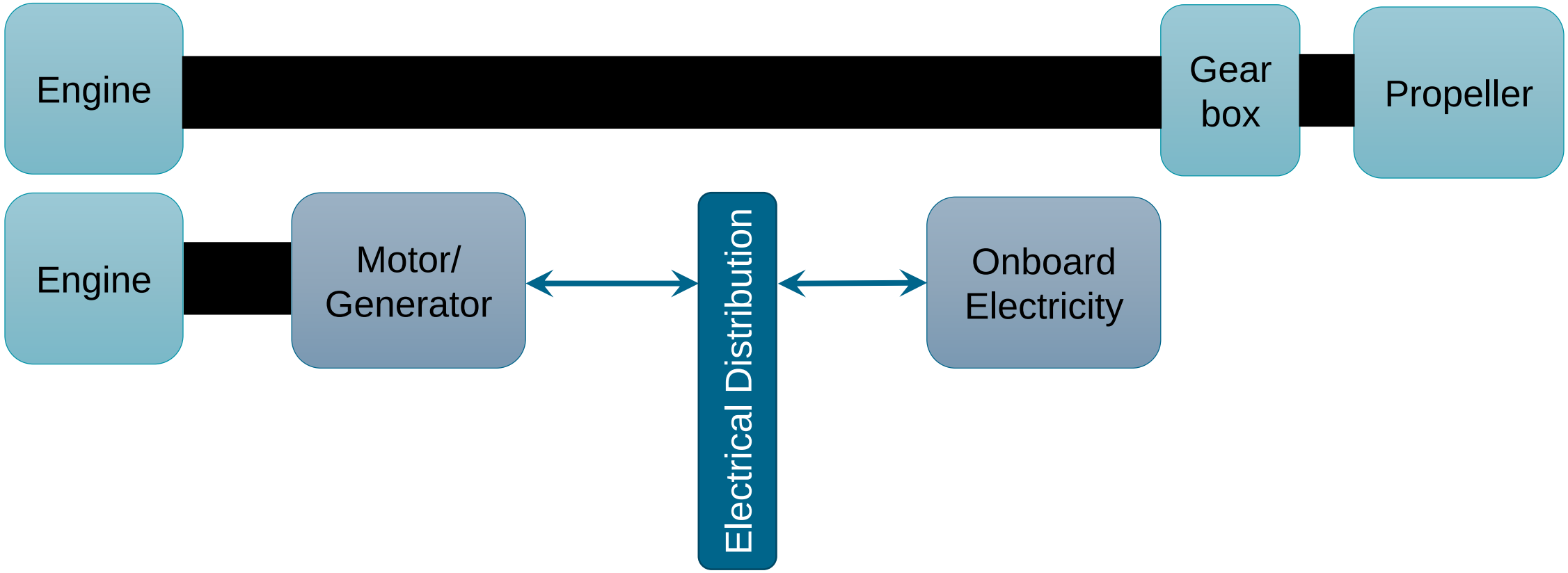


Energy Lab for Maritime Applications

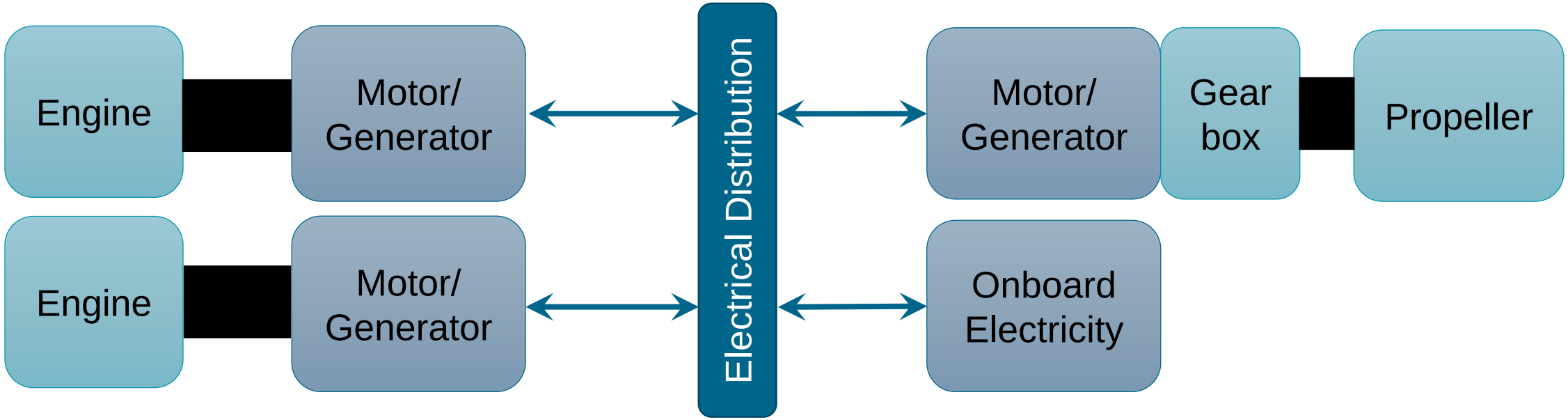
Research Vessel

Modelling and Simulation

Powertrain Configuration



All Electric Ship



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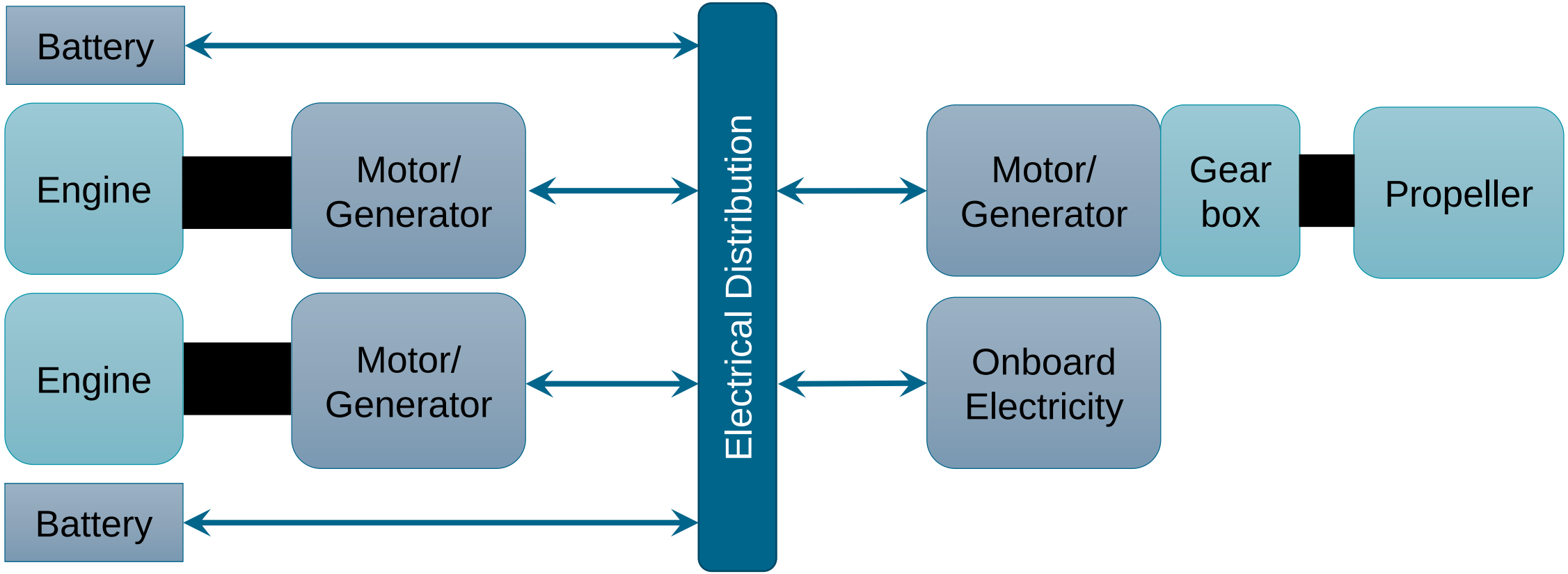

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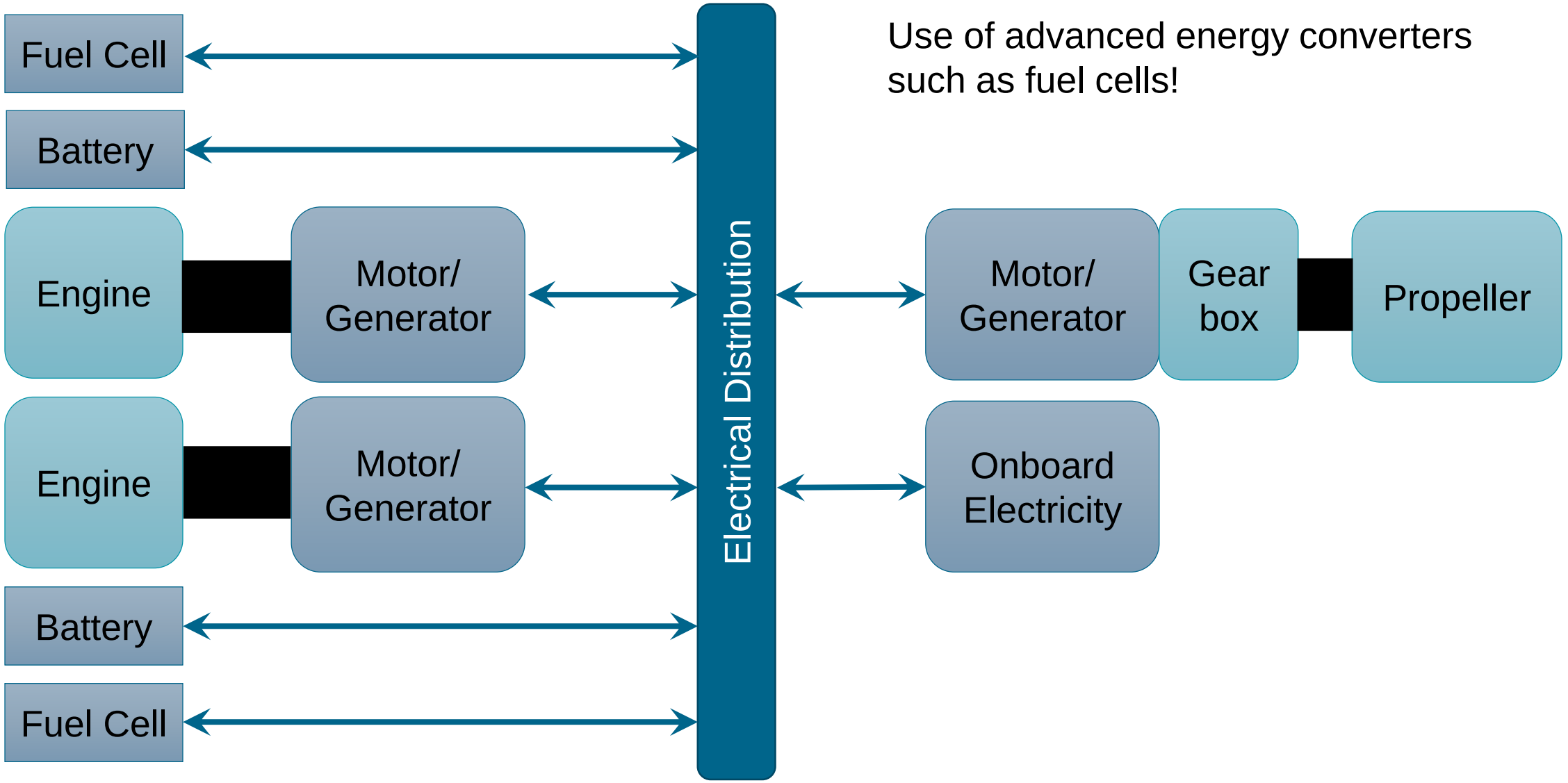
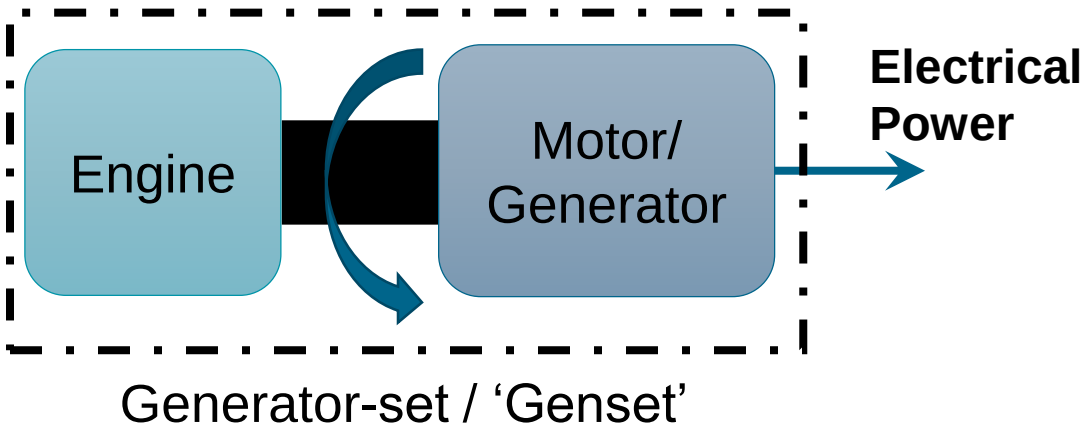
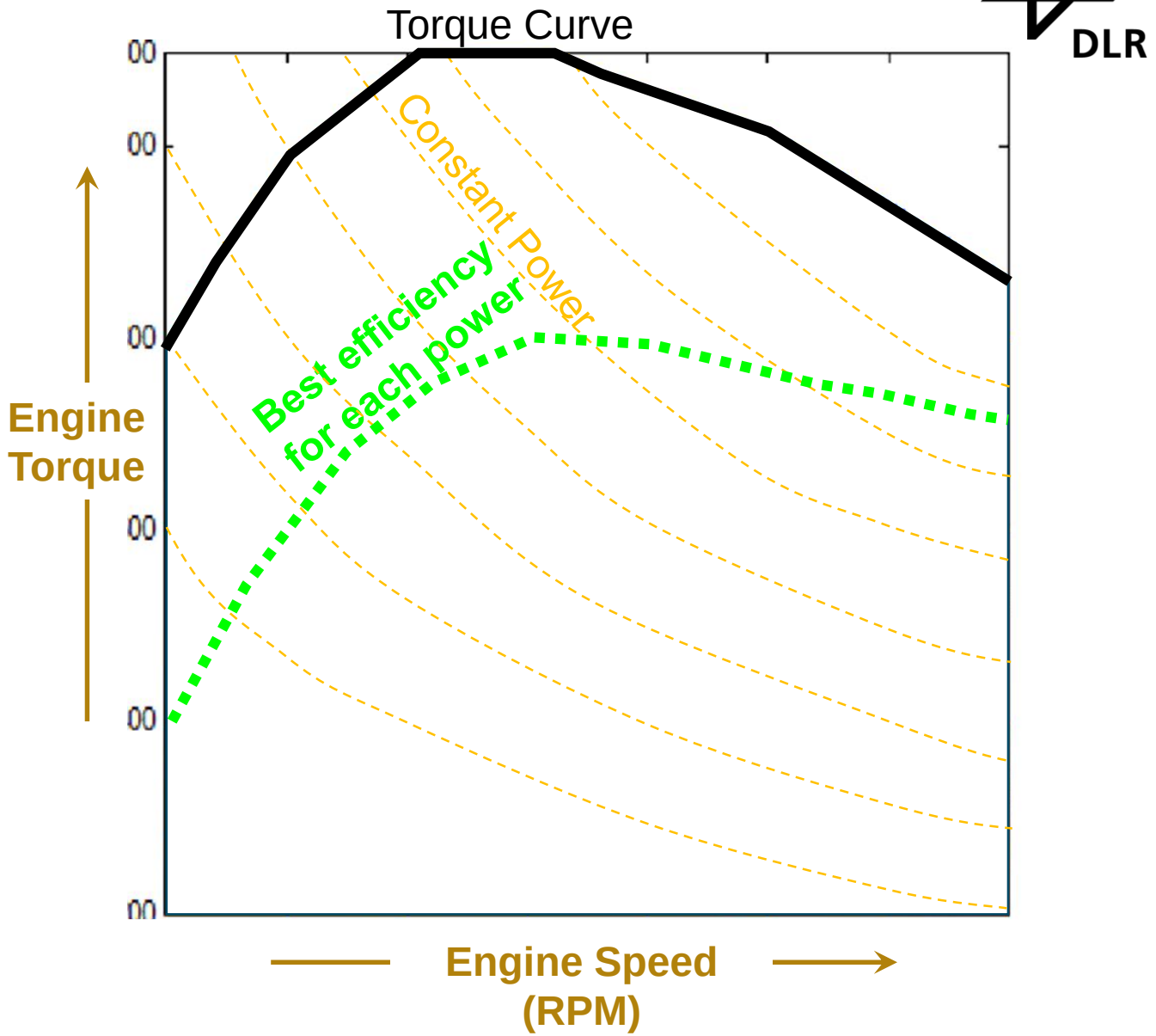


