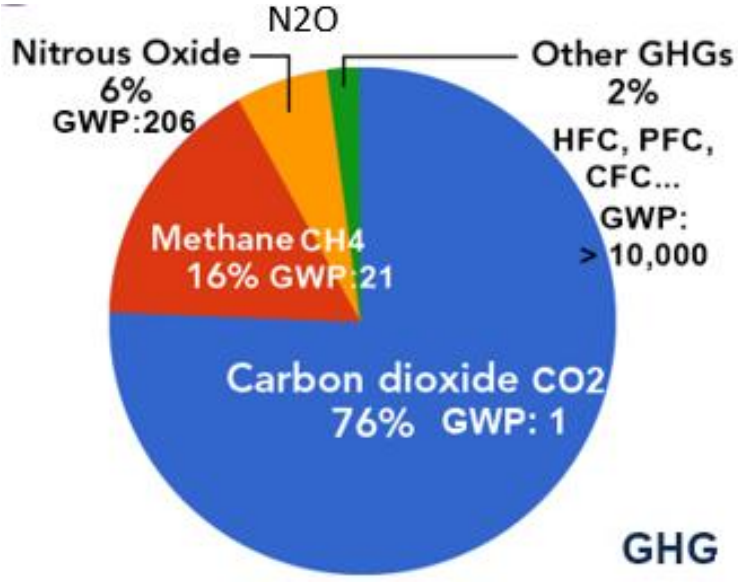
ENTERING A NEW ERA FOR ELECTRICAL VESSELS ON INLAND WATERWAYS

Jean Michel Chatelier

Table of contents

Introduction

Challenge!



ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

-40% CO_2

-50% GHG

-70% CO_2

2021
Nth warning from IPCC

2030
Almost tomorrow!

2050
Measure the effects

*as compared to 2008

SUSTAINABLE DEVELOPMENT GOALS

IMO NEW TECHNOLOGIES FOR GREENER SHIPPING

Challenge!

CCNR
COMMISSION CENTRALE
POUR LA NAVIGATION DU RHIN

2018	2035	2050	
	-35% GHG & PM	Zero GHG & PM	0%
Ministerial Mannheim Declaration	Report on progress in 2023	GHG & other pollutants largely eliminated	

*as compared to 2015

Purpose & objectives

There is a growing expansion of port requirements and environmentally controlled areas (ECA).

Electrical propulsion is part of a growing list of solutions to carbon-neutral or zero-emissions shipping.

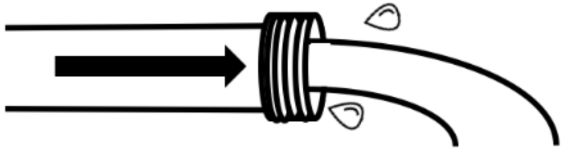
Batteries and fuel cells become a strong choice. There is also a large range of hybrid solutions which can be combined with alternative fuels.

The presentation proposes a short review of state-of-the-art electrical solutions, considering technologies, safety and operational challenges, bringing to light the experience of Bureau Veritas in electrical vessels, in both new constructions and conversions as well as in vessels in service.

