H2 Demand Off-take: Challenges & Opportunities for PEM Fuel Cells in Auto, Marine, and Aviation Applications

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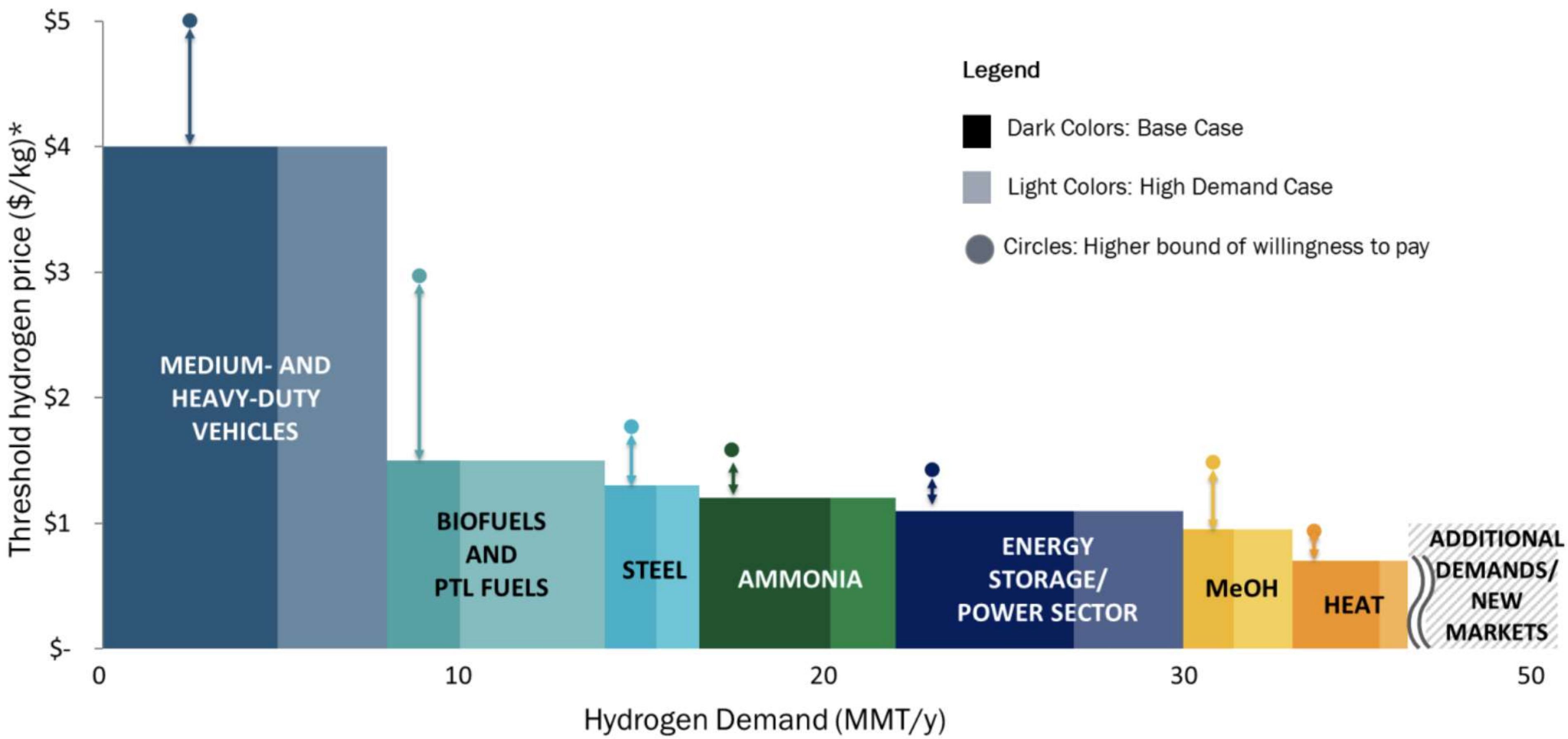
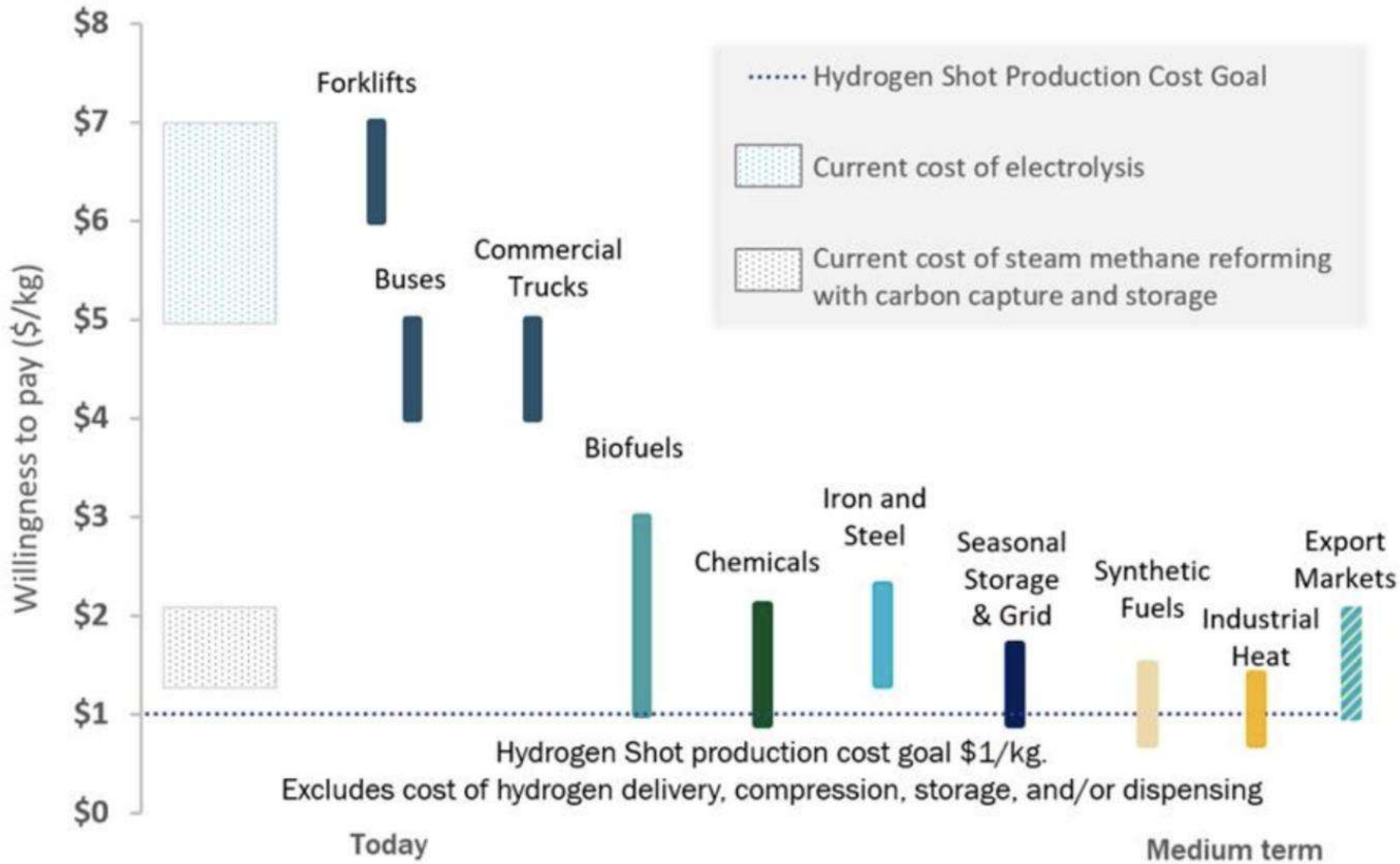
HyperMotive Fuel Cell Systems