Use of advanced energy converters such as fuel cells!

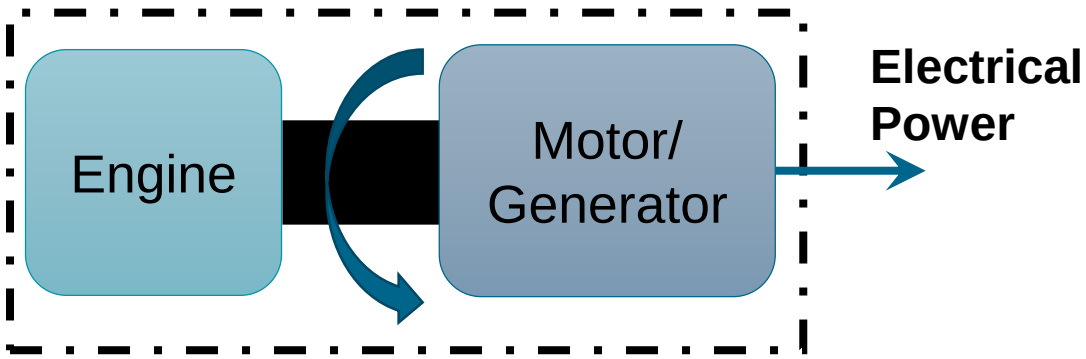
Speed – Torque Map





Naik et al., “Achieving Bharat Stage VI Emissions Regulations While Improving Fuel Economy with the Opposed-Piston Engine ”, SAE Intl. Journal of Engines, 2017

Speed – Torque Map: Fixed Speed Gensets

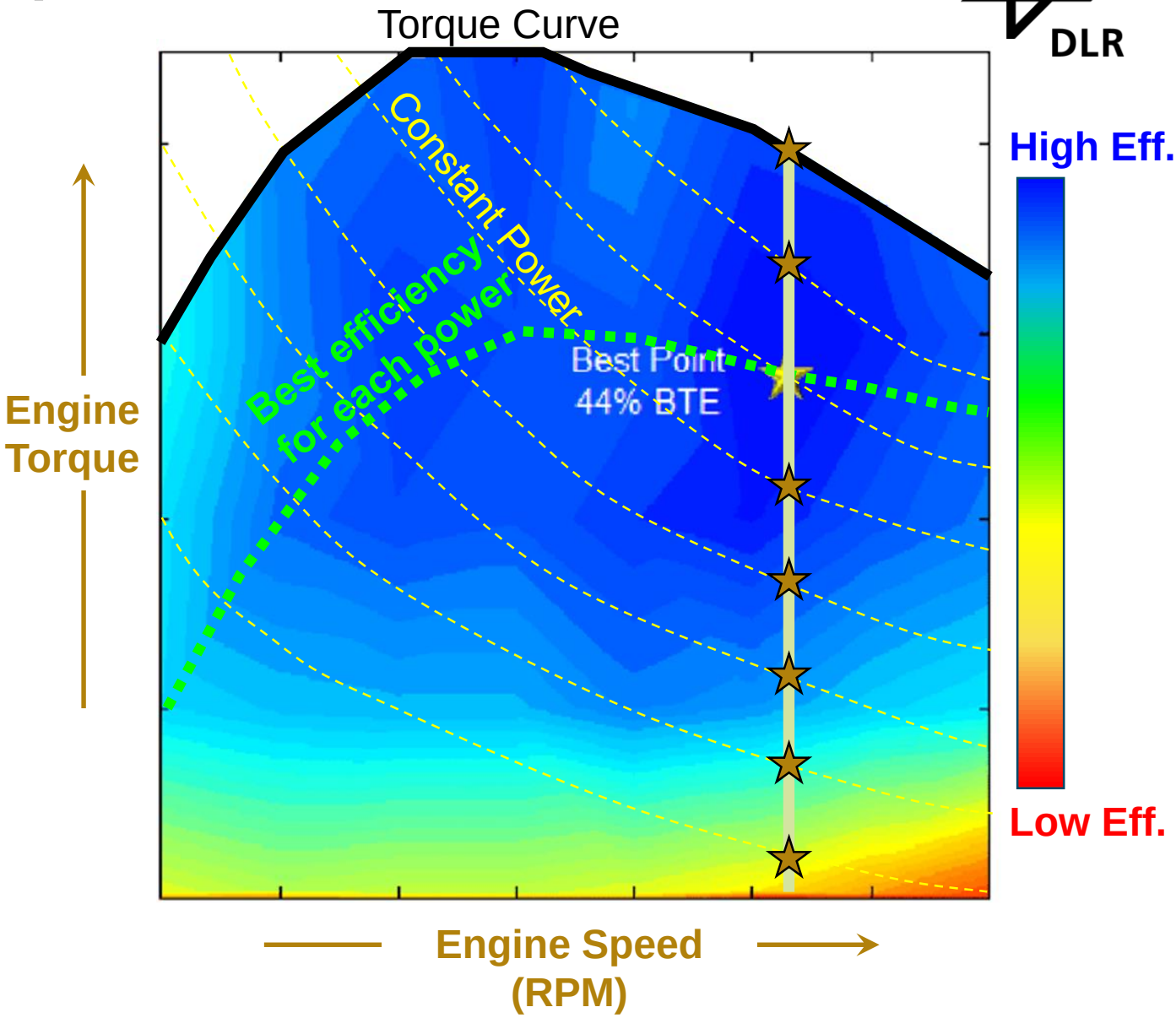


Generator-set / ‘Genset’

AC Grid

Grid frequency : 50 Hz

Genset speed : 1500 rpm



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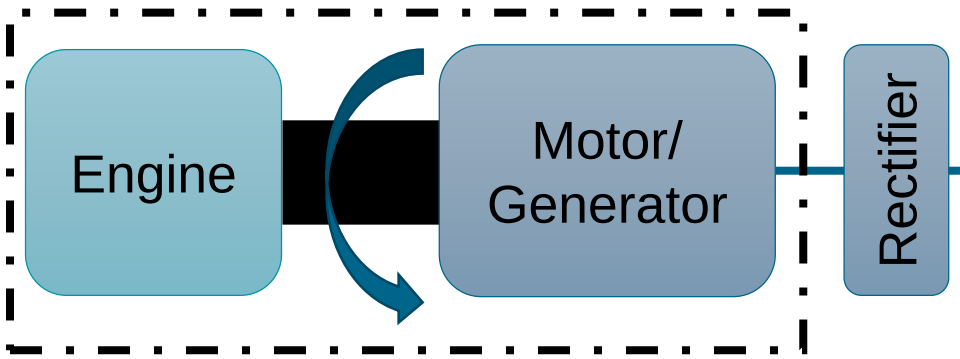
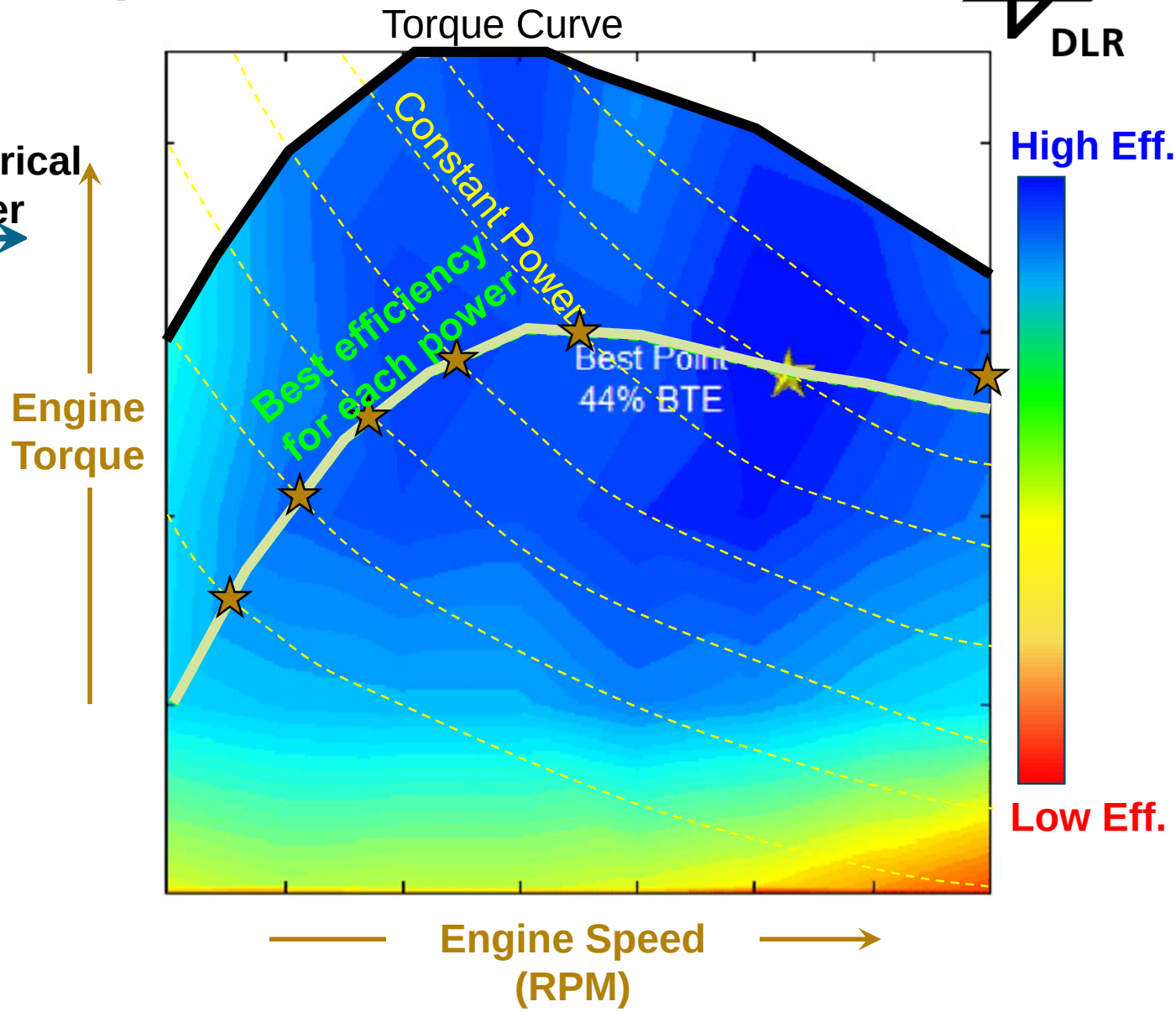
Speed – Torque Map: Variable Speed Gensets



Generator-set / ‘Genset’