Purpose & objectives

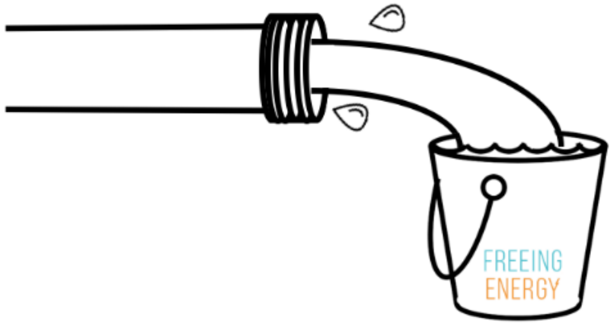
Electric Power vs Energy

Power — Watts or kilowatts



...is like the flow rate of the water

Energy — Watt-hours or kilowatt hours



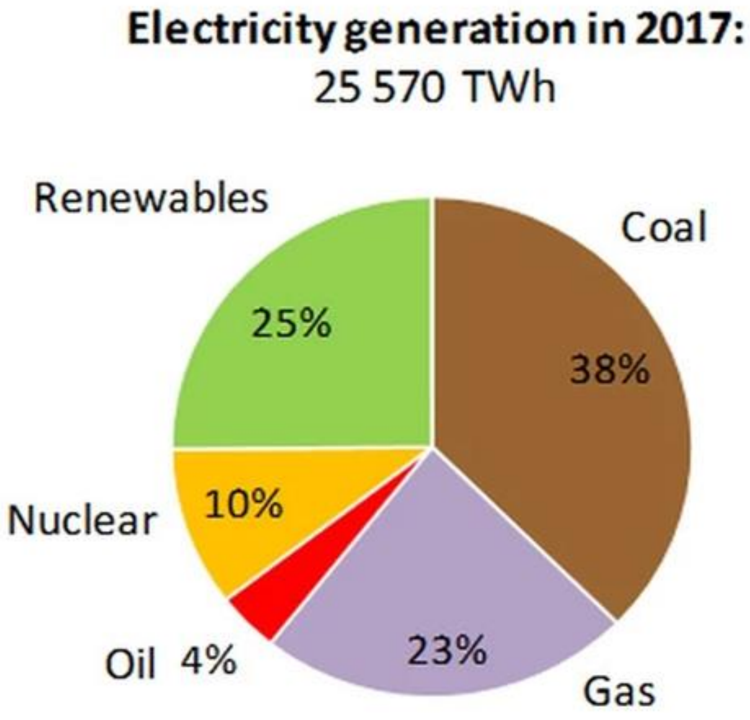
...is like the the amount of water that ends up in the bucket

$$E = Pt$$

Energy consumed (E), Power (P), Time (t)

Technical aspects

Battery



Batteries are the central part of the electric system which store the energy and release it according to the needs of the vessel.

Energy is required to produce electricity used for battery charging: the assessment of environmental footprint depends on how the electricity is produced.

Battery charging can be from shore, generator, fuel cells, solar panels…

Lead batteries have been used to provide back-up power to ships: low CAPEX, reliable and recyclable, but low energy density, heavy and bulky, with no option of fast charging.

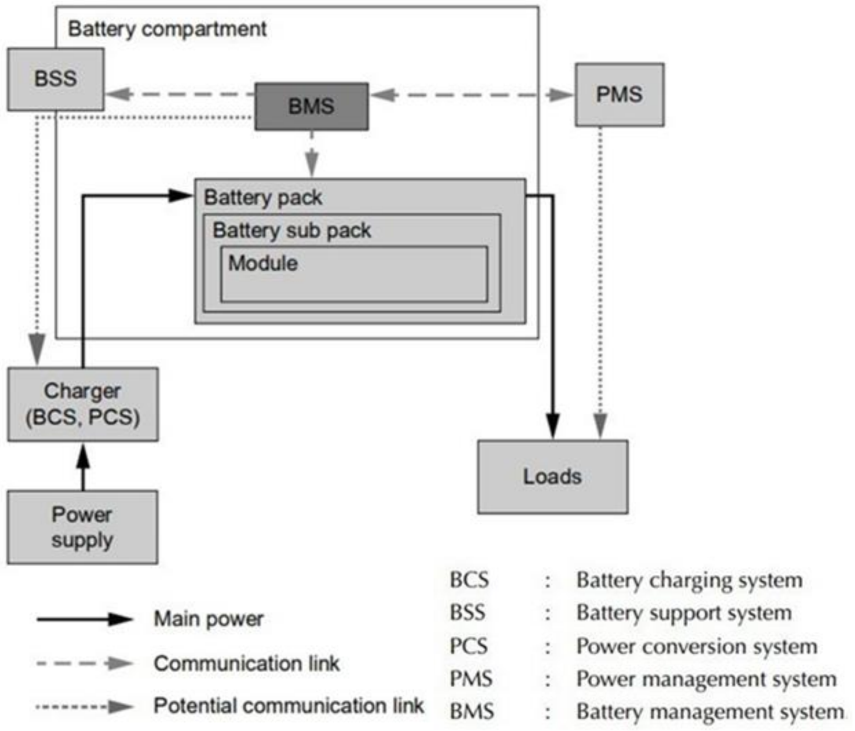
Lithium-ion battery technology is developing fast. Those batteries are the best energy density on the market (200Wh/kg).

Li-ion batteries design and characteristics depend on need for power or energy. They can be designed to meet demands for high energy / low current / long discharge applications to those operating with high-power pulse output.

C Rate is the current which described how fast the cell is charging or discharging.

Battery

They can enable ships to run in zero emissions mode when they function as the only source of electricity.