APR 17
Gulf Coast Hydrogen Ecosystem: Opportunities & Solutions

Demand: General



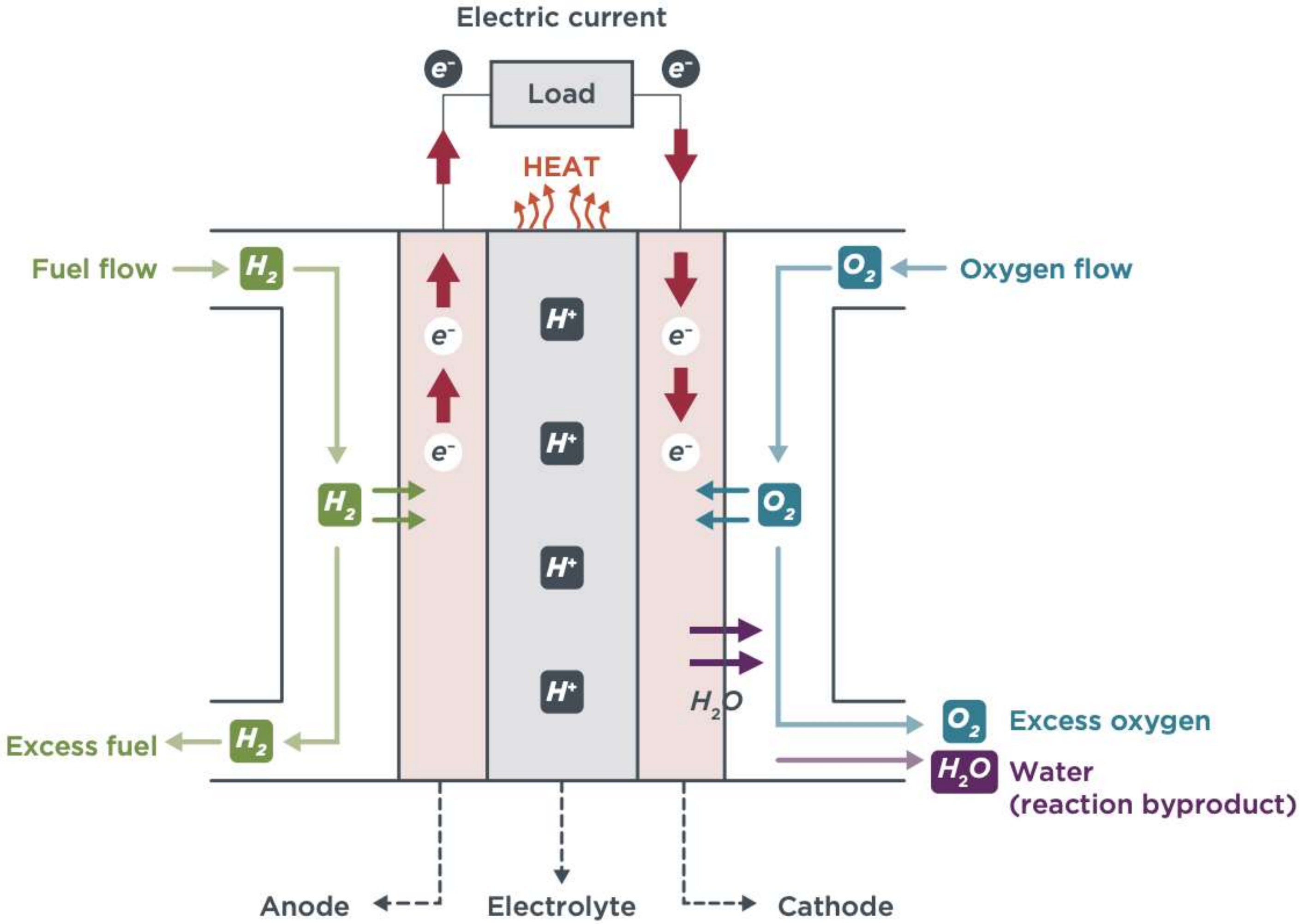
Source: IRENA


$8
$7
$6
$5
$4
$3
$2
$1
$0
Willingness to pay ($/kg)
Forklifts
Buses
Commercial Trucks
Biofuels
Chemicals
Iron and Steel
Seasonal Storage & Grid
Synthetic Fuels
Industrial Heat
Export Markets
Hydrogen Shot Production Cost Goal
Current cost of electrolysis
Current cost of steam methane reforming with carbon capture and storage
Hydrogen Shot production cost goal $1/kg.
Excludes cost of hydrogen delivery, compression, storage, and/or dispensing
Today
Medium term