DC Grid - Rectifier converts alternating current to direct current



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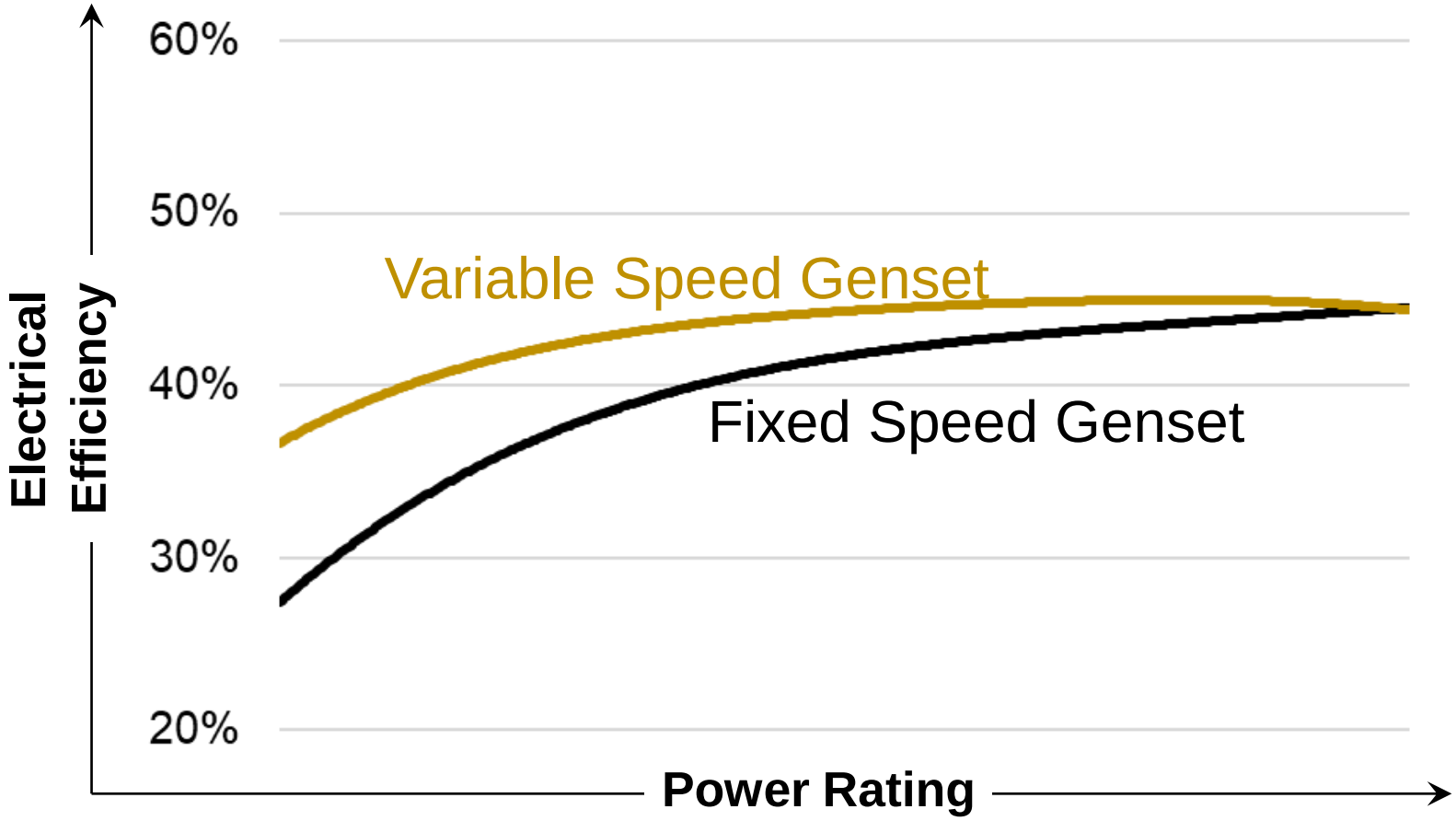
Energy Converter Efficiency



Variable Speed Gensets display higher part-load efficiencies

PEM Fuel Cells

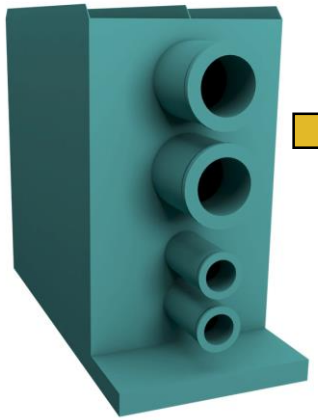
Diesel, NG, methanol, ammonia, etc.

Reforming Systems

H2

High purity requirements

PEMFC



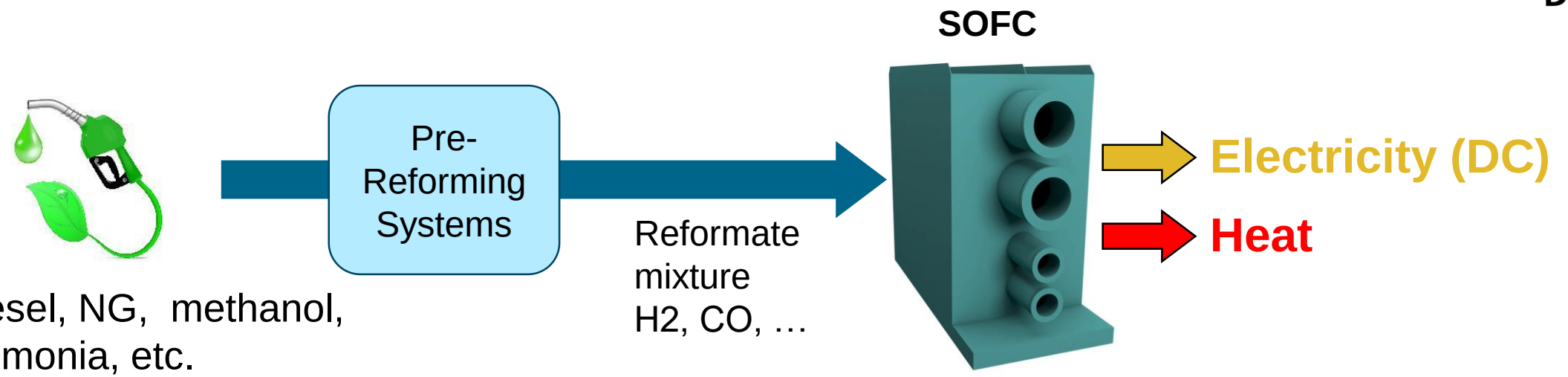
Electricity (DC)

- Low temperature operation (60 ºC)

- High technology maturity
- No pollutant emissions (NOx, PM, ..)
- Quiet operation – no NVH implications

> 50% electrical efficiency

Solid Oxide Fuel Cells (SOFC)

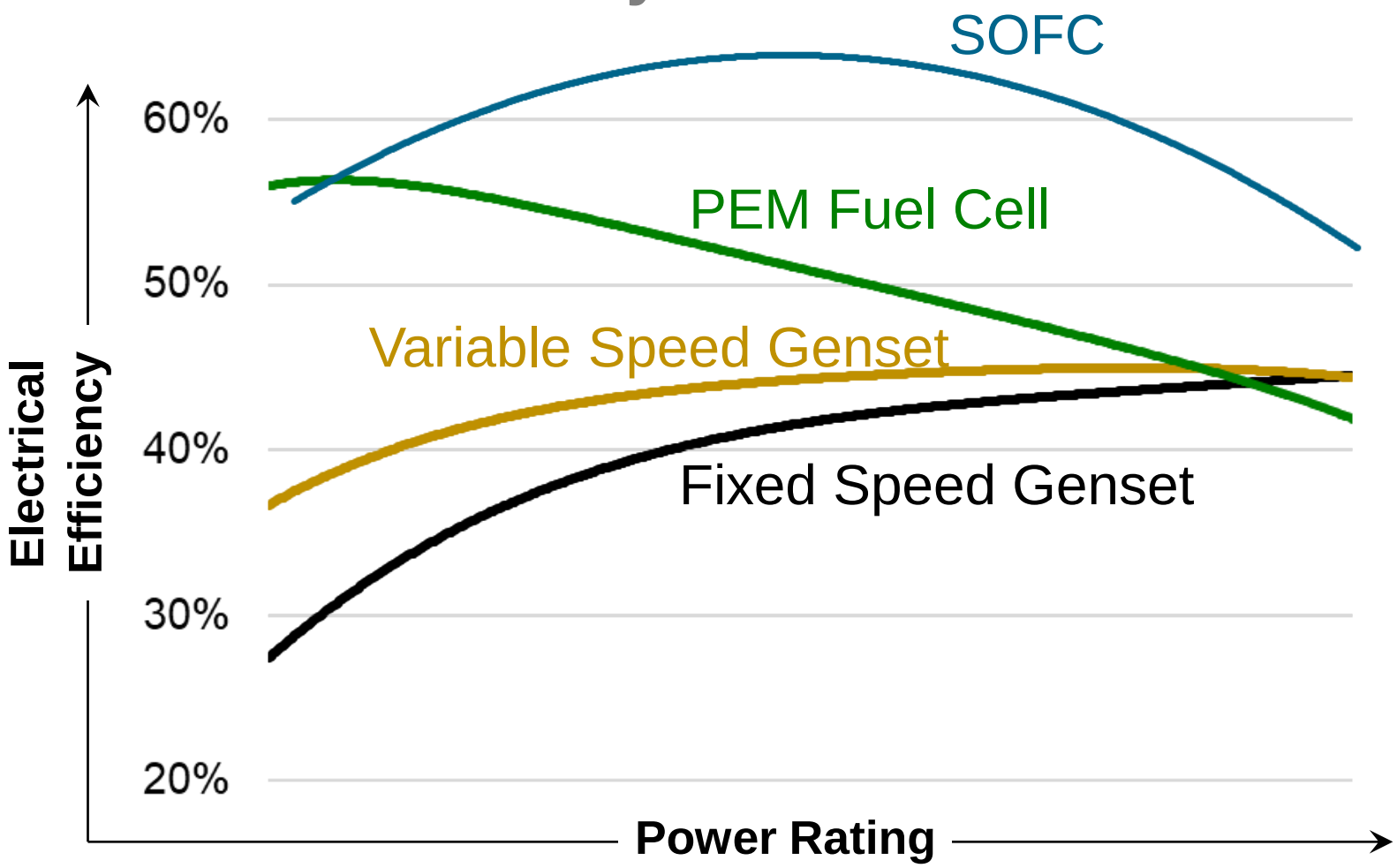


- High temperature operation (600 ºC)
- Internal fuel reforming possible
- Slow transient operation

- Low technology maturity
- No pollutant emissions (NOx, PM, ..)
- Quiet operation – no NVH implications

60% electrical efficiency
85% comb heat & power efficiency

Energy Converter Efficiency

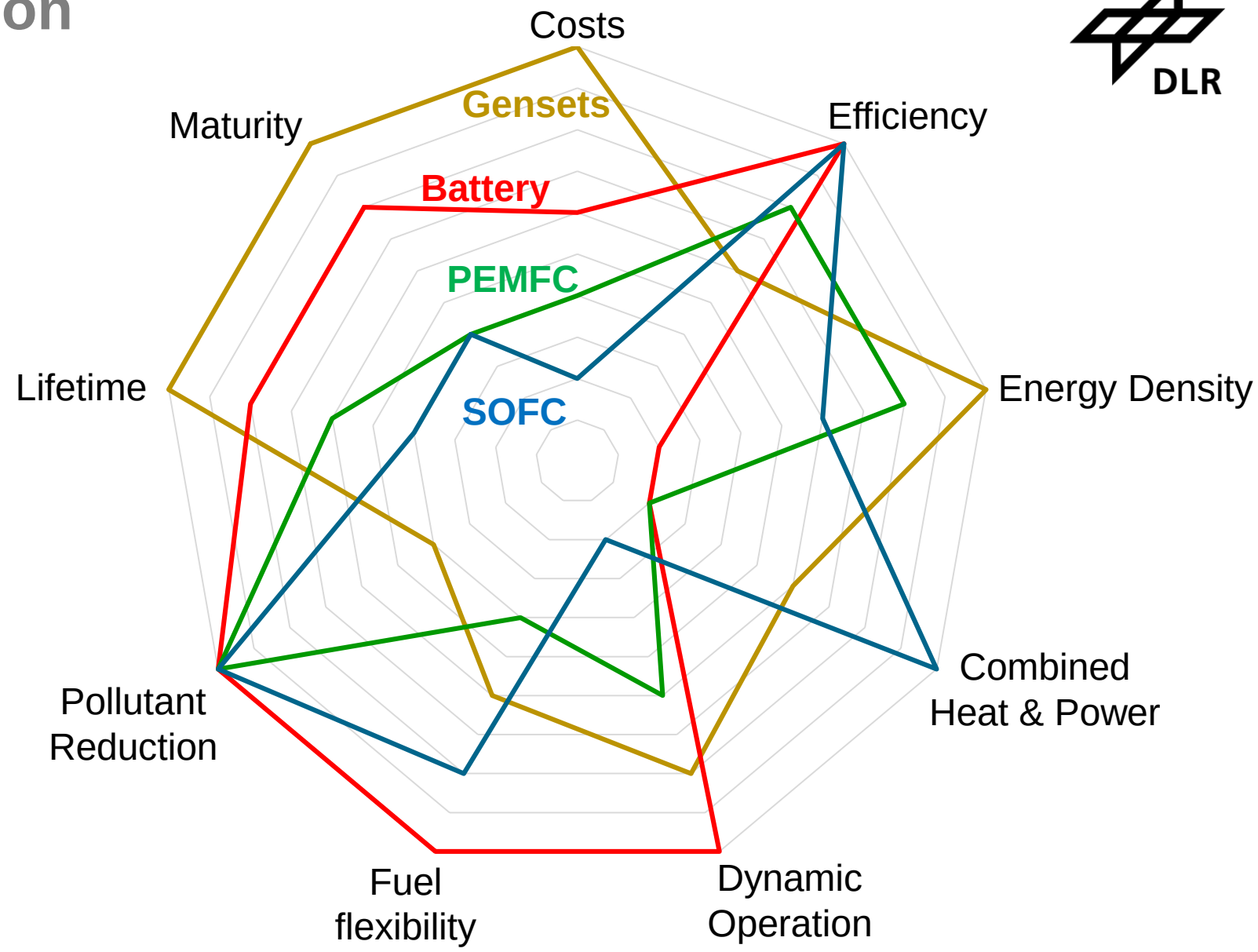


Fuel Cells & Variable Speed Gensets display higher part-load efficiencies

Technology Comparison

Different strengths of different converters

Optimal energy system requires a combination of several components, depending on the operating requirements