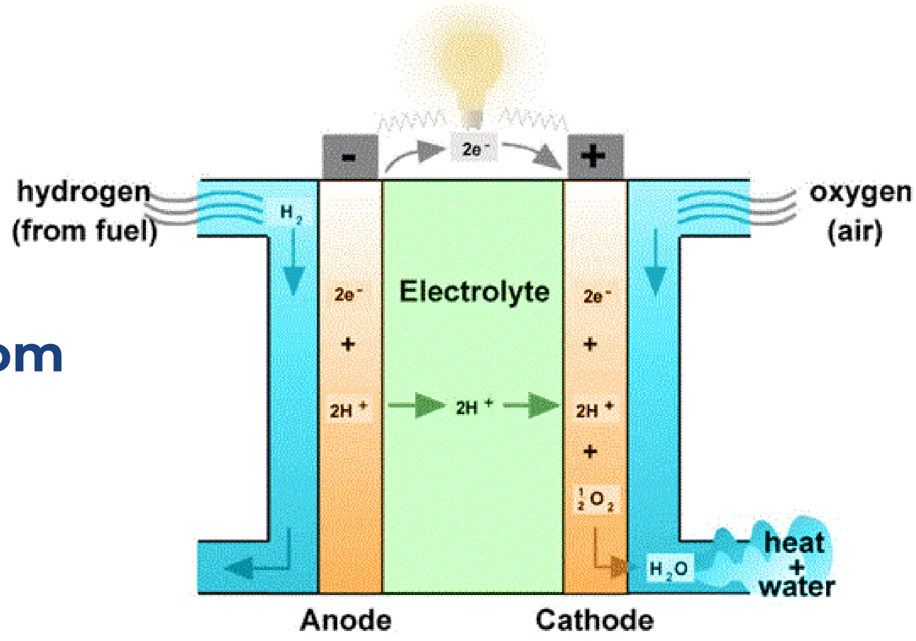
Various types: e.g., Lithium iron phosphate (LFP) and Lithium titanium oxide (LTO).

⚠ ! Risk of uncontrollable thermal runaway exists.

Battery management system (BMS) monitors and manages electric and thermal state, and provides communication with other macro-system controllers, such as a power management system (PMS). The BMS monitors the modules, sub-packs, packs (voltage, temperature) and controls proper connection / disconnection of battery packs and sub-packs when in critical state.

Fuel cells

Fuel cells is a device which convert chemical energy from hydrogen (H2) into electrical energy to create a direct current through the electrochemical reaction between hydrogen and oxygen from air.



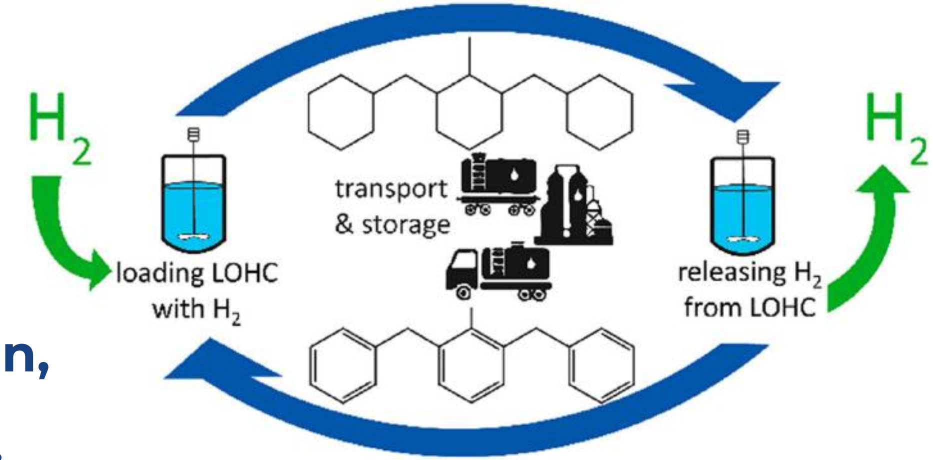
To date, fuel cells have seen limited application in the marine industry, and installations and components have still to be adapted and approved for the marine environment.

Depending on the fuel and electrolyte, fuel cell technology covers a range of cells. The choice between these technologies will depend on parameters such as starting time, operating temperature, power, and lifetime.

PEMFC is the most used, but it needs only pure hydrogen and requires platinum as a catalyst. It is compact and runs at 80°C. The axis of improvement would increase the temperature (up to 200°C) for better efficiency, while the lifetime could be increased.

⚠ Special care is required when handling hydrogen as it is flammable, explosive, and prone to leak.

Fuel cells



In view of challenging storage and carriage of hydrogen, Liquid Organic Hydrogen Carriers (LOHC) provide significant advantages in terms of availability, recharging, and safety.

SOFC is suitable for heavier power requirements. It is operated at high temperatures (800 – 1,000 °C) and requires a significant start-up time. It stands out with the advantageous feature of fuel flexibility since it is not limited to pure hydrogen.

Several possible LOHC, including Methanol (MeOH) and Ammonia (NH3).

To date, fuel cell is not able to supply a sizeable ship alone. The dynamic of the fuel cell is not able to face the load impact coming from the starting / stopping of large auxiliaries.

In combination of fuel cells and batteries, the high discharge rate of batteries can compensate for the low dynamic of the fuel cell discharge current, the fuel cells deliver a continuous current used to supply the vessel and charge the batteries.

Hybrid

By definition, “hybrid” is of mixed character, a composition of different elements, where each of it can commonly serve propulsion and services.

