Università di Genova

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L’energia pulita e il mare: il ruolo dell’Idrogeno

Fuel cells per applicazione marina

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Genova – Villa Cambiaso - 1° piano - I.015 - Aula A2
Pisa – Scuola di Ingegneria, Polo A, Biblioteca Poggi
EVENTO in modalità ibrida

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What makes a Fuel Cell

1) An ionic path between two volumes containing reactants at different partial pressures
    1) Electrolyte

ΔV

2) An electrical connection through a load to create a closed circuit

$I \times \Delta V = \text{Power}$

3) The ability to maintain the electrochemical process and sustainably produce meaningful power
    1) Feed reactants, remove products
    2) Maintain the conditions that create the ionic path i.e temperature, humidity

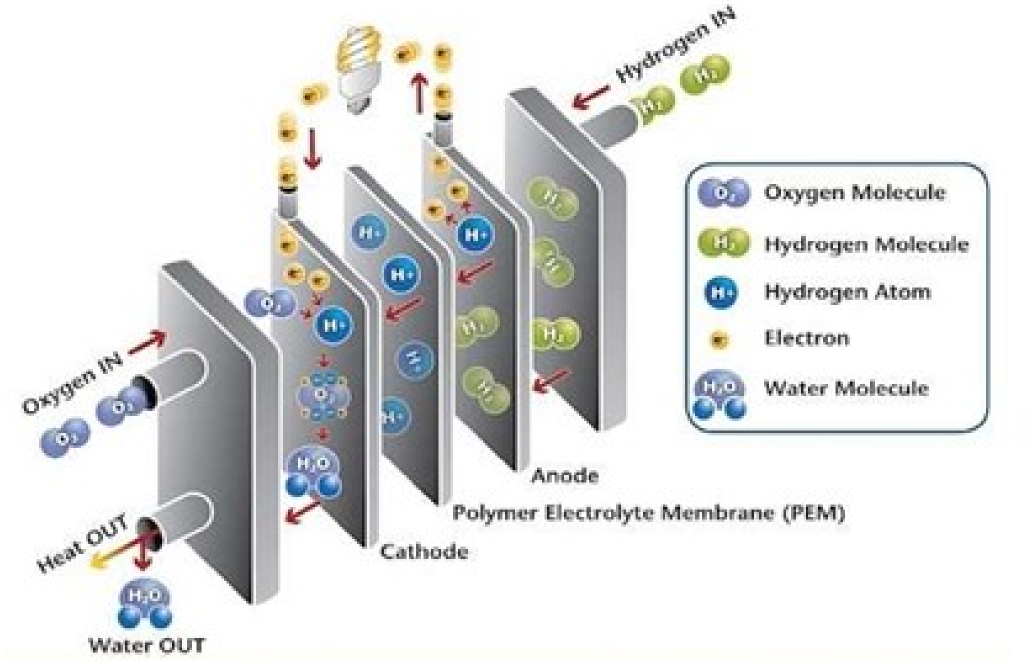
Fuel Cell Technologies

	AFC	PAFC	MCFC	SOFC	PEMFC
Electrolyte	Potassium hydroxide	Phosphoric Acid	Molten carbonate salt	Ceramic	Polymer
Operating Temperature	60-200 °C	140-200 °C	650-800 °C	500-1000 °C	60-180 °C
Fuel	H_2	H_2/LNG/CH_4 reformate	H_2 /CH_4 reformate	H_2 /CH_4 reformate	H_2
Ion	OH^-	H^+	CO_3^{--}	O^{--}	H^+

PEM vs SOFC: high level comparison

Power density	PEM: 10x advantage
Efficiency	SOFC: more pronounced at high power
Dynamic response	PEM: Faster dynamics, seconds vs minutes+
Thermal integration	SOFC: higher temperature heat rejection
Maturity/Cost	PEM: design solutions converging
Fuel flexibility	SOFC: PEMs need high purity H2