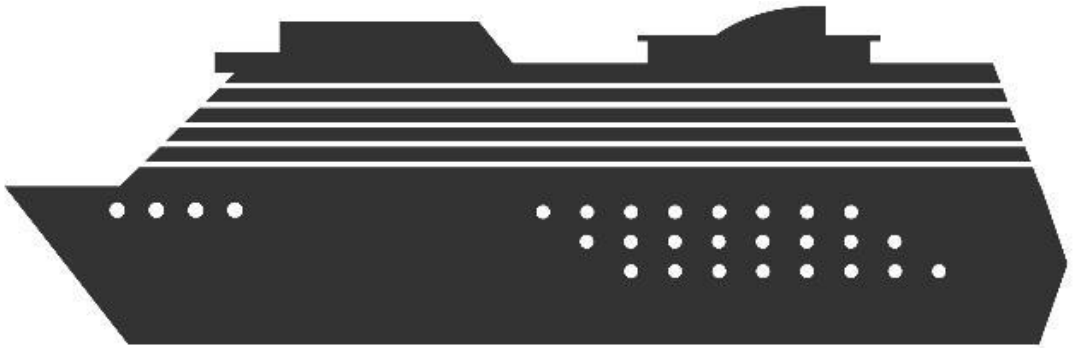


Cruise Ships

- Major contributor to global tourism
  - > $150 billion economic activity
  - 1.2 million jobs
- Significant emissions from cruise ships
  - CO2 ≡ 84,000 cars
  - NOx ≡ 420,000 cars
  - PM ≡ 1.05 M cars

Energy efficiency & pollutant reduction of cruise ships essential to meet sustainable development goals

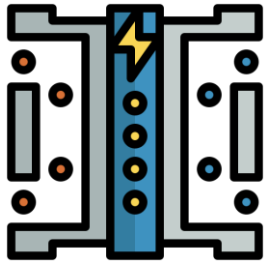
Scope



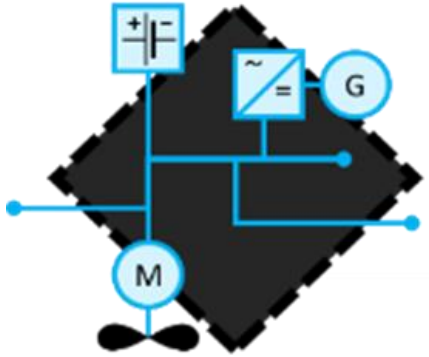
- Improve efficiency
- Reduce pollutant emissions (harbors & sensitive areas)