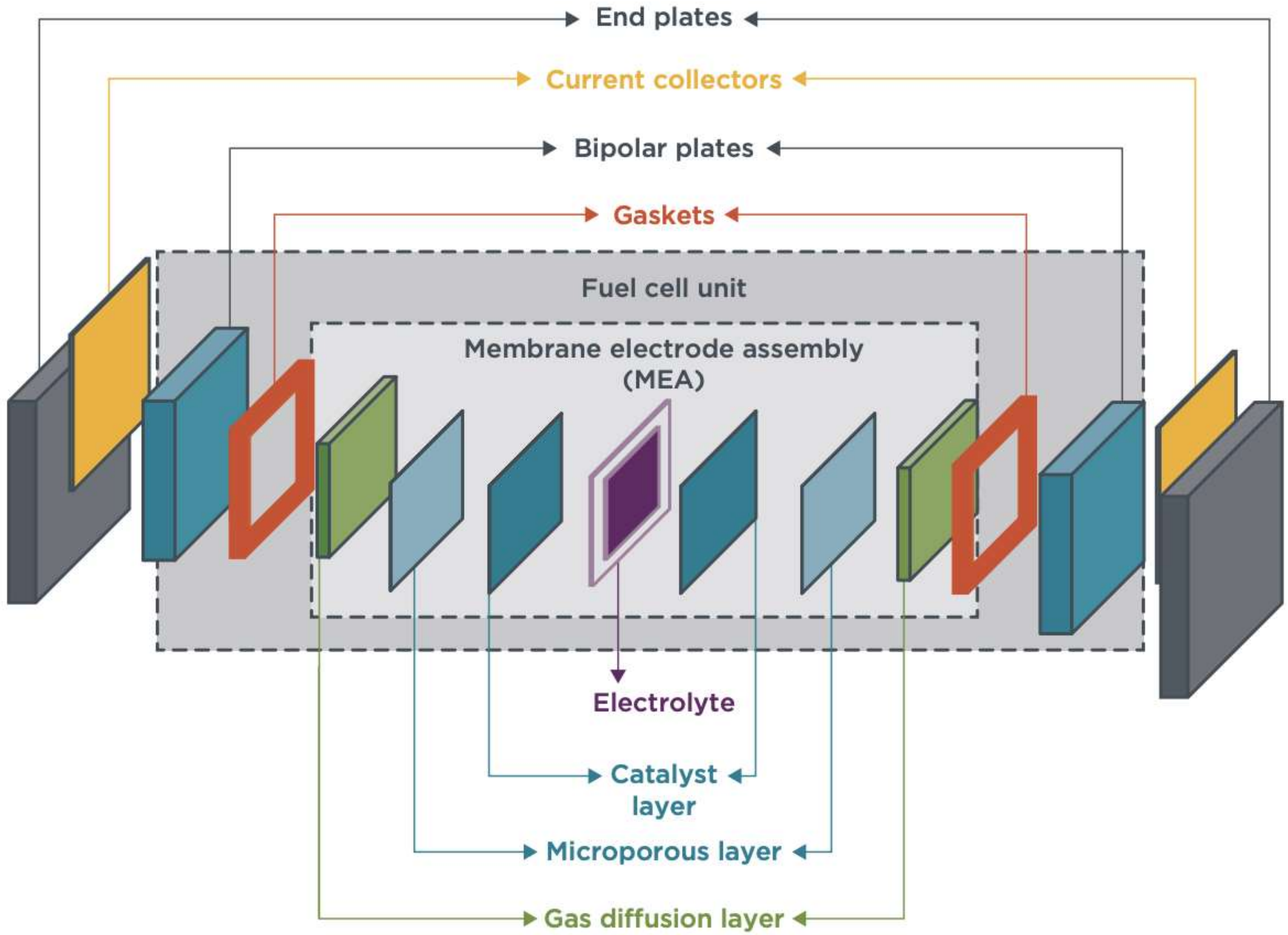
Source: BNEF

Demand: Fuel Cells

Vehicles, ships, and airplanes



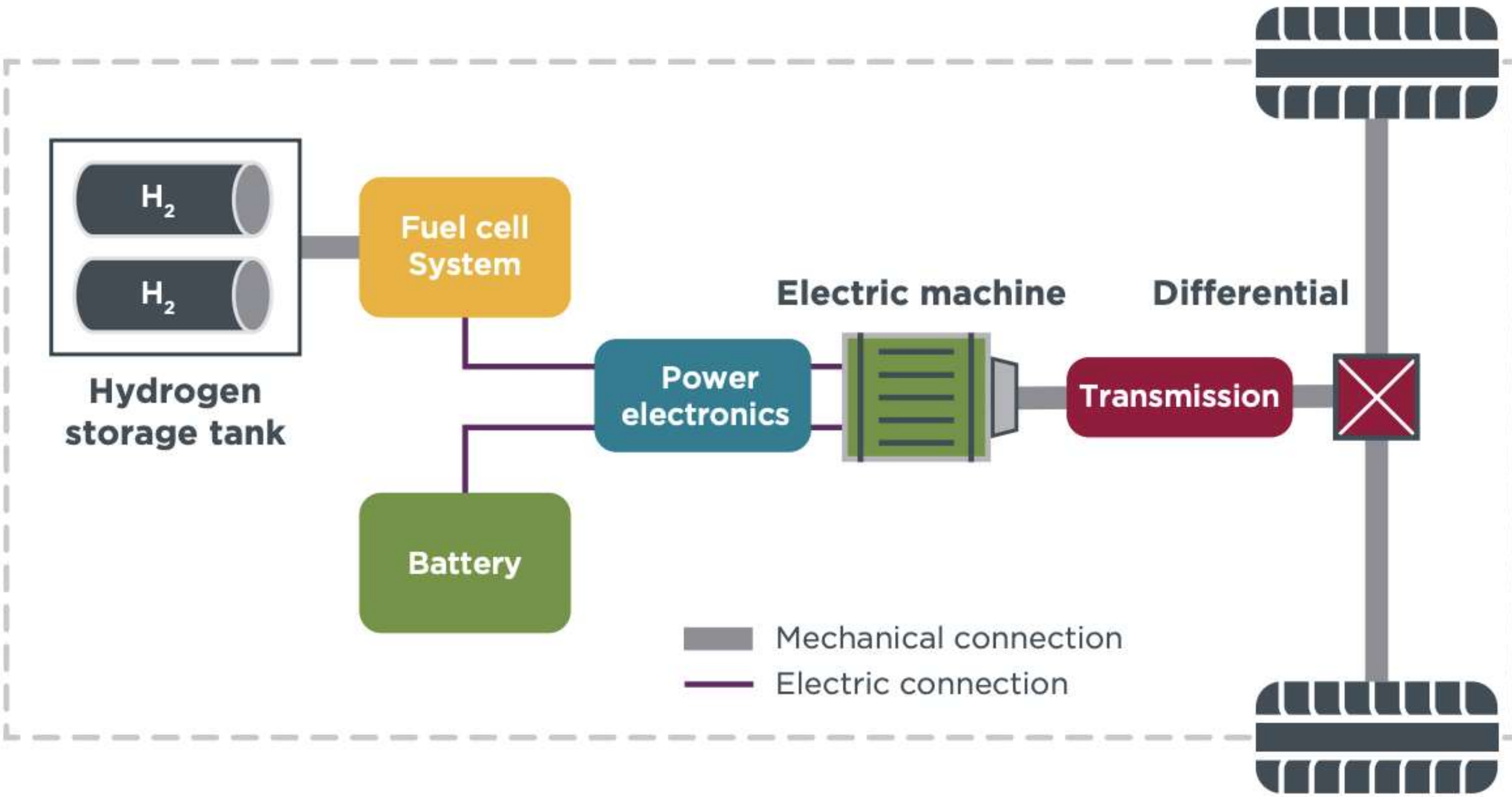
Source: DOE HFTO



Source: DOE HFTO

Fuel Cell Electric Vehicles (FCEV)

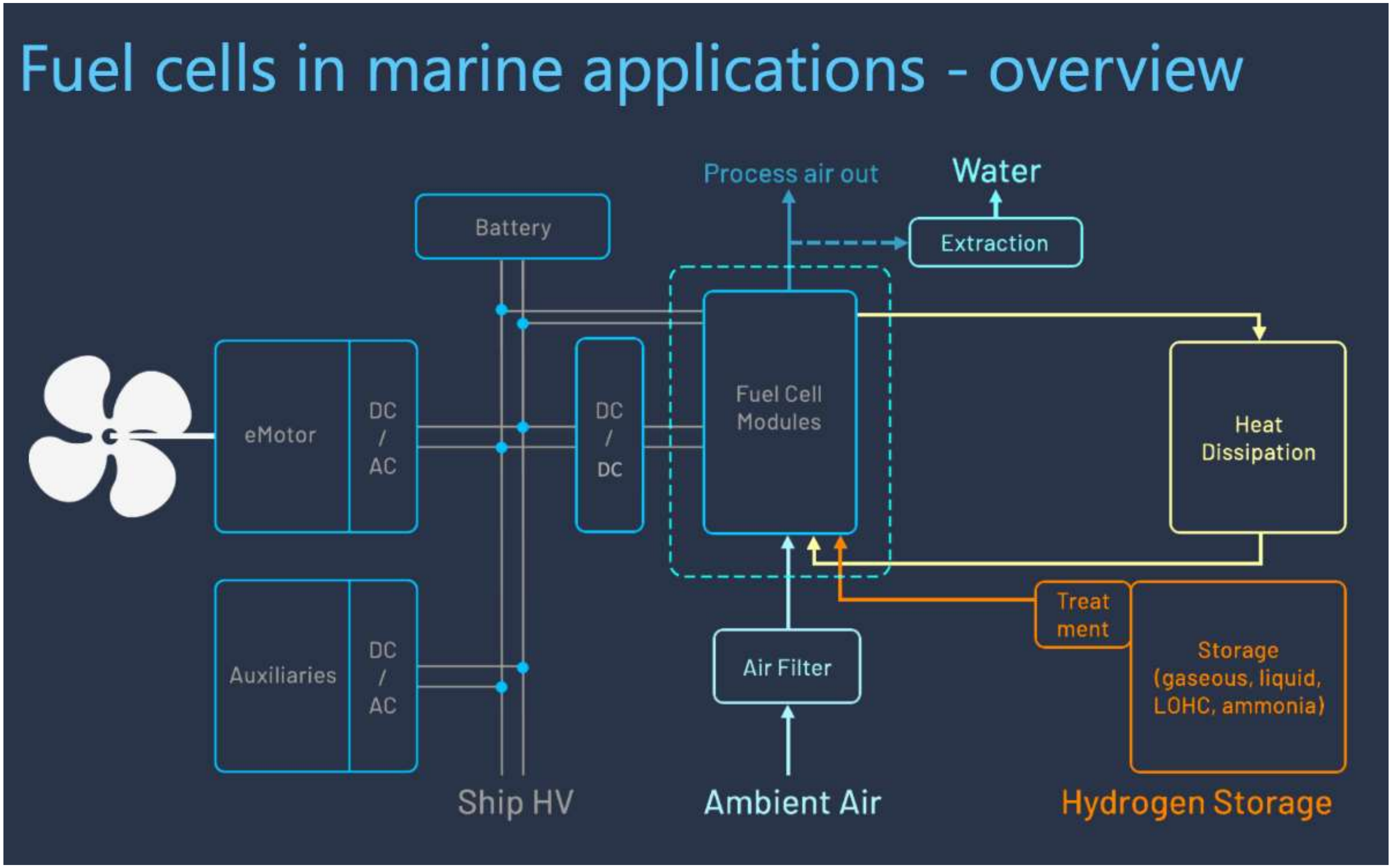
- About 8,000 FCEVs in US
- Total H2 demand ≈ 0.5 MTA
- FCEV average fuel economy (efficiency): 7~9 kgH2 / 100km
- Opportunities for transportation emissions reduction
    - Med-duty and heavy-duty vehicles (MHDV) account for a small fraction of total vehicles, but about 20% of total emissions
        - Therefore, decarbonizing these vehicles *first* will have an outsize impact on decarbonization of transport sector.
- H2 Infrastructure
    - Hydrogen refueling stations (HRS)
        - About 60 HRS in US
            - Most in CA