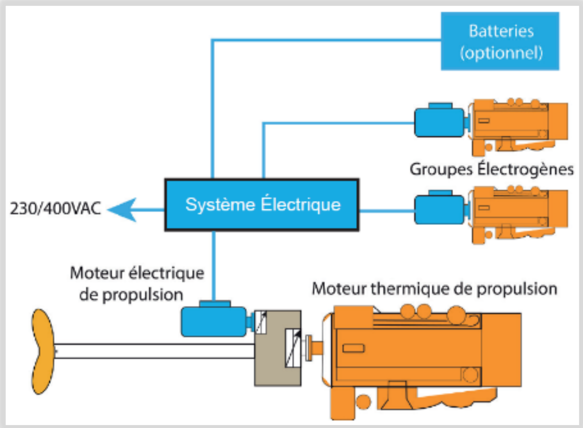
Commonly, hybrid systems are based on diesel-electric system coupled with battery system.

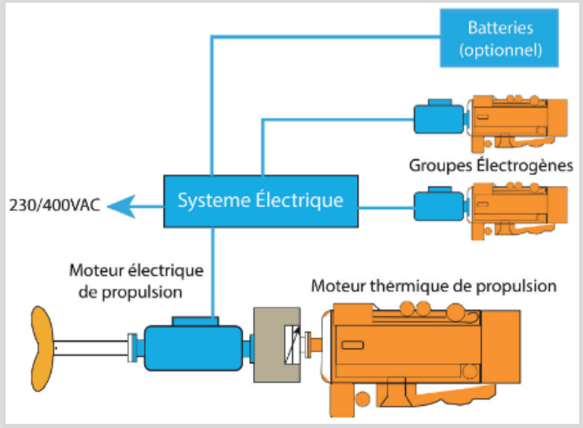
To reduce gas emission, diesel engines would be replaced by alternative fuel engines, such as LNG (or CNG) or biofuels (form of energy derived from the harvesting and processing of different types of biomass, including waste, charcoal, wood, fishery and agricultural products).

Hybrid

There are two main types of electrical hybrid:

hybrid propulsion and hybrid production.





Hybrid propulsion:

- Parallel hybrid concept: the electrical motor is fitted in parallel of the propeller shaft. Either the thermal engine or the electrical motor can be used (or both), depending on the needs (e.g., urban operation, manoeuvre).

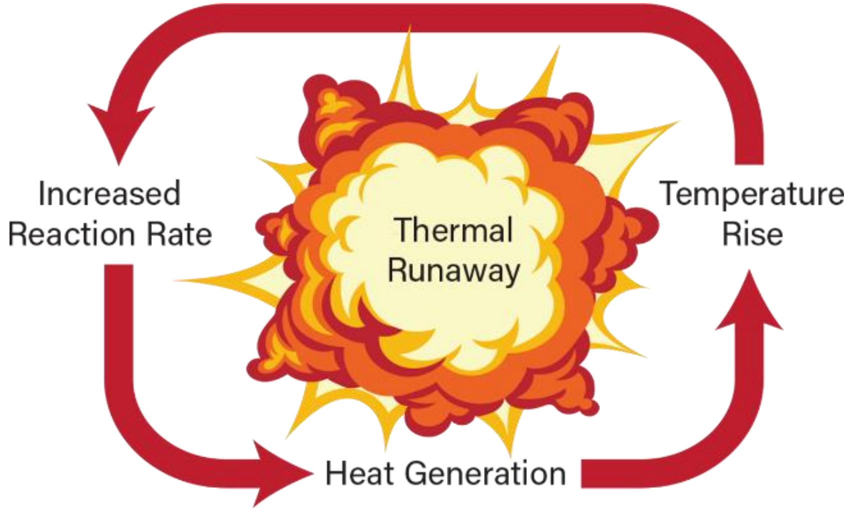
- The serial electrical hybrid: the electrical motor is fitted in series of the propeller shaft, avoiding mechanical loss due to reduction gear.

Hybrid production: Batteries are associated, wired in parallel with generator.

3 power management modes: Load smoothing mode, where the batteries are charged and discharged all the time to compensate for the network load variations, Peak shaving mode to supply peaks of a highly variable load (e.g., during manoeuvring), and Enhanced dynamic mode, where the batteries instantaneously supply the corresponding power demand.

Safety aspects

Battery



The primary safety challenge is "thermal runaway" which may occur due to increase in temperature (short circuit, overcurrent, overcharge, heating).

It causes a chain reaction, creating a large-scale conflagration, with flammable/toxic gas emission, possibly bursting, flame ignition, heat emission and thermal runaway propagation from cell to cell or battery to battery.

Standards are used to test batteries, such as IEC 62619 and 62620, while additional safety measures apply.

Manufacturers must carry out a risk analysis, including risk evaluation for sensor failure, internal and external short-circuiting, thermal runaway, fluid leakage, and possibility of gas release (toxic or explosive).