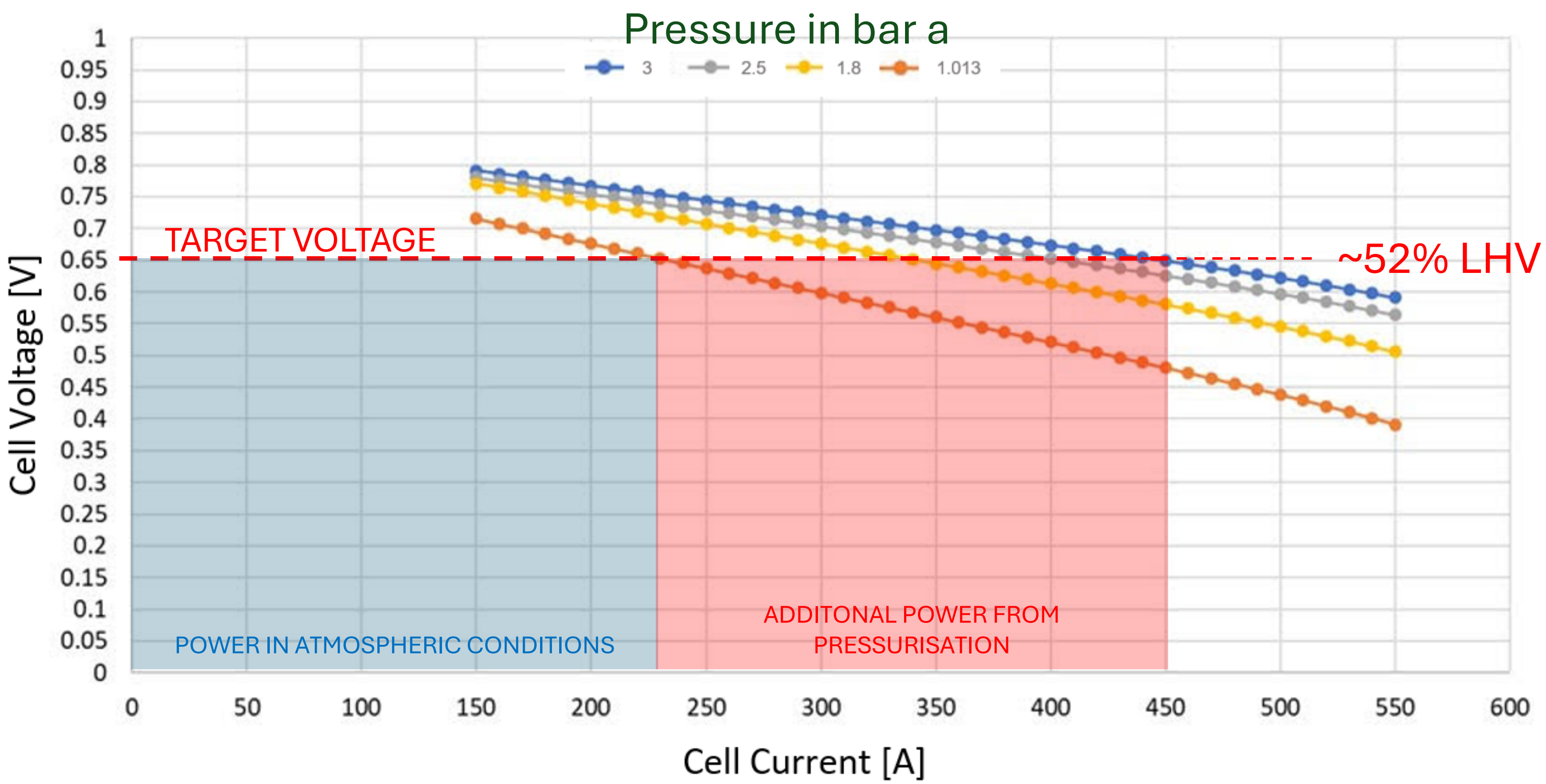
Example: Proton Exchange Membrane FC



Fundamentals of fuel cell performance

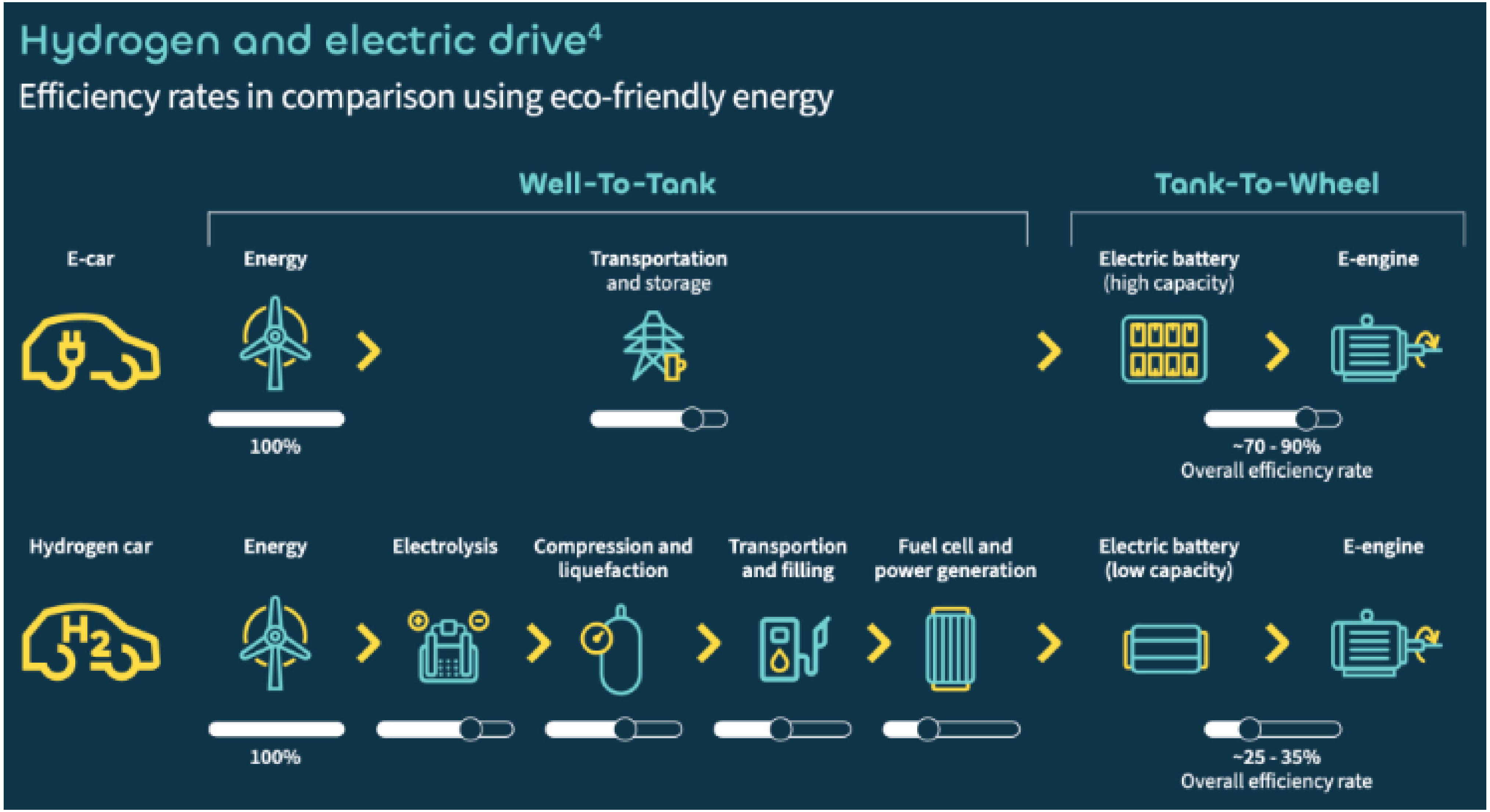
- Fuel cell VI curves as a standardised way to define steady-state cell performance
- Choice of stack size and operating point is key to performance
- Pressurisation is a higher performance enabler
- VI curves cannot be used to represent the performance of a full stack in transient conditions
- A more detailed model fitted consistently to the reference curves is required

$$\eta = \frac{IV}{LHV\ \dot{m}_{H2}} \quad \text{Hence, given } \dot{m}_{H2} \propto I, \quad \eta \propto V$$



Example: PEM

Fuel Cell efficiency: is it too low?