Source: DOE HFTO

Hydrogen-Electric Hybrid Propulsion for Maritime (a.k.a. "FC Ships")

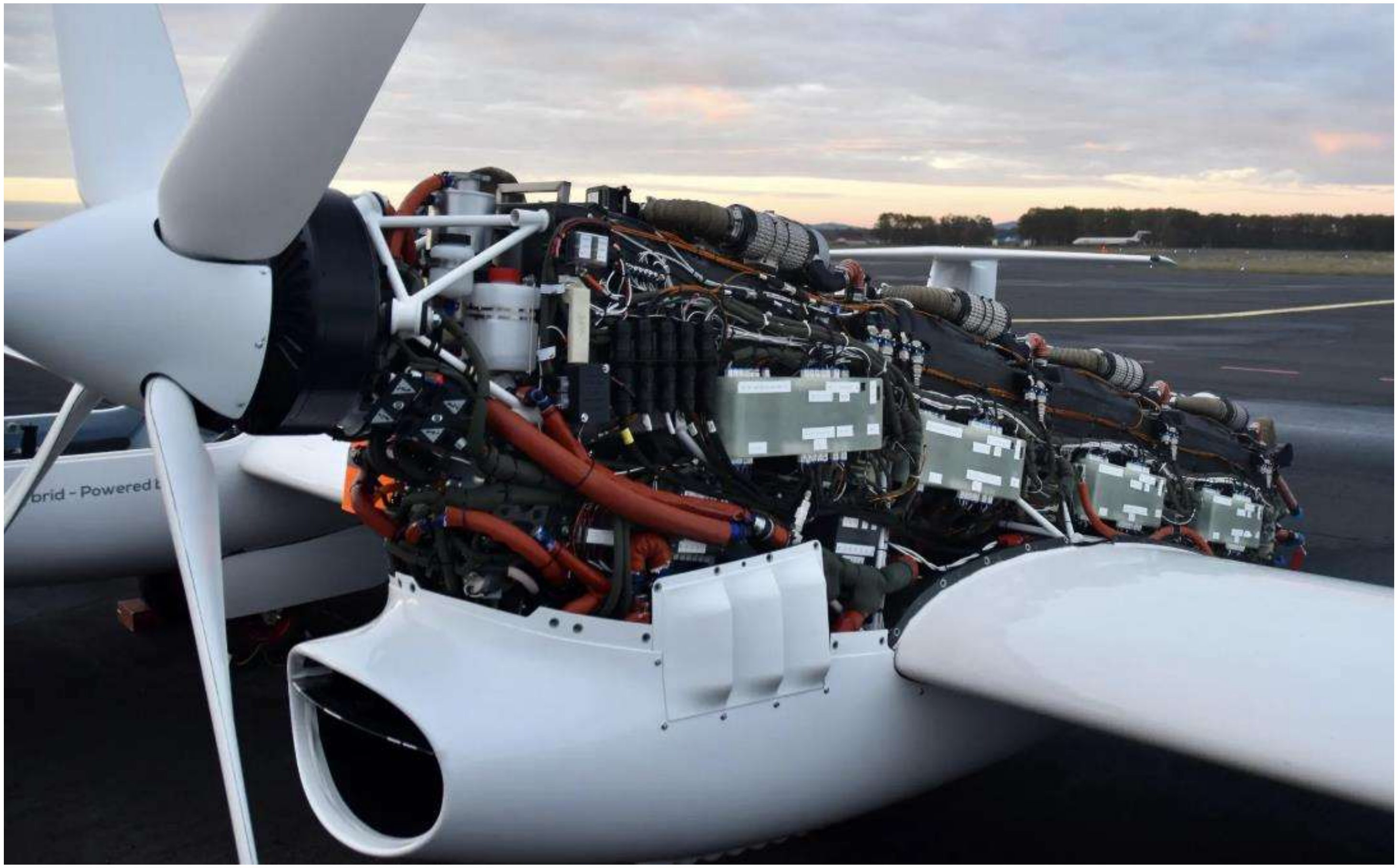
- Electrification
  - Shift towards electric equipment for reliability, primarily 480 VAC.
  - Replacing mechanical/hydraulic systems with electric ones.
- Maritime Industry Alternative Fuels
  - Shipping industry exploring various fuels to reduce its 3% global emissions share.
  - Initiatives like Maersk's use of green methanol could reduce CO2 emissions by 60-95%.
- FC Maritime Propulsion Tech Maturity Level
  - No Fundamental Tech Challenges
    - Development of marine energy-H2 systems is technically feasible, needing significant R&D but facing no insurmountable obstacles.
  - Tech Advancements Required
    - Commercial devices in early testing; advancements needed in marine energy technology.
    - R&D focuses on improving fuel cell durability, reducing hydrogen production costs, and enhancing storage solutions.
- Transition from Auto to Maritime
  - Current FC technology derived from automotive sector, not specifically designed for maritime use.
  - Challenges with module size, technology limitations, and unproven efficiency for marine applications.
  - Adapting equipment for marine environment protection against corrosion and electrolytic reactions using materials like 316L stainless steel, varnish, and silicone paste.
  - Development of specialized air filters to protect against sulfur-like particles while optimizing for weight and integration.