Shipyards must also perform comprehensive risk analysis, assessing ventilation systems, hazardous areas, and energy storage system spaces.

Floodable battery compartment would stop the overheating escalation process in case of fire.

Battery

Battery cells and battery packs must be type-approved with prototype tests conforming to a national or international standard.

The type approval must cover both the battery pack and the BMS.

Bureau Veritas class notation “Battery System” must be assigned to ships relying only on batteries for propulsion or electrical power supply for main sources.

The fire-extinguishing system must be suitable for the battery type. There are also specific requirements for ventilation.

NR320 “Certification Scheme of Materials and Equipment for the Classification of Marine Units”

NR544 “Requirements for survey of materials and equipment for the classification of inland waters-operated vessels / units”

NR217 “Rules for the classification of inland navigation vessels”

NR467 “Rules for the classification of steel ships”

Fuel cells

Hydrogen has one of the widest explosive/ignition mix ranges with air.

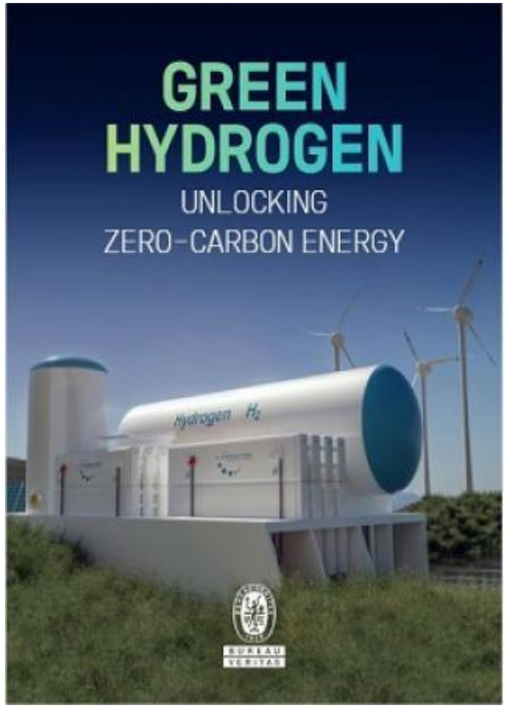
Hydrogen application entails specific procedures regarding transportation, bunkering, storage at high pressure or very low temperature, and use.

As with batteries, specific rules and standards are used to test the fuel cells, and a risk analysis of installation must be performed to assess the ventilation systems, hazardous areas, and fluid leakage. This risk analysis must cover installation, but also gas storage and supply piping.

Using LOHC implies to implement the corresponding safety measures.

Fuel cells

The functional requirements are based on fail-safe design principles (minimize hazardous areas and ignition sources, arrangements to sustain or restore operation, shutdown arrangement, fire detection, fire protection, etc.).



Bureau Veritas' Rule book NR547, "Ships using Fuel Cells", covers fuel cell technologies and multiple alternative fuel types, each with their own risk profile.

NR547 focuses on the fuel cell system, it must be used in conjunction with several other Rule Notes for alternative hydrogen carriers, including methanol (NR670), LNG (NR529), and ammonia (NR671).

An extensive range of risk assessments must be carried out to be granted the "fuelcell" notation, including HAZID (hazard identification) study of fuel cell spaces, HAZOP (Hazard and Operability) study of fuel cell power system, and FMECA (Failure Mode, Effects & Criticality Analysis) analysis of fuel cell power installation when used for essential services.

Hybrid

Hybrid design allows multiple solutions where the alternative fuels and technologies can be combined.

The regulations and the classification Rules applicable to each part of the complete system cover the risks generated by each fuel or technology.

Pilot boat, Penguin International - Singapore

The notation **"Electric Hybrid"** caters for vessels fitted with a combination of diesel engines and batteries used to supply the electric propulsion or the main electrical power distribution system (Rule book NR467).

The ESS is not considered as forming part of the main source of electrical power and it remains independent of the emergency source or transitional source of power. A Failure Mode and Effects Analysis (FMEA) demonstrates the availability of ship propulsion and main electrical source of power in case of failure of the ESS.

"Electric Hybrid" must be completed with either:

• "PM" for Power Management mode (load smoothing mode, peak shaving mode, enhanced dynamic mode).

• "PB" for Power Back up mode where the ESS is permanently connected to the main electrical power distribution system and is able to deliver power immediately in case of failure of one main generating set.

• "ZE" for Zero Emission mode where the ESS is temporarily the only source of power connected to electrical network. The ZE mode is activated intentionally.

Hybrid

POA1 – Port of Antwerp

The notation "Hybrid Mechanical Propulsion" may be assigned to vessels provided with a propulsion plant which combines diesel mechanical system and electric system.

It provides requirements for remote and local control of both systems and switch over from one propulsion type mode to another one. The notation does not require battery.