Source: EVBoosters.com

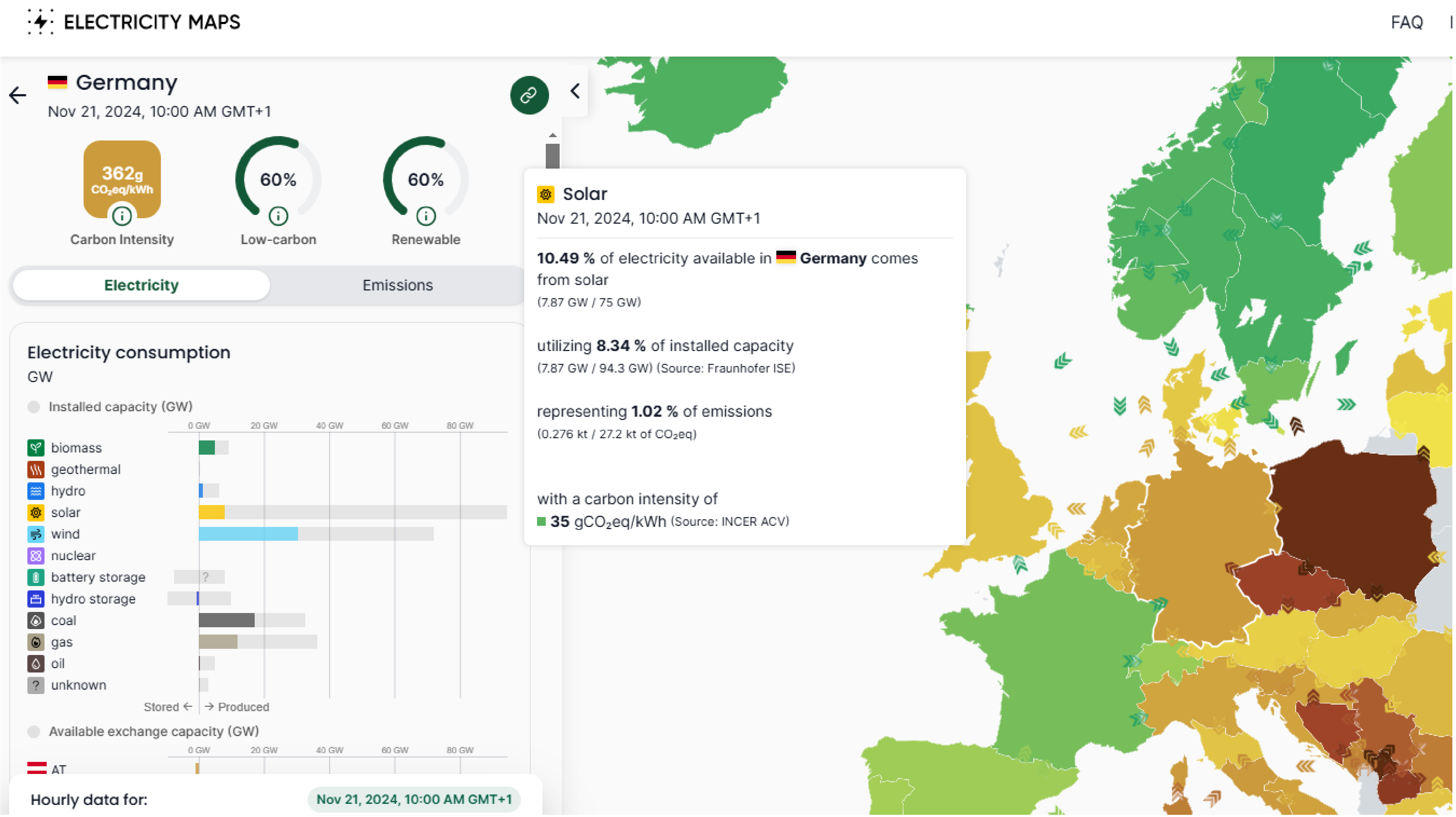
Is there a deeper meaning?