Batteries

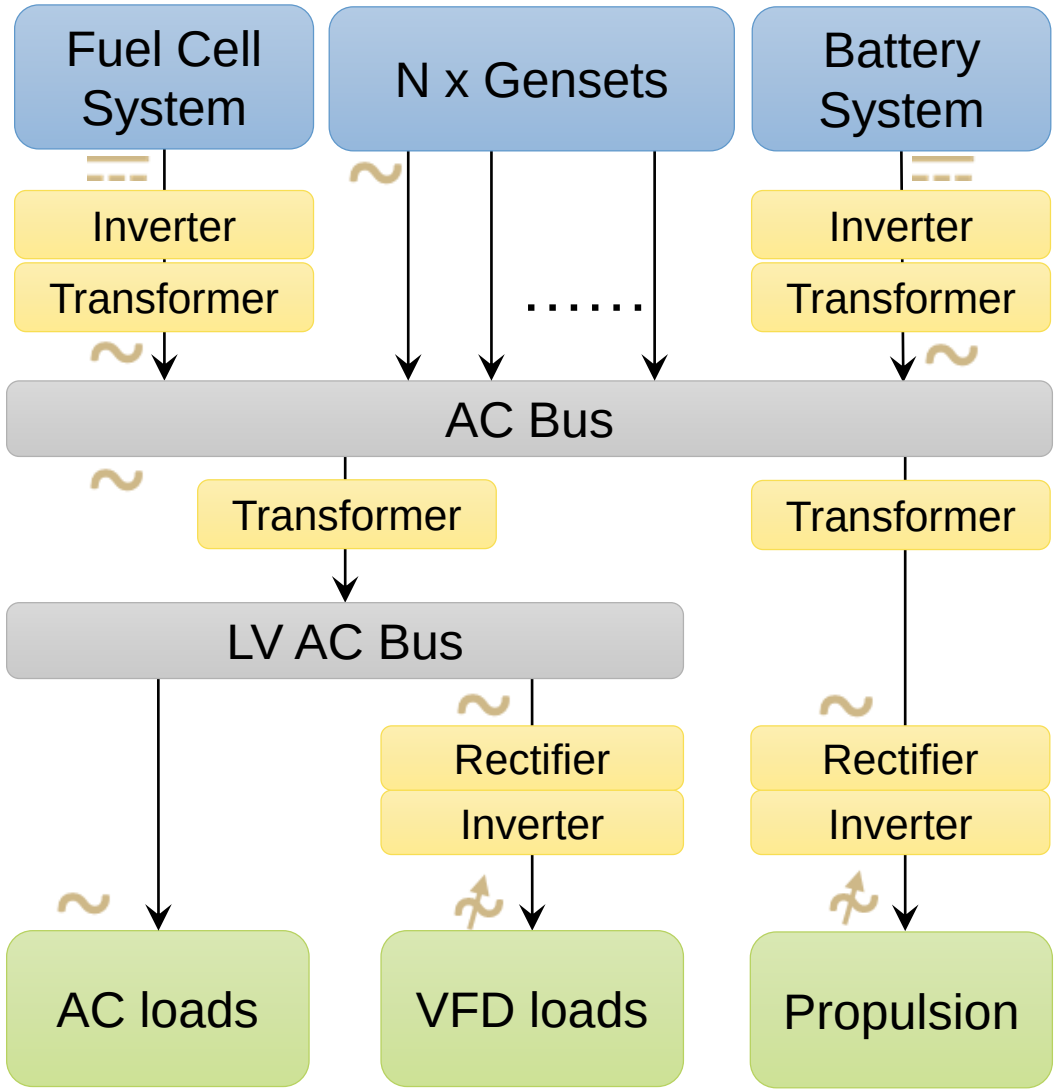
PEM Fuel Cells



DC grids



Grid Configuration in Modern Cruise Ships

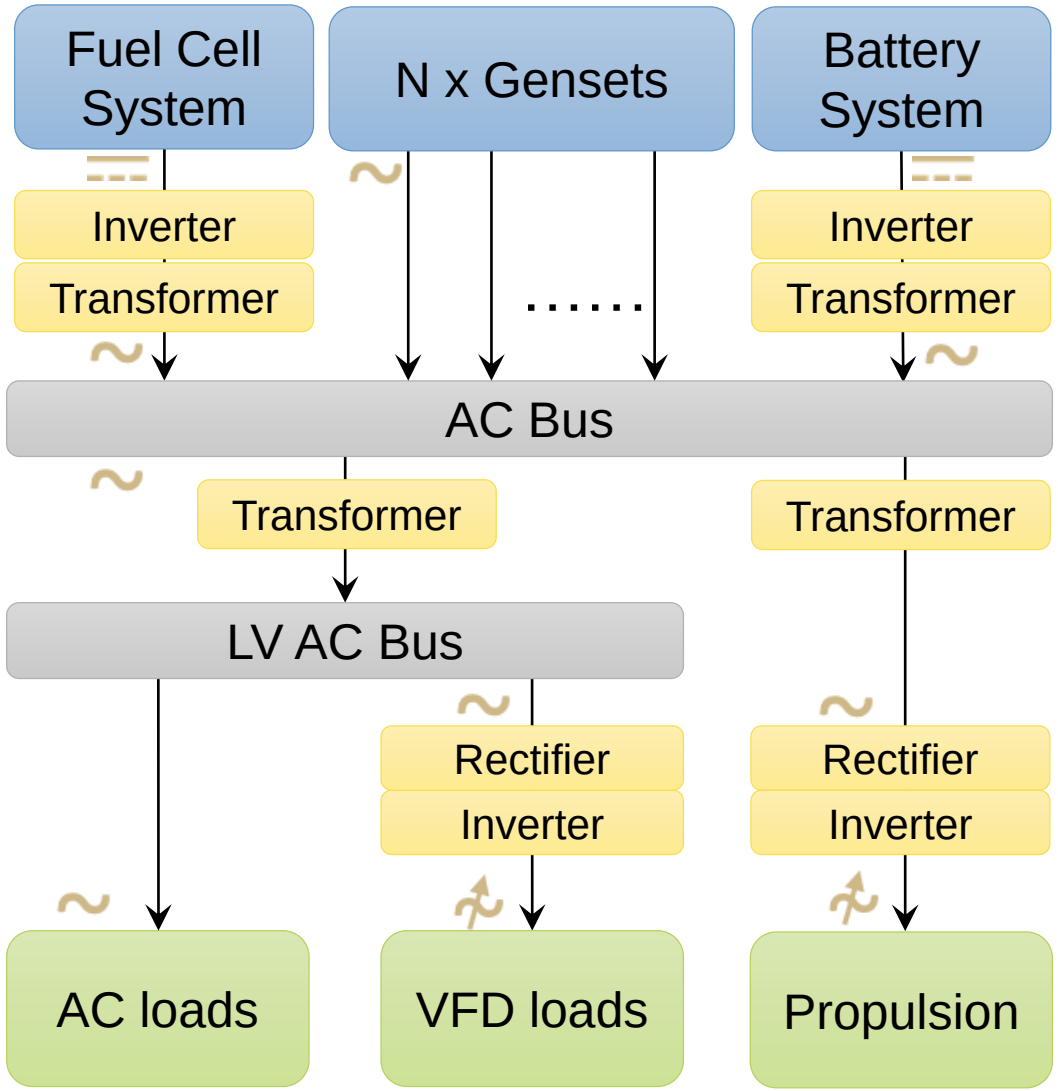


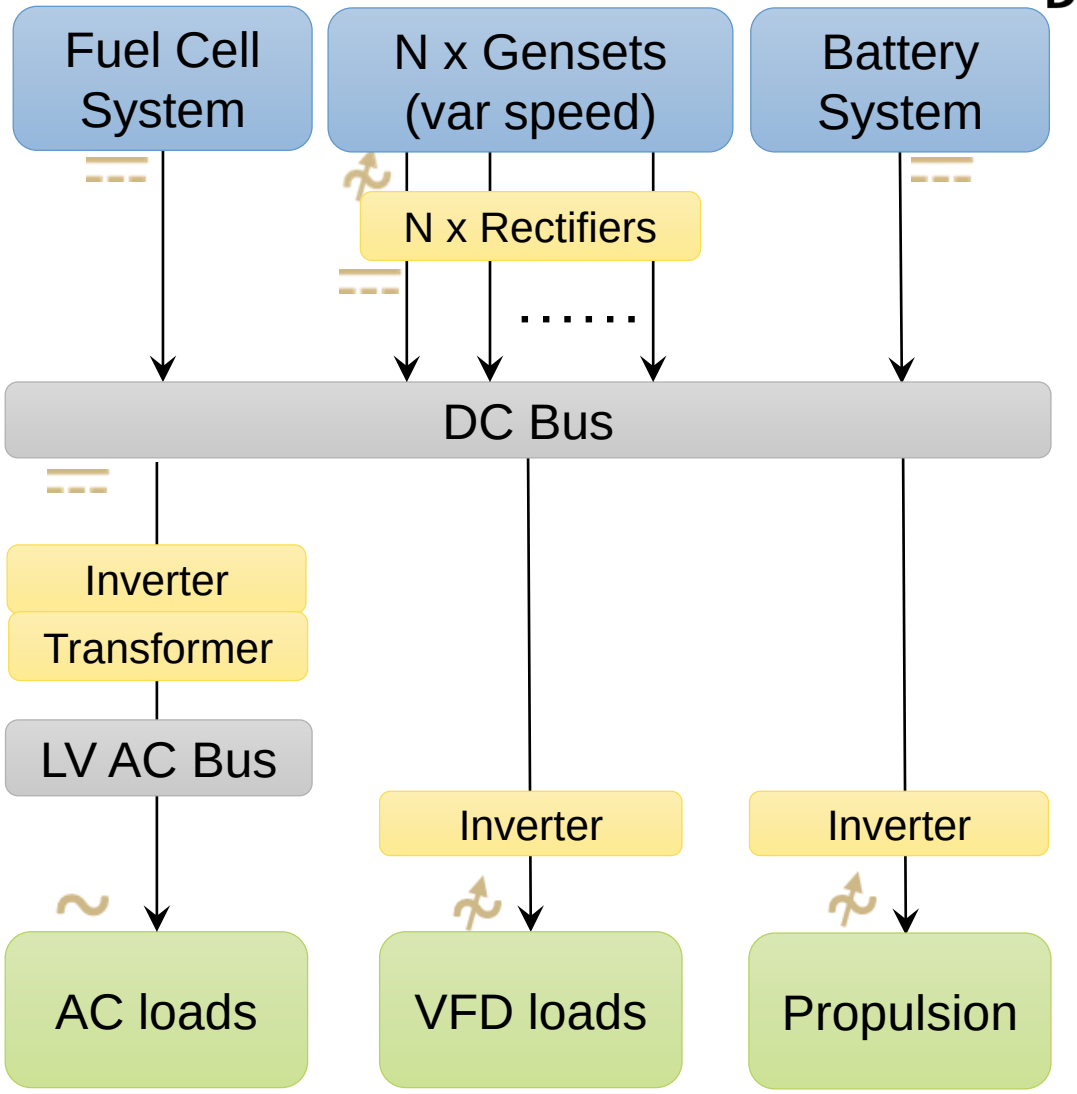
Power Generation & Energy Storage

AC Power Distribution

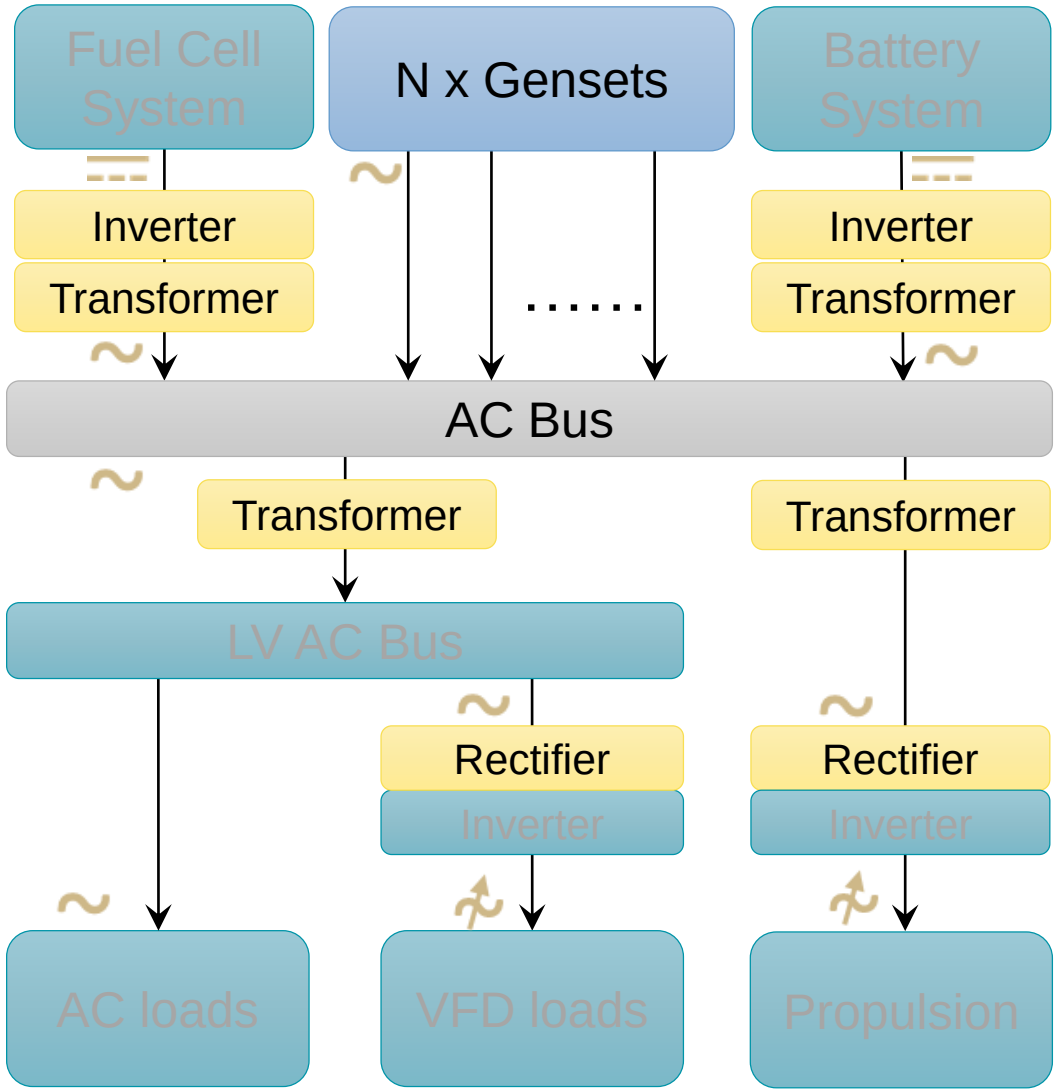
Power Consumers

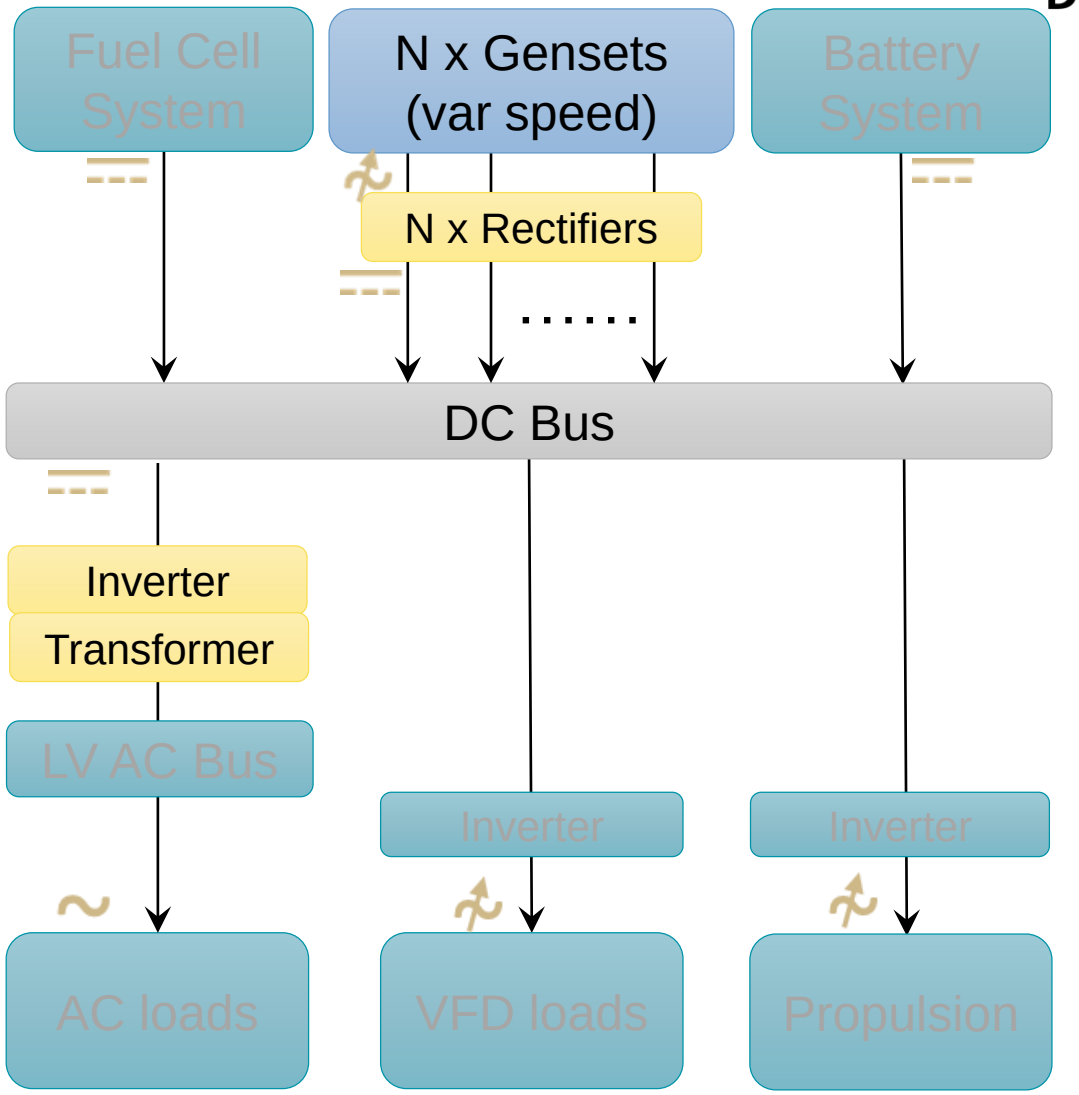
Grid Configuration in Modern Cruise Ships



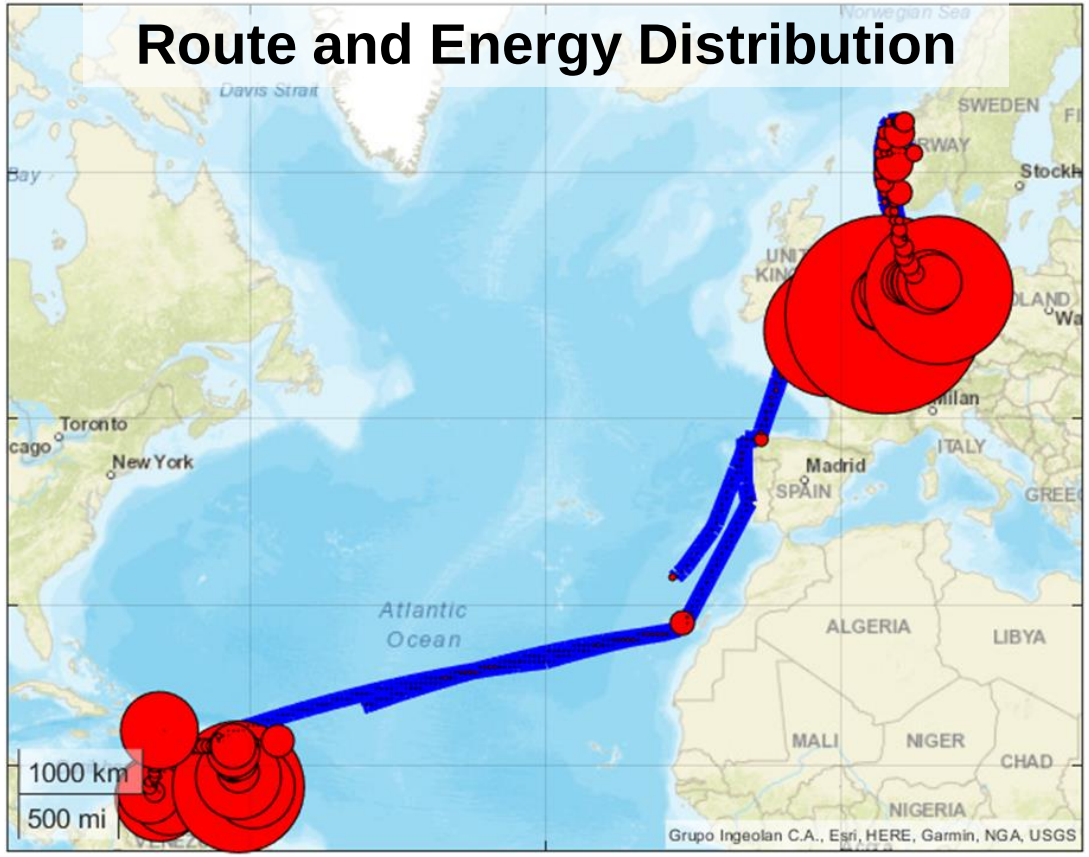


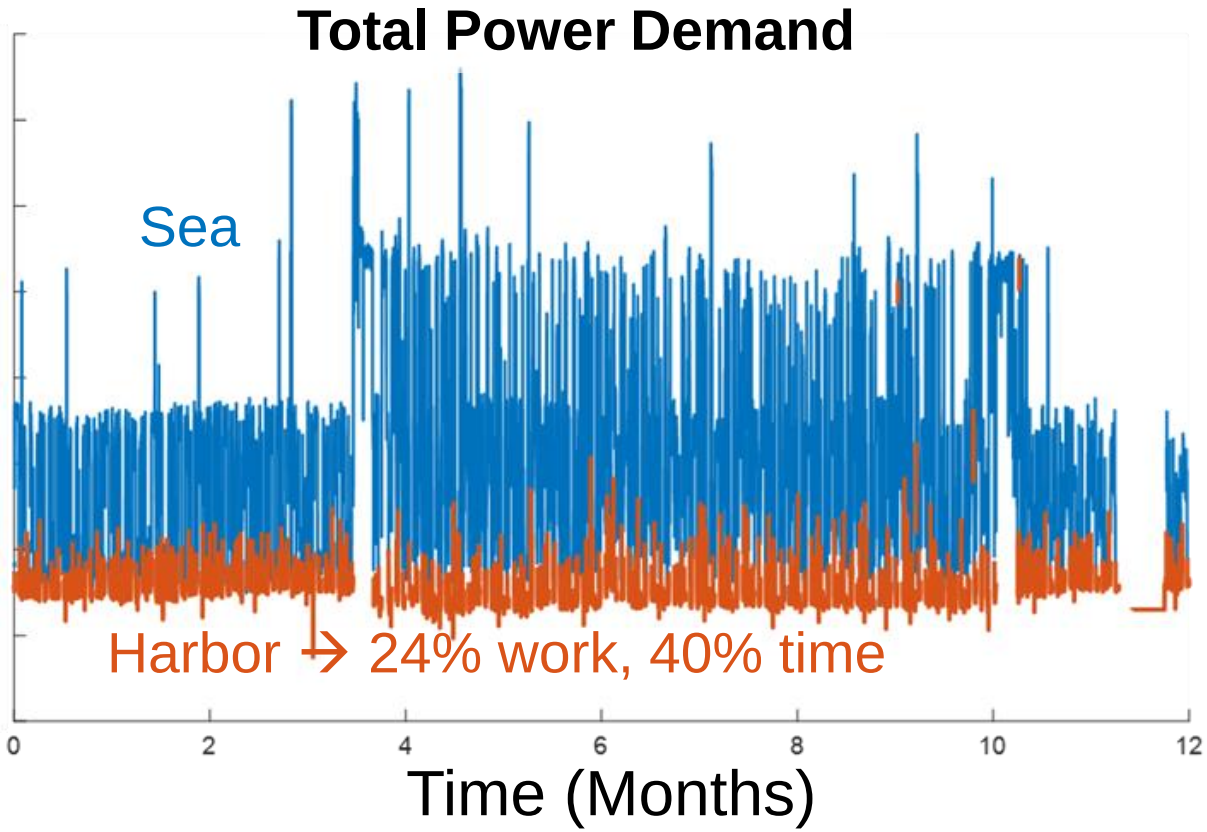
Grid Configuration in Modern Cruise Ships