The additional notation AVM ("Availability of machinery") is relevant to systems enabling the ship to carry on limited operations when single failure affects propulsion or auxiliary machinery or when an external event such as fire or flooding affects the availability of the machinery.

The notation is complete with the system (i.e., Alternative propulsion, Duplicated propulsion or Independent propulsion).

Operational aspects

Battery

Ships need to recharge their batteries by connecting to the electrical grid in port. Ports must have the suitable installations and electrical capacities, coming from renewable sources.

Batteries can also be charged with onboard generator sets, using decarbonized fuels.

The average cost of lithium-ion batteries has declined by 89% since 2010 ($132/kWh in 2021). Shipowners anticipated lower prices thanks to improved technology and increased competition.

The cells make up only 40-50% of overall battery pack cost. BMS is significantly expensive (it depends on the nominal voltage and the quantity of parallel stacks). Large power systems level up in BMS design.

Li-on batteries are preferred but they suffer from ageing and there are additional safety concerns. Beyond providing critical safety information, BMS also enables ship operators to optimize energy use and availability, and increase battery lifetime.

Swappable containerized battery

The swappable containerized batteries system may help accelerate electrification of inland waterway traffic with a lower investment for shipowners and operators.

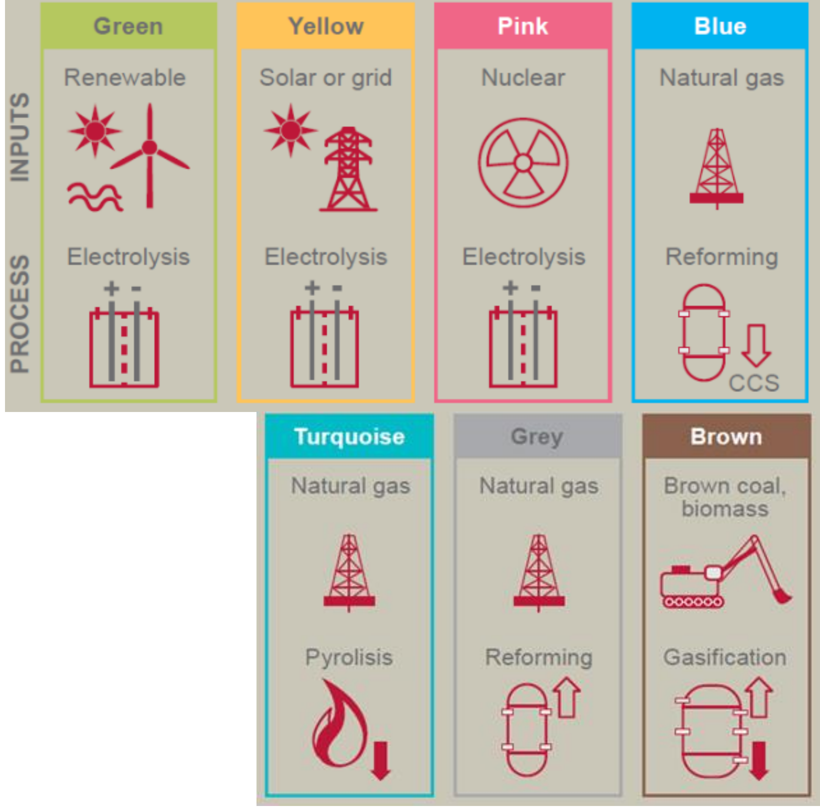
It is notably interesting when operation constraints do not give enough time for recharging.

Roughly, considering the volume of a 20' container, 1 MWh of batteries - with DC voltage supply - or 3 MWh of batteries - with AC Voltage - can be installed. A 3 MWh containerized battery pack can be integrated on board within minutes when using a swap-and-carry concept.

A battery container needs to fulfil all regulatory requirements from structural and fire integrity aspects.

The distance between swaps is the key point. There is a necessity to build a network of stations along the route and pay the associated cost for the system.

Fuel cells



Hydrogen is increasingly viewed as a contender among alternative fuel solutions, receiving increased investment.

Meanwhile, creating hydrogen by splitting water by electrolysis is a costly process. ~50 kWh of electricity to produce 1 kg of H2 (~33 kWh of energy).

There is a high initial cost of hydrogen installation, and storage and transport are complex due to hydrogen's low energy density by volume and special pressure/temperature requirements (storage under high pressure, 350 bar even 700 bar, or cryogenic, -253°C).

One must consider the fuel cell system cost and the hydrogen fuel cost. Manufacturers of fuel cell system estimate a price reduction down to € 1,000/kW towards 2025.

International distribution could arrive by 2030 at total costs of $2-3/kg (excluding cost of production). Projections show that renewable hydrogen production costs could decline to $1.4 to $2.3 /kg by 2030.

Fuel cells

The fuel cells are not marinized yet since they come from the car industry where proven equipment have been developed.