$$1\ \text{kWh} = 3600\ \text{kJ}$$

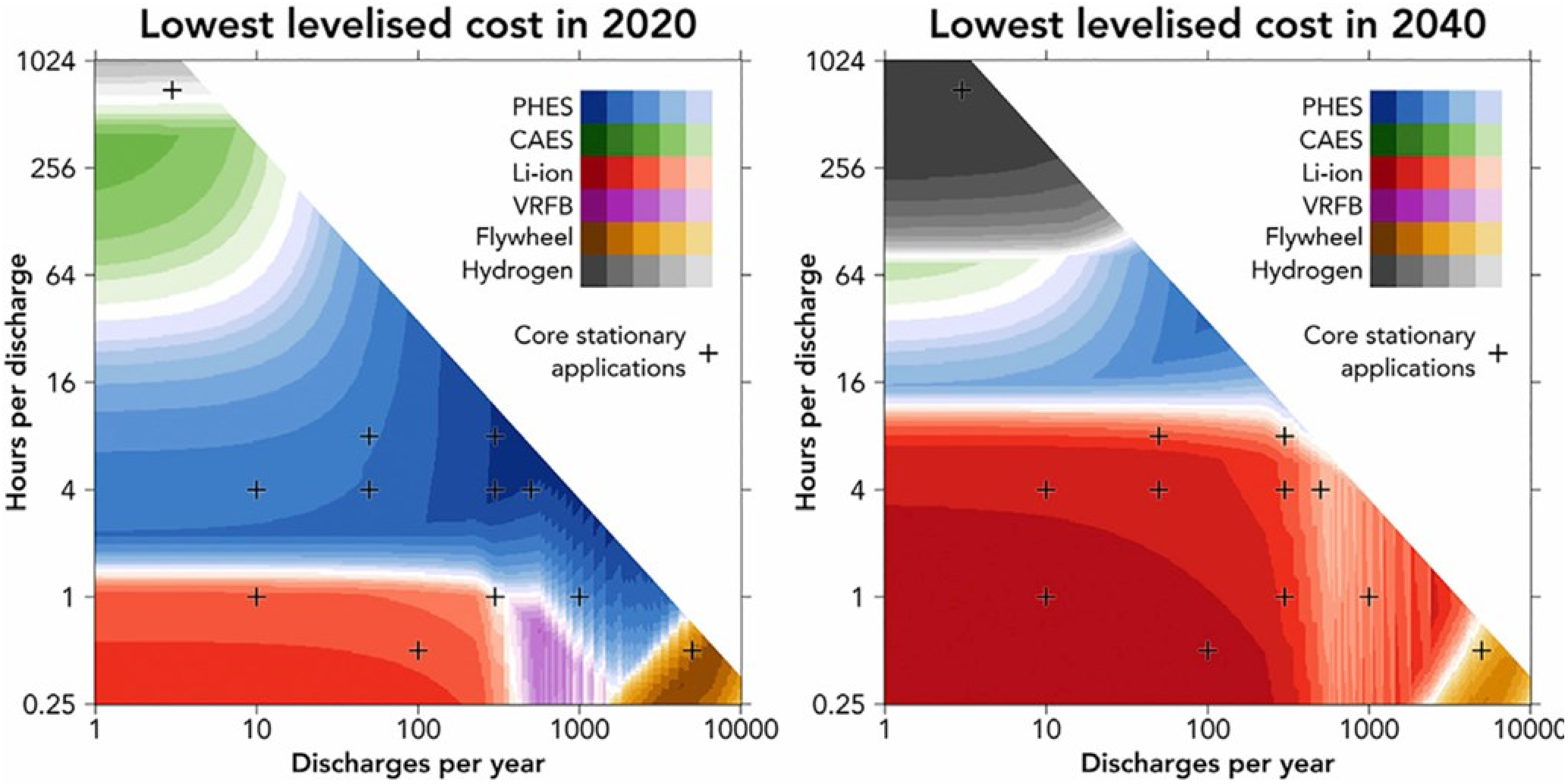
Energy corresponding to a power trasferred in a time interval

Energy

Good days and Bad days



Energy Storage Technologies



SOURCE: Schmidt,Melchior, Hawkes, Staffell – Imperial College – Projecting the Future Levelized Cost of Electricity Storage Technologies – Joule 2019

Acronyms:

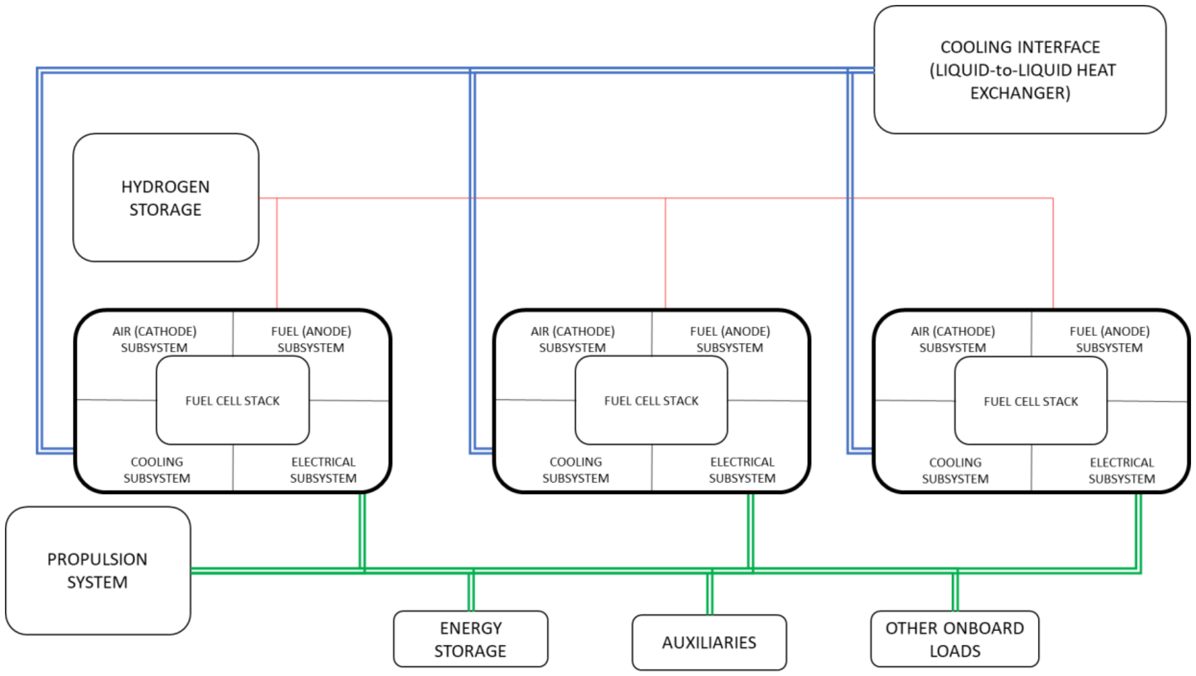
PHES – Pumped Hydro

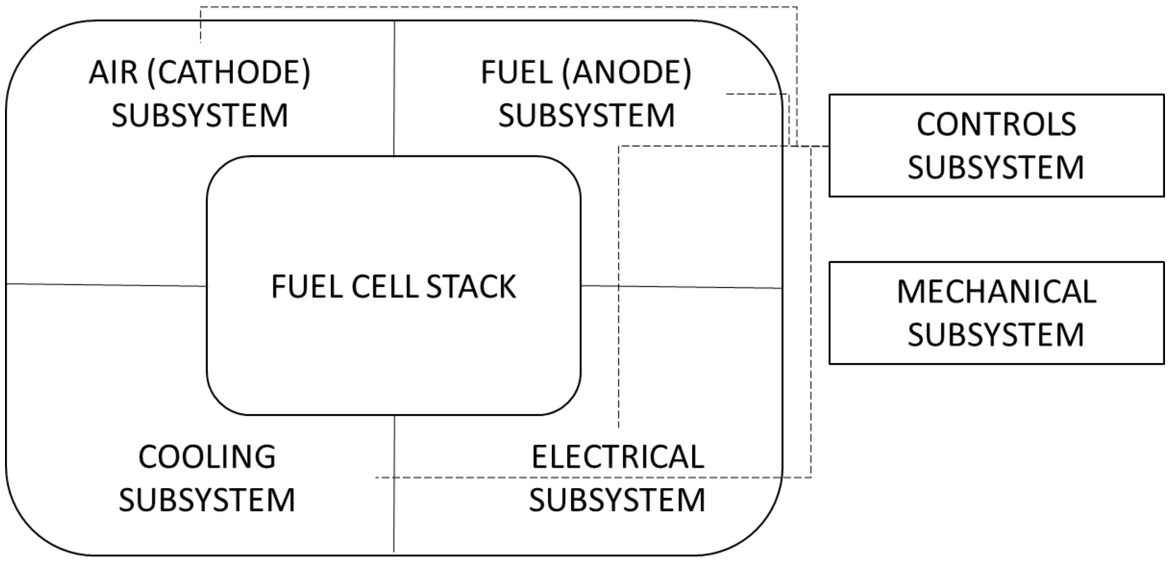
CAES – Compressed Air

VRFB - Vanadium redox-flow

Generic PEM-FC system architecture

A Fuel Cell Module is the smallest unit built around the fuel cell stack that is independently operable