Cruise Ship Operation

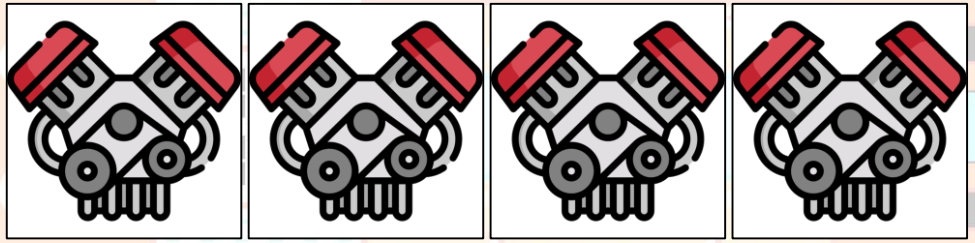




Pollutant-free operation in harbors and sensitive areas important

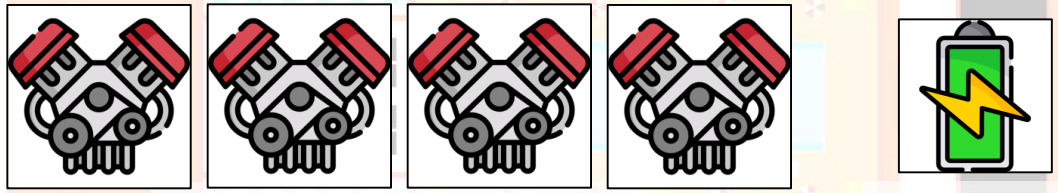
Energy System Configuration

Original



4 x Diesel Gensets

Gensets + Battery

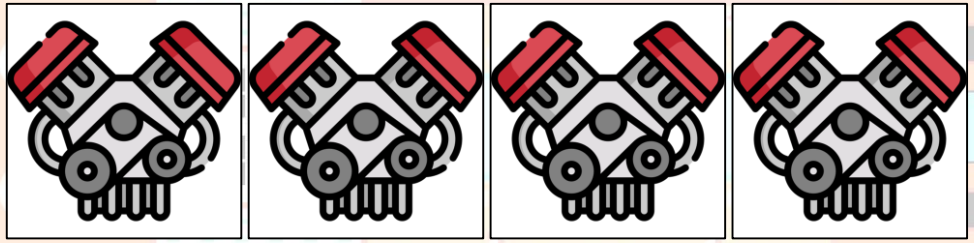


4 x Diesel Gensets **Battery**

Power Rating 90% 10%

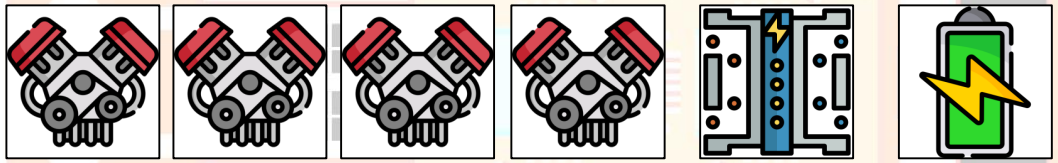
Energy System Configuration

Original



4 x Diesel Gensets

Gensets + Battery + Fuel Cell



4 x Diesel Gensets **PEMFC** **Battery**

Power Rating 60% 30% 10%

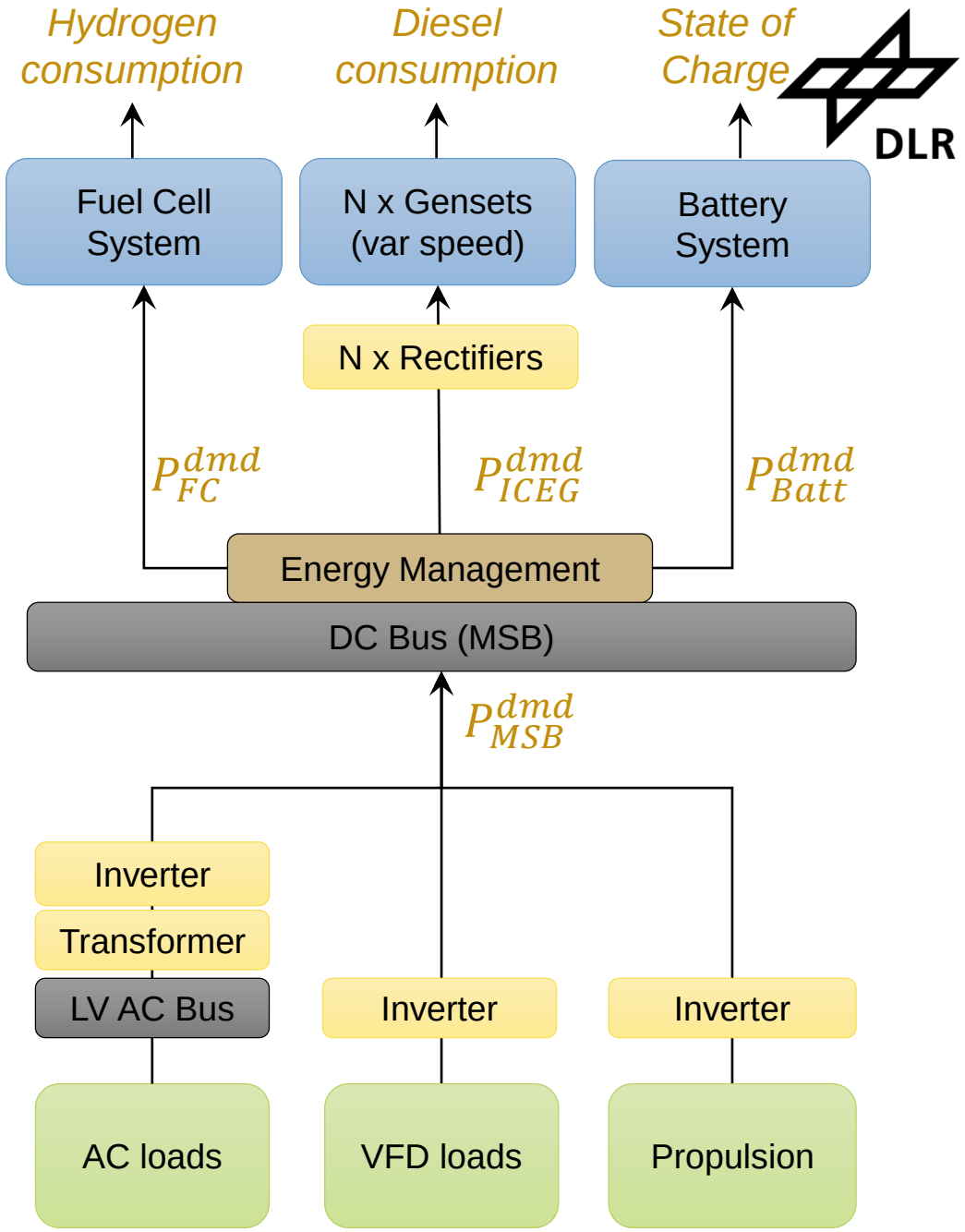
Simulation Setup

- Backward model
- Static efficiency maps
- Lumped loads
- Power-domain analysis

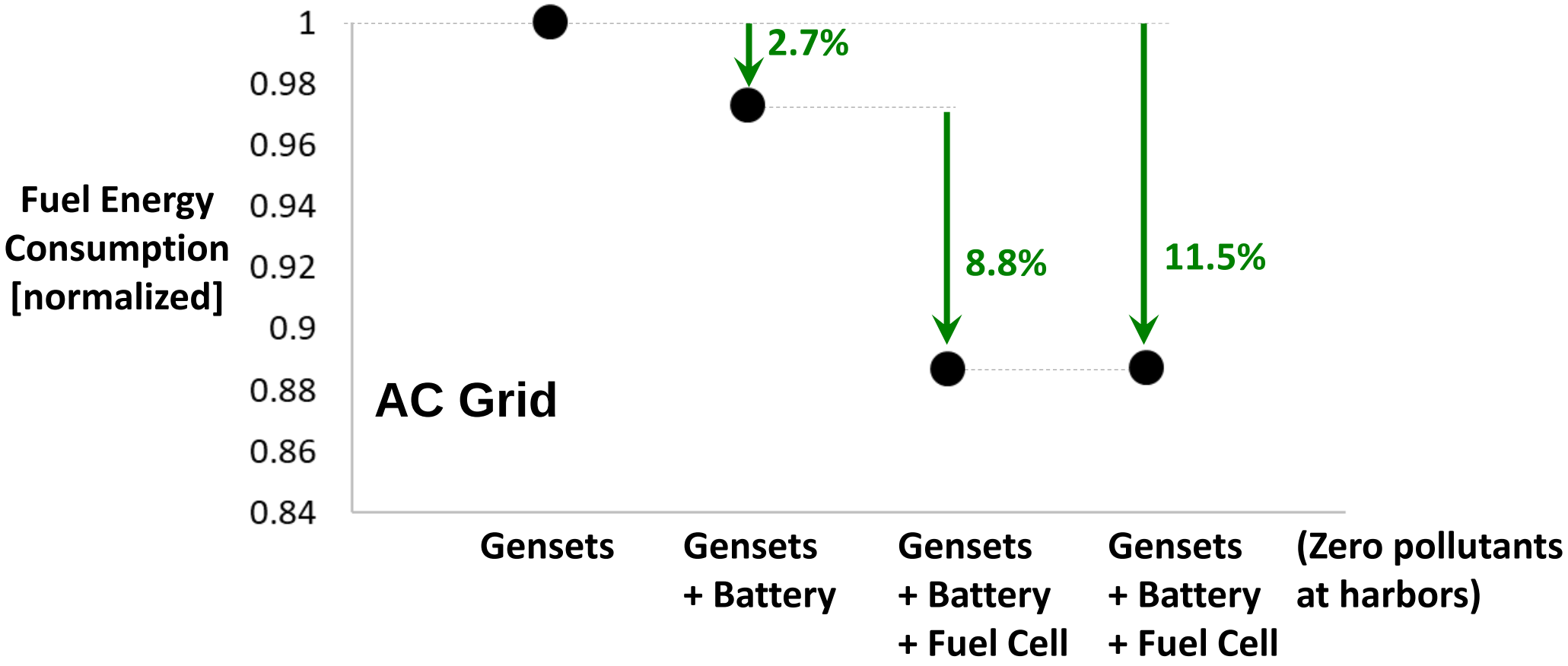
Model Outputs:
Fuel consumption

Model Parameters:
- Component efficiencies
- Component sizes
- Energy Management

Model Inputs:
Load profiles of lumped consumers

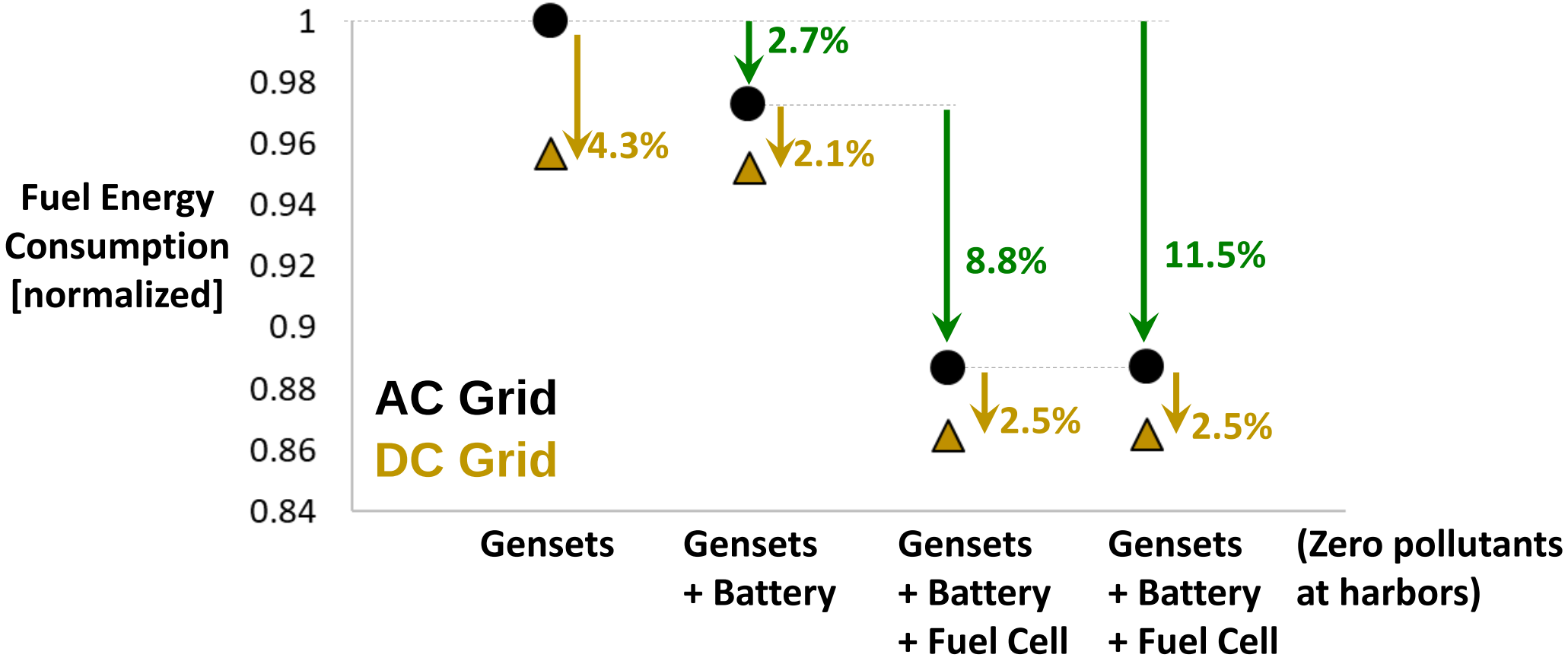


Results – Fuel Energy Consumption



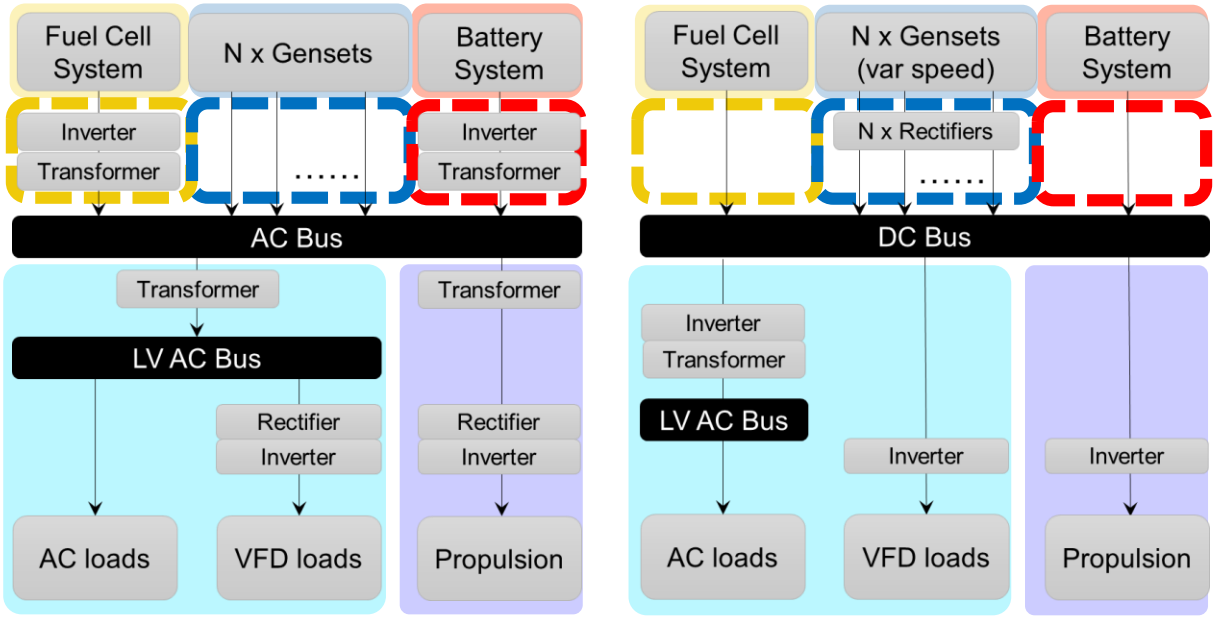
Batteries and fuel cells can yield up to 11.5% energy savings