If one of the LOHC is used instead of pure hydrogen, the technology and equipment must be suitable for the fuel, and the specific regulation must be complied with.

Investment depends on the type of equipment corresponding to the fuel, including safety aspects, and operational costs are dependent on availability of bunker stations.

Once fuel cells are integrated onboard, ship operators must safeguard crew and ensure appropriate training for proper handling of fuel cell equipment.

Hybridization with batteries is expected to increase the lifetime of the fuel cell system significantly.

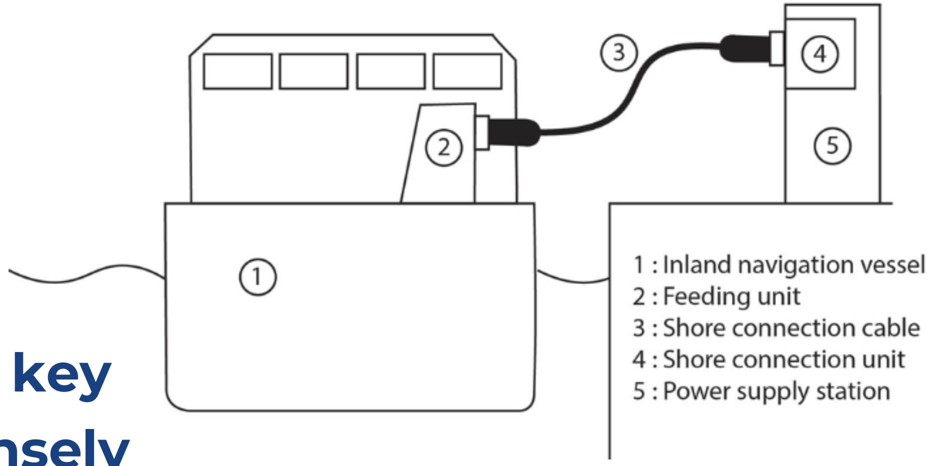
Hybrid

There is a multitude of solutions, each of them with its own advantages and disadvantages, depending on the technology and fuel.

From an environmental point of view, the efficiency of the solution would imply using biofuel – made from sustainable source – or natural gas, or other alternative fuel.

Electrical hybrid solution may save on fuel, however the expected reduction in consumption depends on the engine load. It would be more significant during manoeuvres (e.g., ferries).

Power in port



Supply of electricity to vessels in port has become a key issue in the fight to reduce exhaust emissions in densely populated areas.

Power installations at berth are technically sophisticated and must provide enough power to supply several vessels simultaneously. Distribution systems and power receptors must also be harmonized so that a ship can connect in each port with its own onboard equipment, while the installation must also cater for many different types of vessel.

To guarantee the effective safety and functionality of installations, there are appropriate technical standards, depending on the nominal power of the shore installation, e.g., European Norms EN15869-1: 2019, EN15869-3, EN16840, as well as Bureau Veritas' Rules. The additional class notation "HVSC" (High-voltage shore connection systems) may be assigned to ships fitted with electrical and control engineering arrangements allowing operation of services by connection to an external high-voltage electrical power supply in port. The requirements for the assignment of this notation are given in the Rule note NR557.

Conclusion

Conclusion

Operators must make their choice depending on vessel type and operational constraints, while also anticipating future fuel alternatives, availability and pricing, and managing challenges of safety and regulatory requirements.

Technologies

Fuel availability

Safety equipment

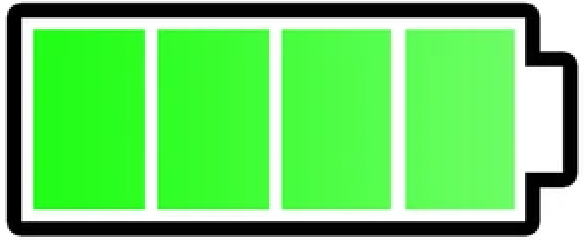
Infrastructures

Cost

Electrical propulsion is increasingly emerging as an alternative solution. Battery systems, fuel cells, and hybrid, in combination with other technologies and alternative fuels, can achieve reductions in pollution, noise, maintenance costs and fuel consumption.

Those solutions are set to play an important role in the shift to sustainable shipping, especially on those vessels transiting waterways and estuaries, travelling short and fixed distances, such as ferries and vessels engaged in harbour operations, but also those sailing on waterways benefiting from suitable infrastructure and designed for fast recharging or swappable battery containers.

Battery



The battery market is now nearly mature, and regulations are well established.

The market for battery systems of lithium-type is increasing, with a growing number of vessels in operation and under construction.

For small-to-medium sized ships on short-haul voyages with multiple port calls – such as passenger ferries, tugs, and specialized vessels – using batteries to store energy may be a viable option.

As progress is made and economies of scale are triggered by the uptake of the technology by terrestrial transportation, the cost of batteries will become more favourable. However, extra cost would remain about safety construction and equipment as well as for battery management.