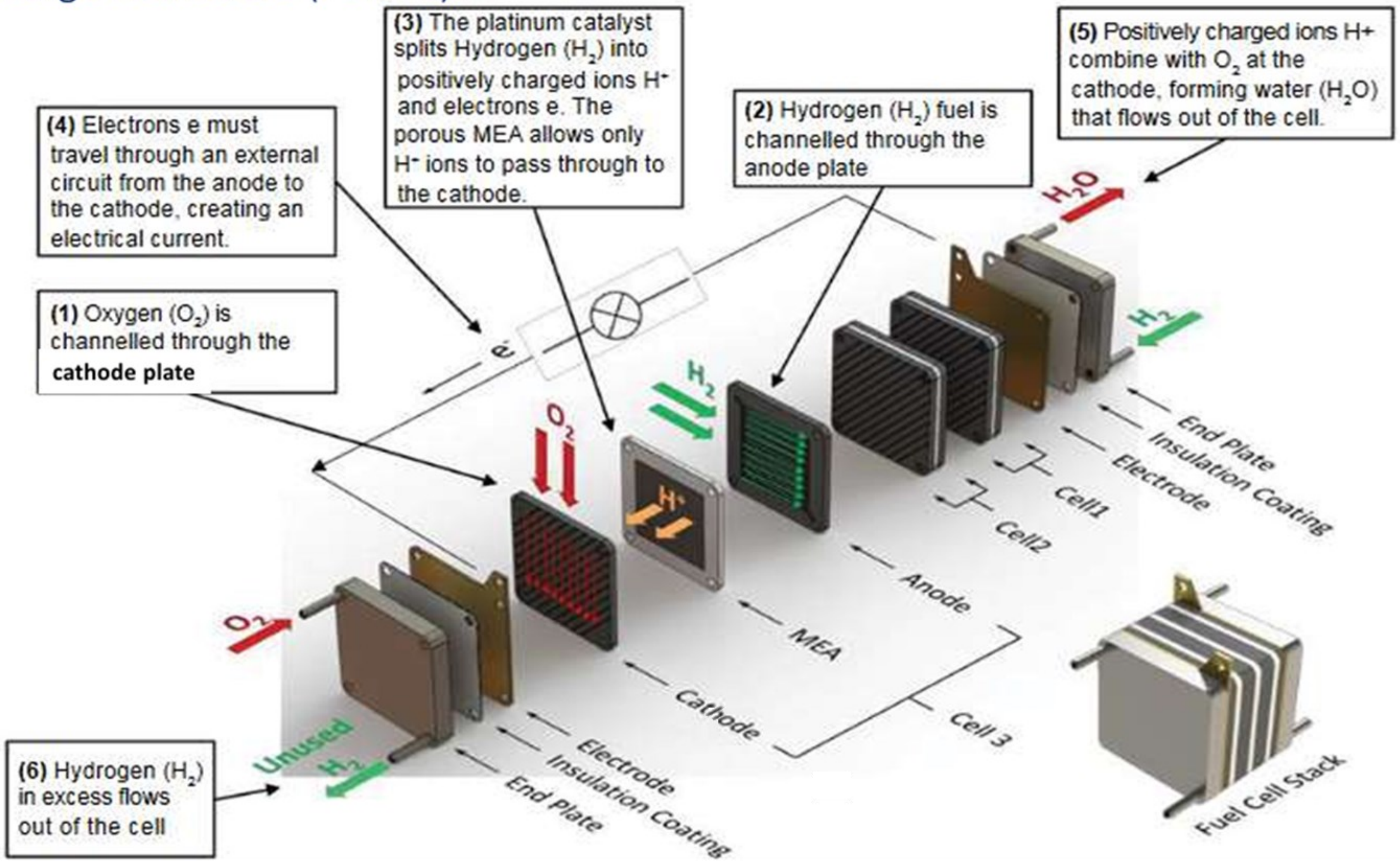
State of the art automotive designs

- Modules designed for on-road applications often constrained as like-for-like replacement to internal combustion engines
  - Volumetric power density is key
  - Unit cost is key
  - Compromise on performance – stack size
- No standard use profile in marine application, however, in general
  - On-road vehicle constraints do not apply
  - Range is often key -> performance optimisation

Example: cellcentric BZA150 truck module

Stack subcomponents

Proton Exchange Membrane (PEMFC):

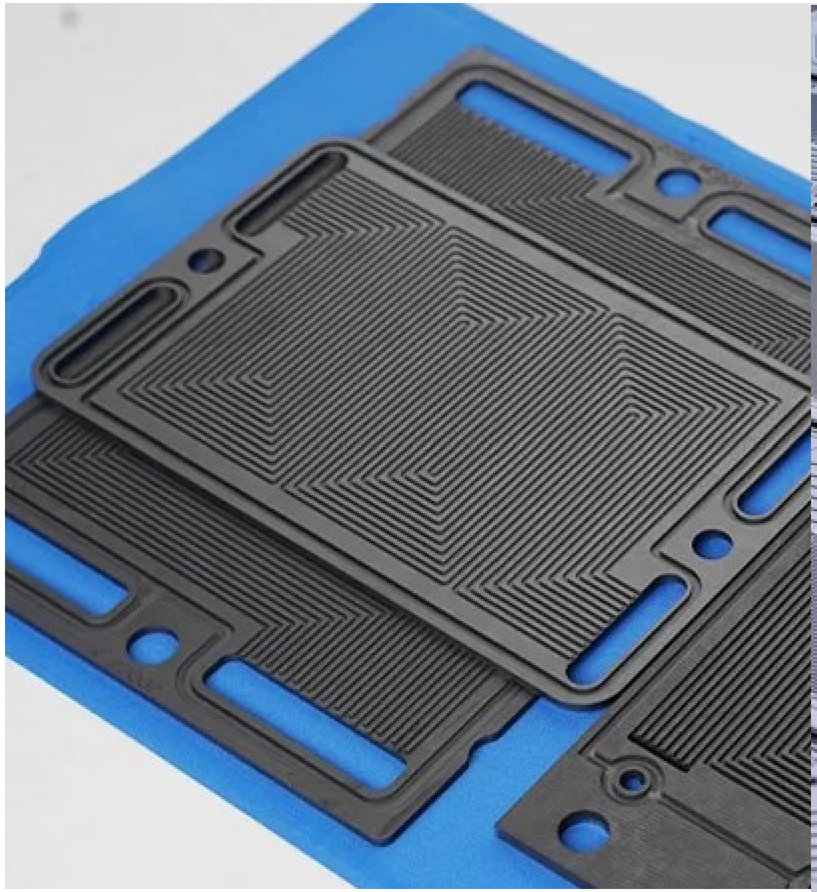


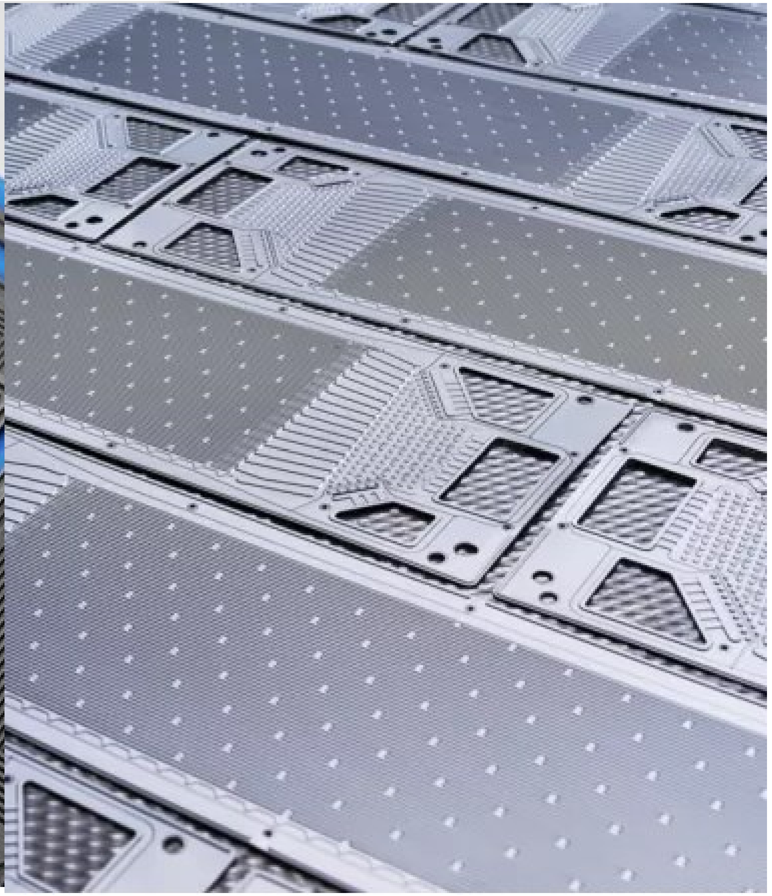
MEA: Membrane Electrolyte Assembly

NB: Polymer Electrolyte Membrane (PEM) is a kind of Proton Exchange Membrane (PEM)
Often the two definitions are interchangeable but there are Proton Exchange FC technologies not based on polymer electrolytes