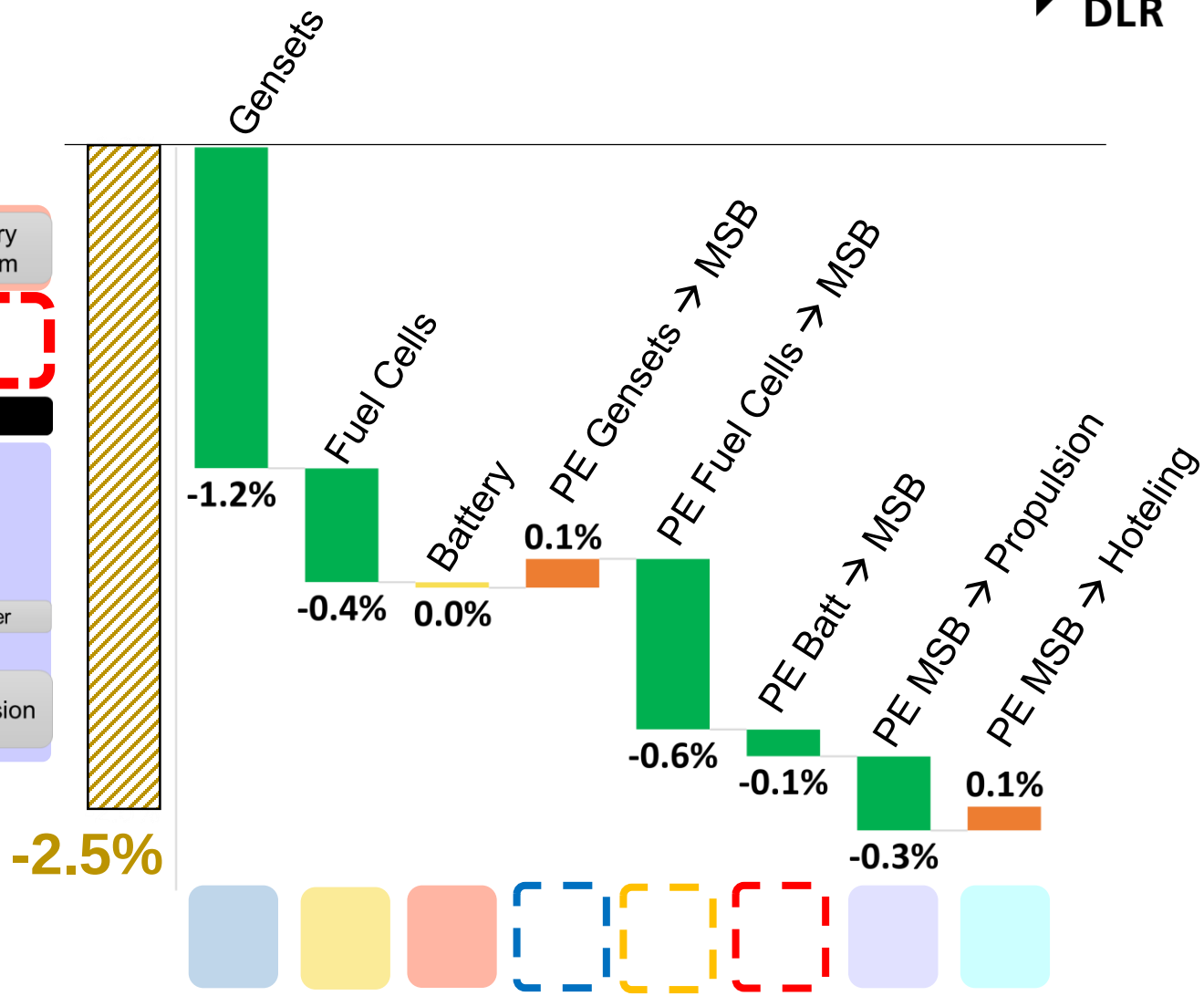
Results – Fuel Energy Consumption



DC grid promises further energy savings of 2.1% – 4.3%

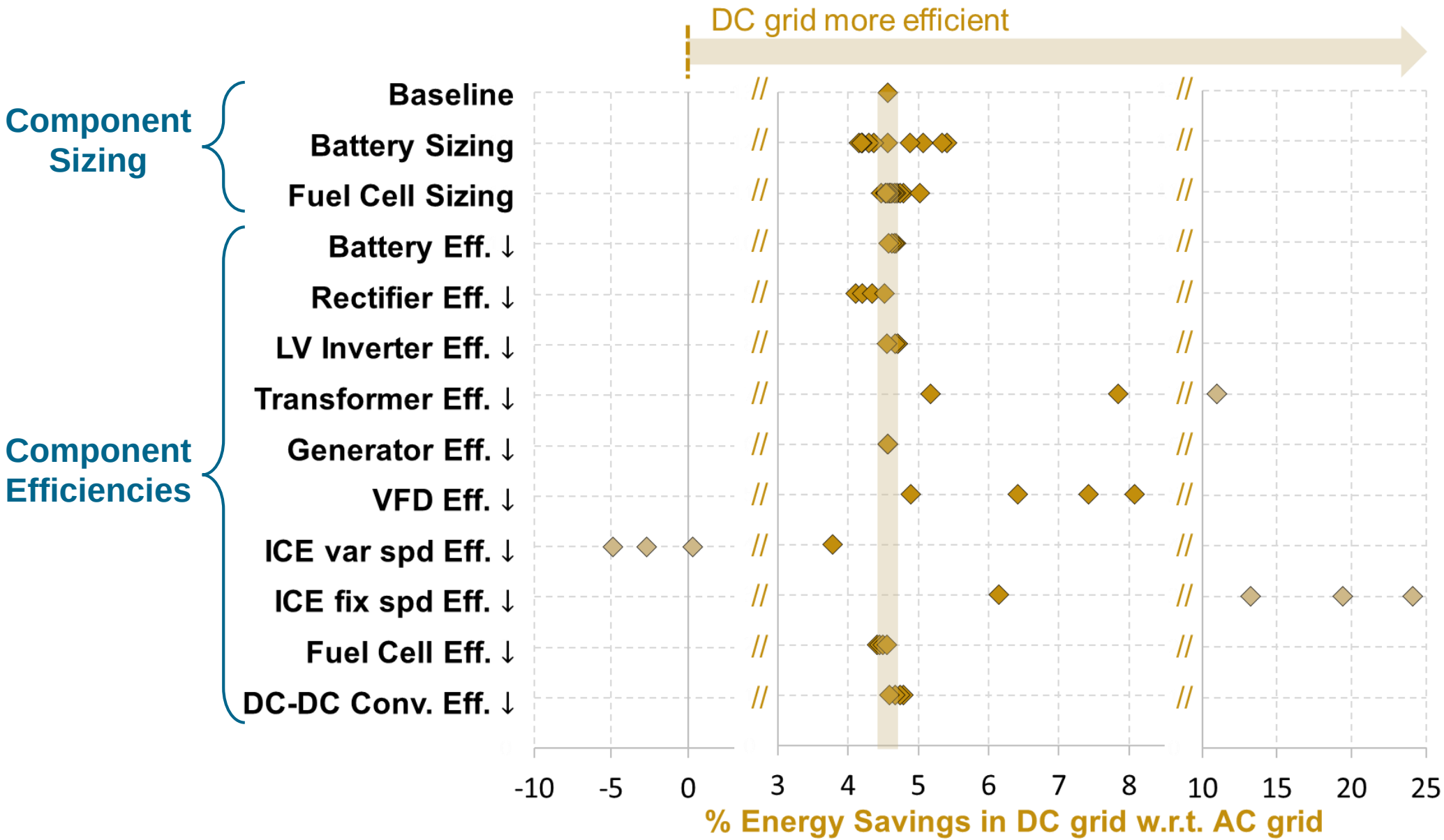
Analysing the 2.5% energy savings of DC grids -





MSB: Main Switch Board
PE: Power Electronics

Sensitivity Analysis



Energy Management

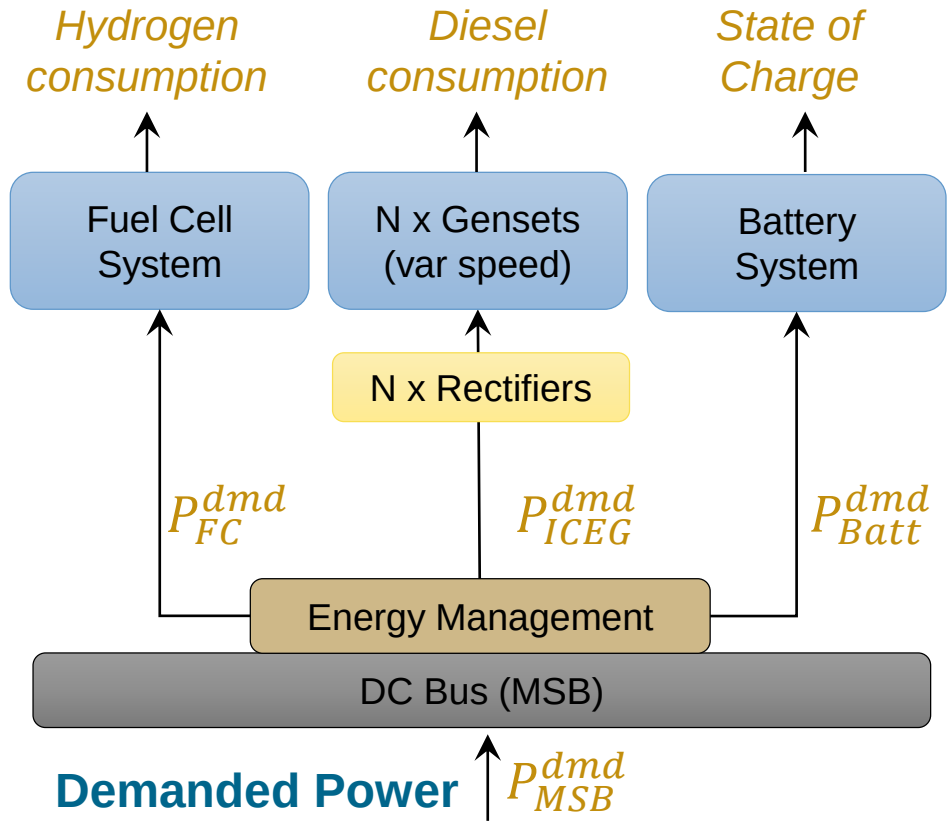
How should the total demanded power be split between all the power producers?

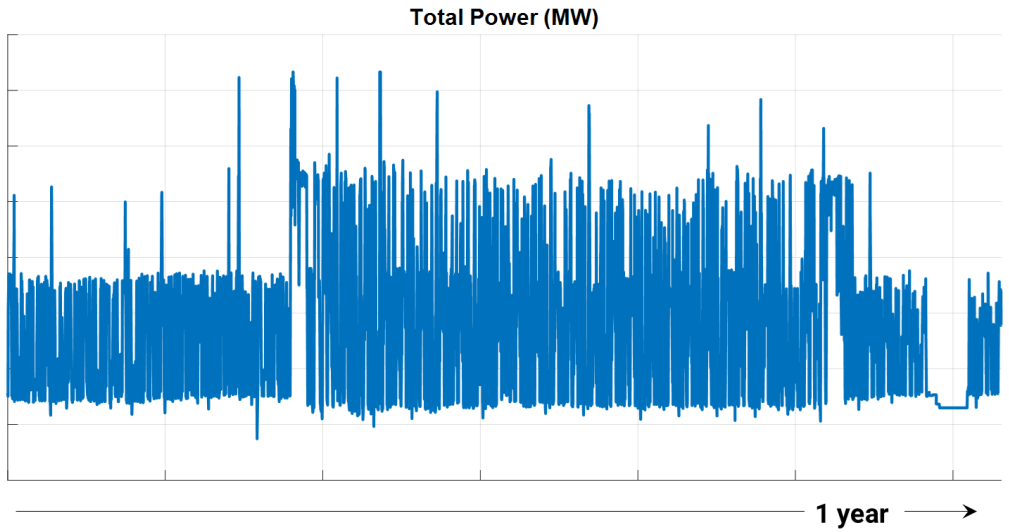
Rule-Based Techniques

- Intuitive and robust
- Easy to implement & diagnose
- Not optimal – depends on how good the calibrator or the designer is

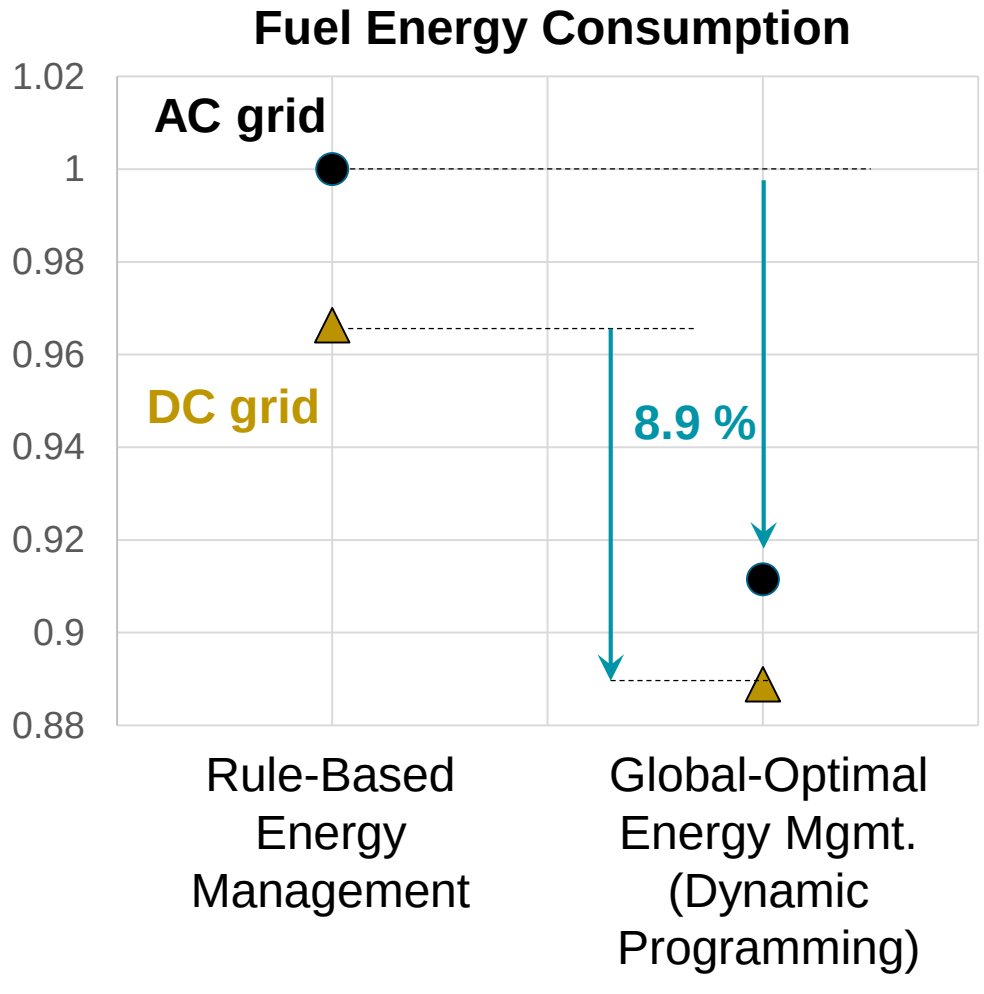
Optimization-Based Techniques

- Optimal/ close-to-optimal solution
- Computationally intensive – real-time implementation challenging
- Knowledge/ prediction of future conditions needed