The positive effect on the environment will depend on how electricity used for charging batteries is produced, either from shore grid or generator on board.

The swappable container solution could be an interesting option, with adaptations of the deck arrangement, mainly for vessels operating short distances, but it would require an extensive network of stations for vessels sailing long haul.

Fuel cells

Hydrogen fuel cells are developing quickly, and they could be serious contenders for vessels that require limited autonomy.

So far, the adoption of fuel cells has been hindered by their short service life and price. Also, the majority of these cells are not adapted yet for marine.

Hydrogen storage remains a technical obstacle that will be expensive to solve in the short term. Currently, there is almost no infrastructure in place for hydrogen bunkering and operations made to date have used custom-made truck bunkering. Cost of green hydrogen would decrease when more production installations are developed.

Each of the other hydrogen carriers have their specific safety challenges and regulations. The choice would depend on availability of bunkering stations and price, which is a key parameter to evaluate future OPEX.

A combination of batteries and fuel cells may offer great flexibility, with the fuel cells delivering a continuous current which is used to supply the vessel, if maximum power output is needed, or to charge the batteries. This combination also reduces charging time at port.

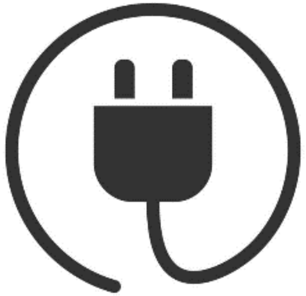
Hybrid

Combination with batteries can provides flexibility and possibility to operate with zero emission in harbour and urban areas.

Electrical hybrid solution may be a valuable investment in conversion of existing vessels by saving on fuel. However, the expected reduction in consumption depends on the engine load. It would be more significant during manoeuvres.

Availability and cost of alternative fuels, to reach the low emissions goal, remain the key point.

Shore connection



Increasingly, ships are connecting to a green energy grid in port, thereby completely eliminating exhaust gas emissions.

It is developing increasingly fast in many harbours and urban areas, following state policy and decision of major municipalities to eliminate easily gas emissions in densely populated zones.

Summary table

Technology	Capabilities			Status	Difficulties		
	Environmental impact	Technical	Operational		Technical	Safety	Operational
Battery	. Depend on the charging mode . Zero emission mode	. Best energy density . Low self discharge . Various C-Rate . Swappable containers	. Small-to-medium sized ships . Mainly for vessels operating short distances	. Nearly mature . Cost would decrease . Increase the energy density . Manage the risk of thermal runaway . Growing number of vessels . Charging network or swap stations	Suffer from ageing	Thermal runaway: . Specific safety measures . Risk analysis . Floodable compartment	. Cost (battery + BMS + extra safety equipment) . Electrical grid in port . Container: Adaptation of the deck arrangement & distance between swaps
Fuel Cells	Best efficiency-pollutant ratio	. High energy density of hydrogen . Fuel flexibility: LOHC (SOFC) - Methanol, Ammonia - and possible mixture (water)	. Small applications . Vessels that require limited autonomy . Waste heat can be recovered . Combination with batteries	. Adaptation to maritime environment . Technology is maturing . Improvement: temperature (PEMFC) . Price would decrease . Hydrogen storage remains a technical obstacle . Cost of green hydrogen would decrease . Swappable containers under study	. Limited power . Hydrogen: 50 kWh of electricity to produce 33 kWh	. Hydrogen is flammable, explosive, and prone to leak. . Risk analysis regarding installation, gas storage and supply piping	. Hydrogen transportation and storage . Additional safety measures . Limited ability to load impact . High Capex . Short service life . Infrastructure for bunkering . Start-up time (SOFC)
Hybrid solutions	. Reduction in consumption depends on the engine load . Depends on fuel (bio-fuel or natural gas) . Reduced exhaust gas emissions . Possibility to operate with zero emission	. Hybrid propulsion / hybrid production . Allows multiple solutions where the alternative fuels and technologies can be combined . Solutions with no battery	. Flexibility . Batteries may take over from generators	. Mature . Alternative fuels under development	Diesel engines would be replaced by alternative fuel engines (e.g., LNG, CNG or biofuels)	. Depend on fuel . Failure Mode and Effects Analysis (FMEA)	Availability & cost of alternative fuels
Shore connection	No exhaust gas emissions in port	Supply power needs	No energy production	Developing increasingly fast in many harbours and urban areas	Must be harmonized so that: . ship can connect in each port . Port installation can cater for all vessels.	High voltage	Standardized connections

Summary of electrical solutions on inland waterways

BUREAU VERITAS MARINE & OFFSHORE

SHAPING A BETTER MARITIME WORLD

YOUR CLASSIFICATION PARTNER FOR TODAY AND TOMORROW

2022