Bipolar Plates

To connect electrically the anode of a cell and the cathode of the following





Example: TMNEtching and Symbio

BPP Material choice is the main remaining discriminant in PEM stack design

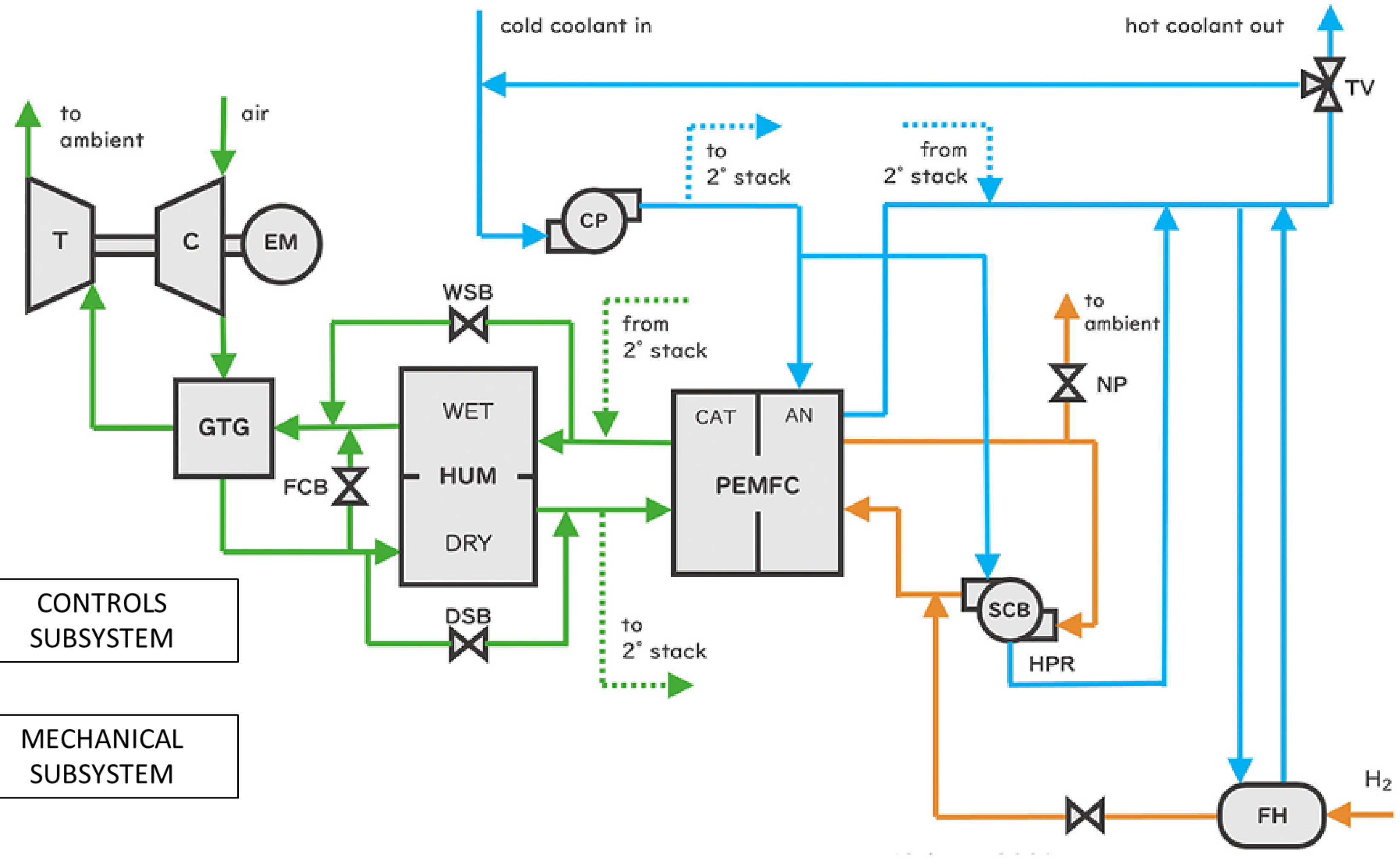
Carbon composite

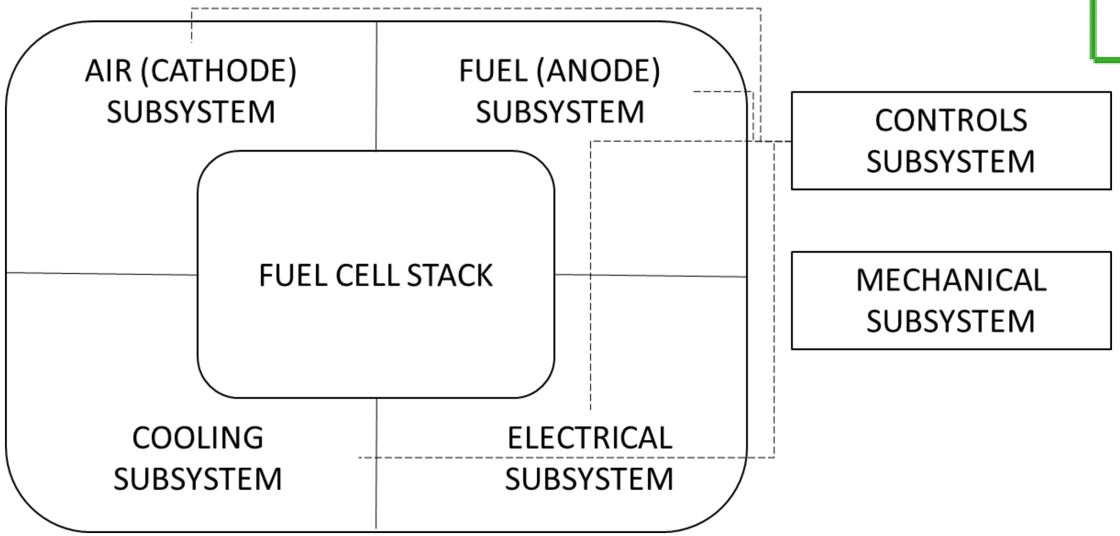
- Free definition of geometry on both sides
- Corrosion resistant
- Already cost competitive at low production volumes