Energy Management



The optimal energy management strategy is 8.9% more efficient than the rule-based algorithm …

… however takes significantly longer to computationally execute

Real-time near-optimal energy management strategies necessary for future maritime energy systems

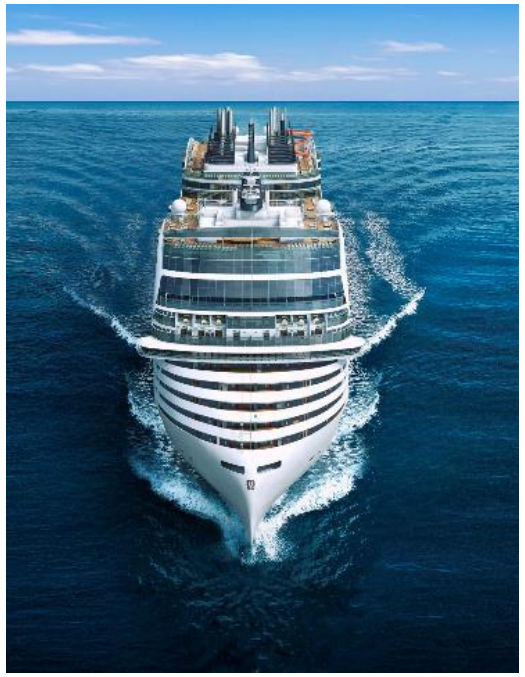
Conclusions

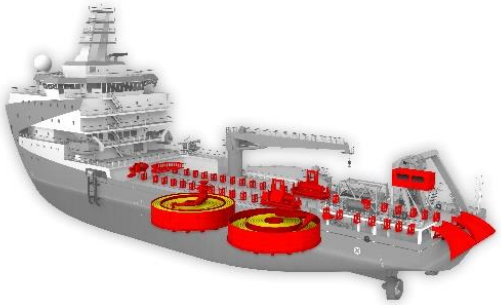
- PEM Fuel Cells and Batteries can enable up to 11.5% energy savings
- DC grids promise further energy savings of 2.2% - 4.3% over AC grids
- Zero-pollutant ship operation at ports and sensitive areas without fuel penalty
- Energy Management critical for hybrid energy system configurations

Upcoming: SOFCs in maritime applications

Horizon Europe-funded project, 2022-2027

- **500 kW** LNG-SOFC-pilot demonstration at TRL7 on a cruise ship by 2027
- **Applicability** over various maritime use cases - cruise ships, dredgers and offshore vessels
- **Scalability** up to 20 MW including hoteling and share of propulsion loads
- **Fuel flexibility** with carbon-neutral fuels





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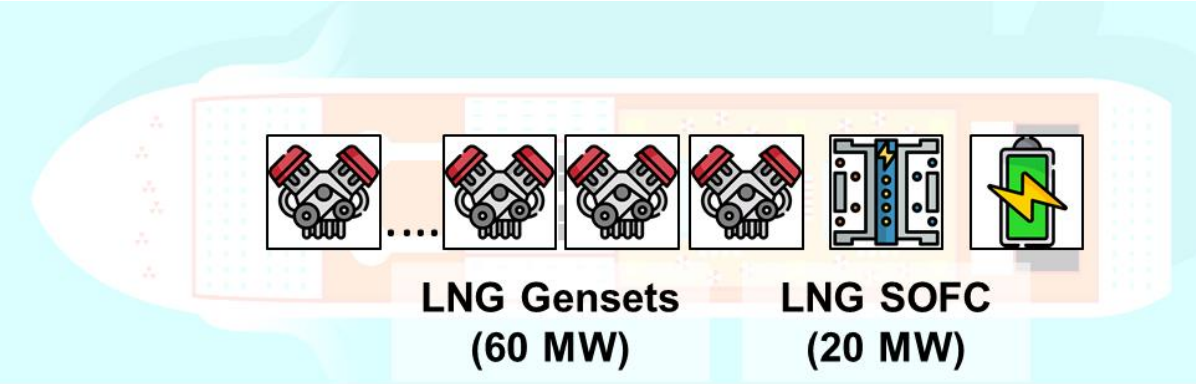


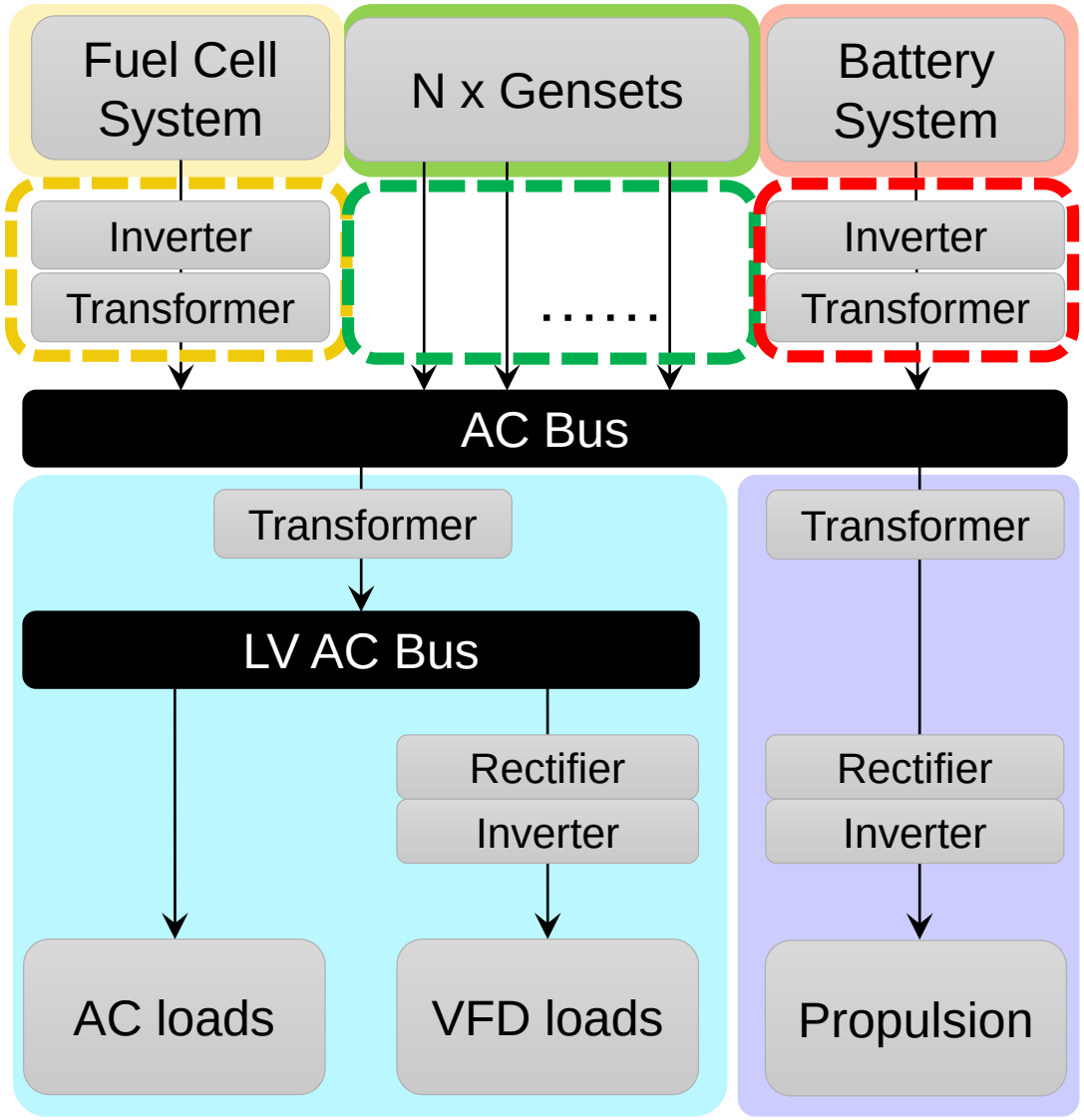
23% GHG reduction expected

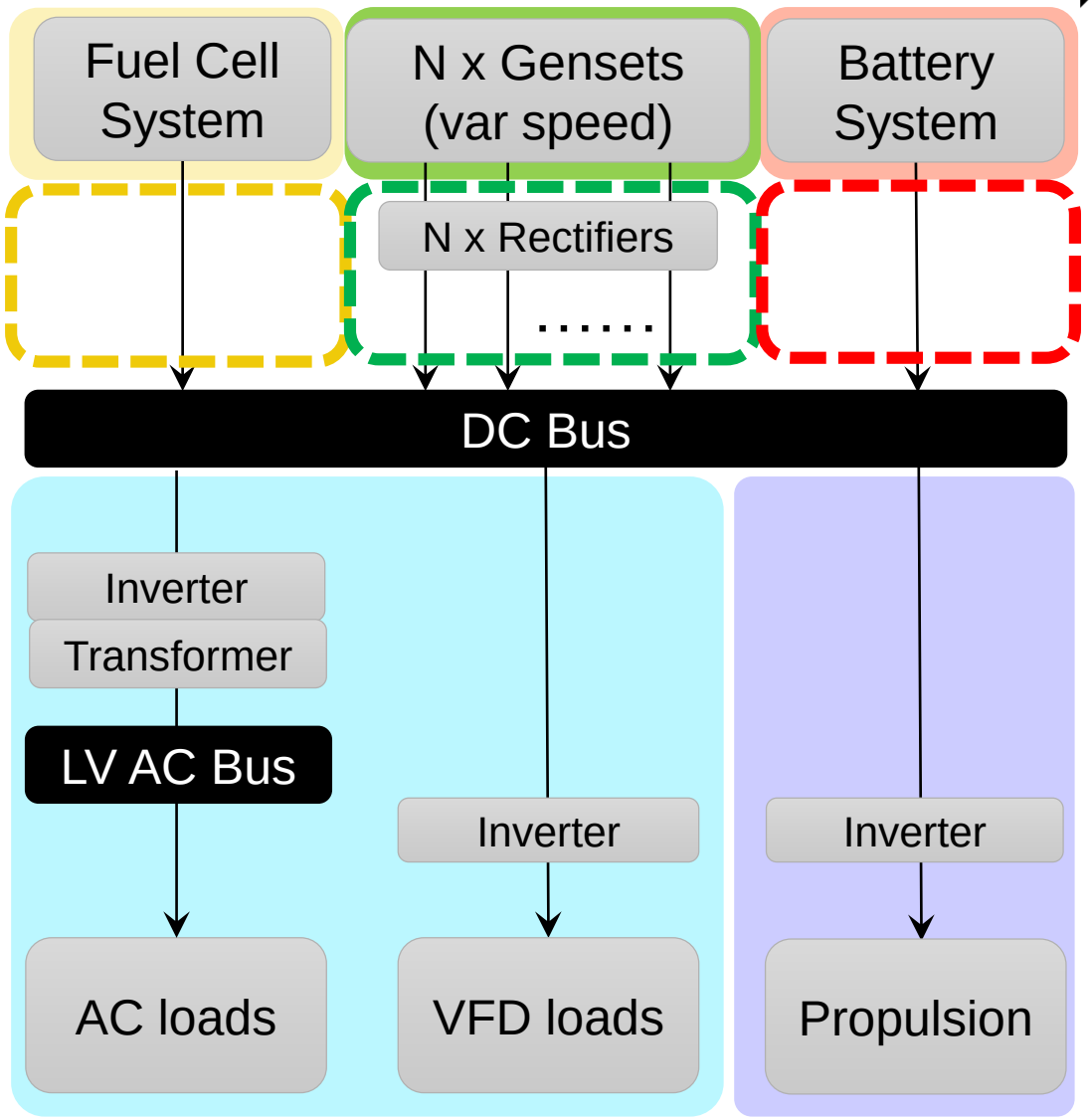
Decarbonizing waterborne transport using fuel cells and DC grids

Dheeraj Gosala

Research Scientist, DLR Institute of Maritime Energy Systems

05.01.2024


Fuel Cell System
N x Gensets
Battery System
Inverter
Transformer
.....
Inverter
Transformer
AC Bus
Transformer
Transformer
LV AC Bus
Rectifier
Inverter
Rectifier
Inverter
AC loads
VFD loads
Propulsion


Fuel Cell System
N x Gensets (var speed)
Battery System
N x Rectifiers
.....
DC Bus
Inverter
Transformer
LV AC Bus
Inverter
Inverter
AC loads
VFD loads
Propulsion

Interdisziplinarität der Abteilungen

2 Energie- und Infrastrukturabteilungen

- Energieinfrastrukturen (EIN)
- Energiekonverter und -systeme (EKS)

3 Schiffbauliche Abteilungen

- Schiffsperformance (SPF)
- Schiffszuverlässigkeit (SZV)
- Schiffsintegration (SIG)

2 Holistisch integrative Abteilungen

- Virtuelles Schiff (VIS)
- Maritime Forschungsanlagen (MFA)