Metallic

- Lower thicknesses thus greater flexibility
- Due to stamping/hydroforming geometries on both sides have to be inverted compromising design
- May require coating to resist corrosion
- Cost competitive only at high production volumes

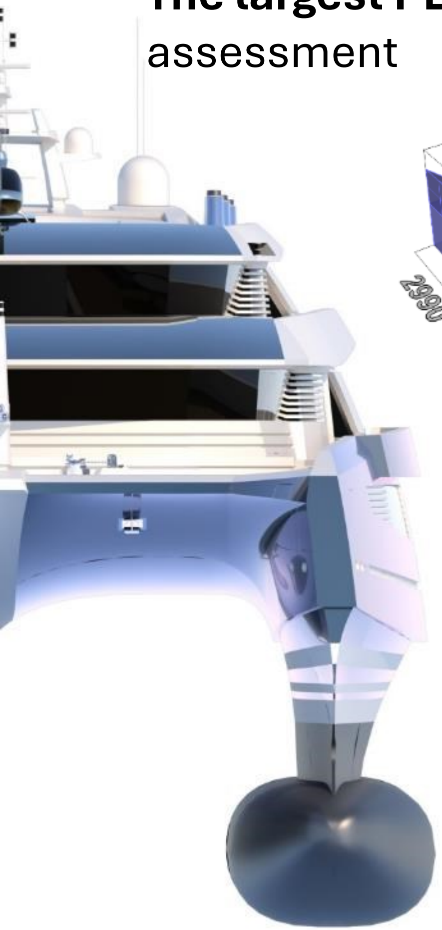
PEM System – Process Flow Diagram

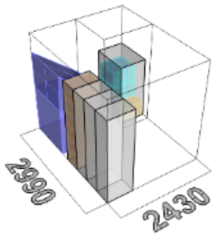


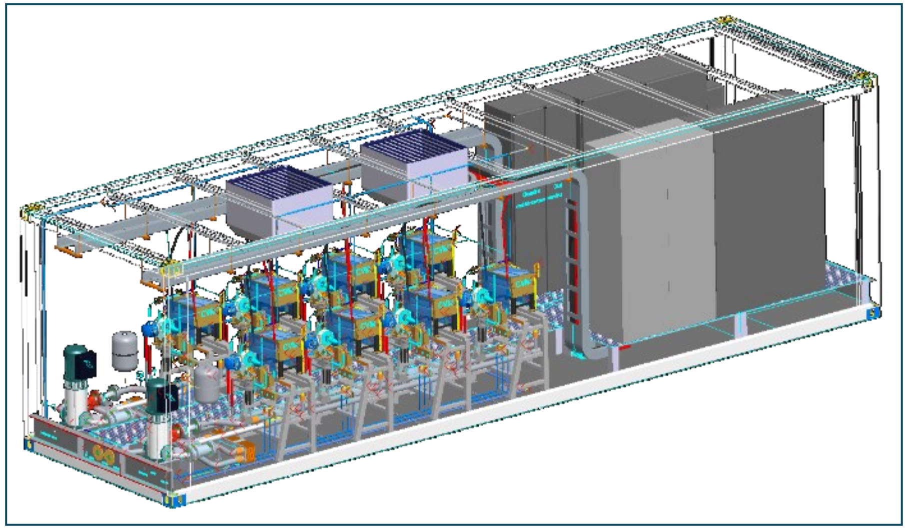


The FINCANTIERI Hi-Sea lab @ UNIGE ...since 2018

The largest PEM fuel cell laboratory systems of the world specifically designed for marine applications assessment



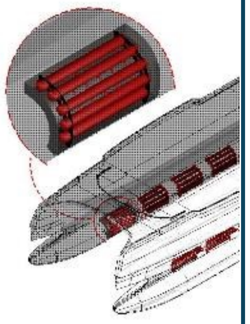




Numbers
Fuel Cell Power 130kW + 130kW
Two DC/DC converter 350-600 V
One AC/DC 60kW

Basic Design
Assessment of Fuel Cell Systems for marine applications: Mega Yacht, Navy, Passenger Ships, Ferries

System Sizing
Dynamic simulations of Fuel Cells and Metal Hydrides Storage systems coupling



***Genova* HI-SEA**

Hydrogen Initiative for Sustainable Energy Applications

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The sea ahead

Grazie per l’Attenzione

Evento di disseminazione del progetto POSEIDON - Piano Nazionale di Ripresa e Resilienza Missione 4 Componente 2, Investimento 1.1 Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN) - Avviso MUR pubblicato con Decreto Direttoriale n. 1409 del 14 settembre 2022 (PRIN 2022 PNRR) - “POSEIDON - *Photo-driven Optimal Seawater Electrolysis for energy-IslanDs OperatioN*” – Settore PE8, Codice progetto P2022ER7KM CUP I53D23006440001

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