Fuel cells in marine applications - overview
Process air out
Water
Battery
Extraction
eMotor
DC / AC
DC / DC
Fuel Cell Modules
Heat Dissipation
Auxiliaries
DC / AC
Treat ment
Air Filter
Storage (gaseous, liquid, LOHC, ammonia)
Ship HV
Ambient Air
Hydrogen Storage

Source: DNV

Hydrogen for Aviation Propulsion (“H2 Planes”)

- De-carb opportunity
  - Aviation responsible for about 10% of all transport emissions in US
- FC use vs turbine combustion
  - For combustion in turboprop & turbofan engines only minor changes required, but do need new fuel delivery system
  - Gas turbines combusting H2 probably the way forward
- Also, indirect use of H2, to create SAF
- Power requirements (too big for FC)
  - Airbus A320 takeoff: ≈ 40 MW
- Aircraft aux power req.: 100 ~ 500 kW (w/in range of possibility for FC)
- FC challenges for aviation
  - Shock & vibe
  - Thermal stress

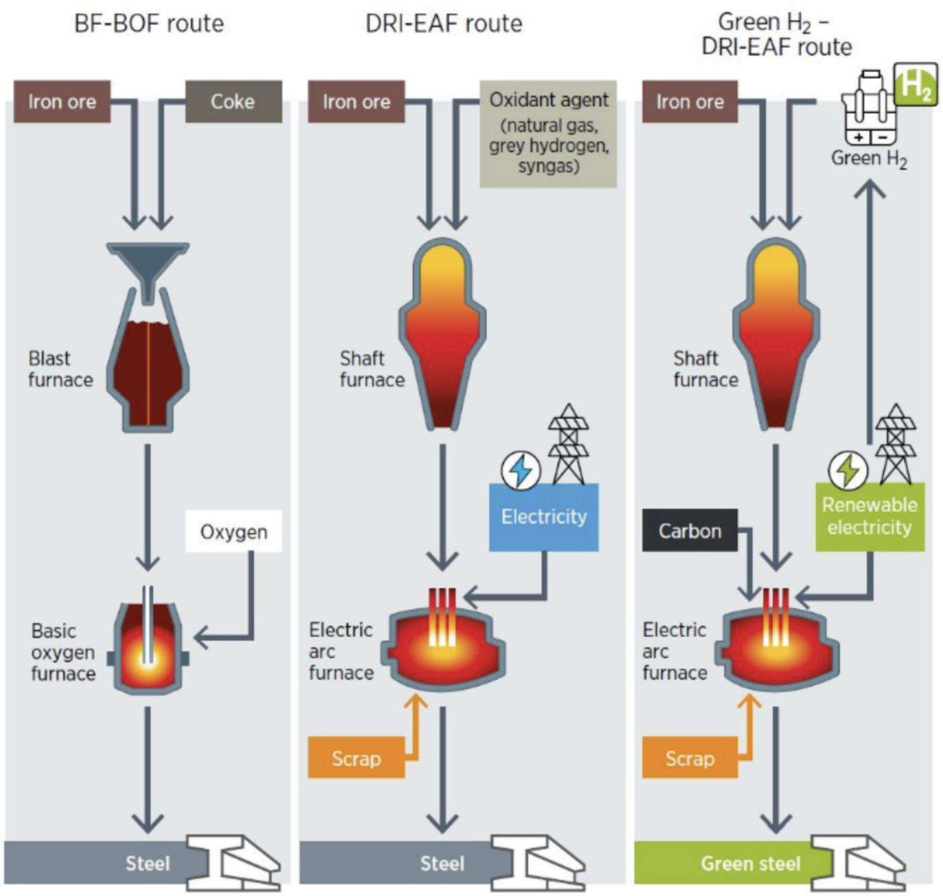


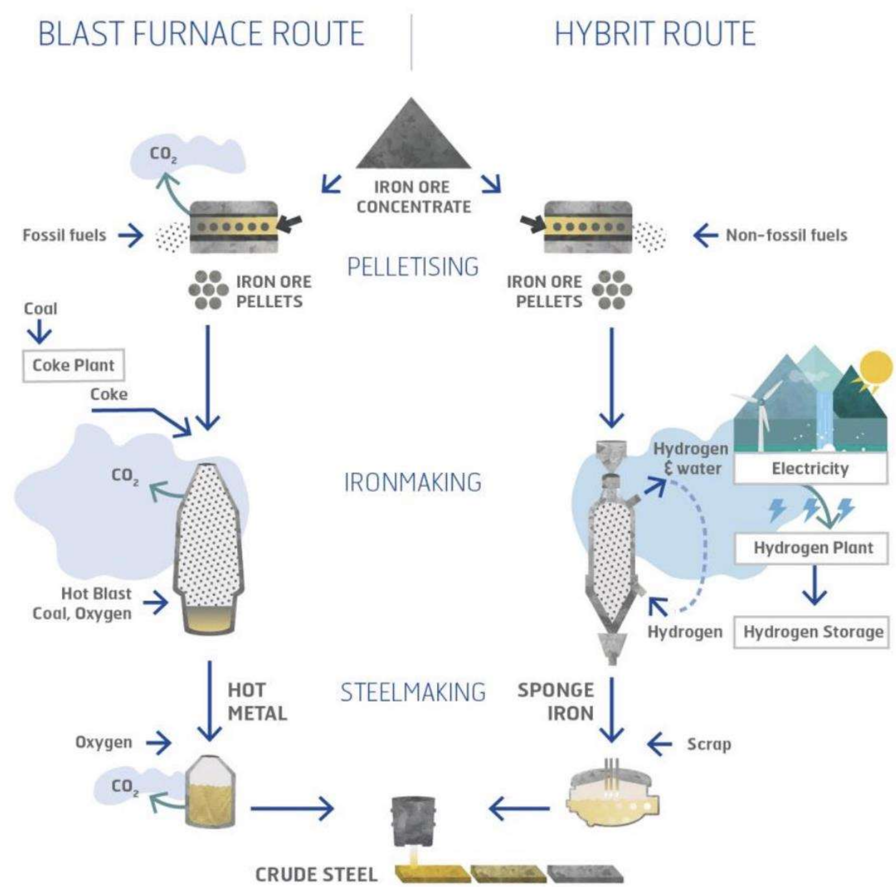
Source: Deutsches Zentrum für Luft- und Raumfahrt

H2 DRI for Steel Production

- 2021 US world's 4th-largest producer
- Applications of steel globally
  - Buildings and infrastructure: 50%
  - Mechanical equipment: 15%
  - (≤ 10%)
    - Automotive
    - Other
- Global steel demand:
  - 2015: 1,600 MTA
  - 2050: 2,500 MTA

- DRI, C-based vs H2-based
  - This involves a chemical reaction where carbon from these fossil fuels reacts with oxygen in the iron ore, producing metallic iron and CO2. The chemical equation for this reaction is:
    - $2Fe_2O_3 + \mathbf{3C} \rightarrow 4Fe + \mathbf{3CO_2}$
  - Alternatively, hydrogen can be used instead of carbon to reduce iron ore, resulting in metallic iron and water as by-products. The reactions for this process are:
    - H2 first pre-heated to 770˚C
    - $Fe_2O_3 + \mathbf{3H_2} \rightarrow 2Fe + 3H_2O$
    - $FeO + H_2 \rightarrow Fe + \mathbf{H_2O}$
- H2DRI requires large volumes of H2
  - Ex. Steel plant in Great Lakes Region
    - Annual H2 consumption: 2 MTA
      - Requires 2.25 GW IRE
        - ≤ 2% of Great Lakes Region IRE forecasted by 2050
  - Ex. 1 MTA mill would require 500 MW solar at 100% capacity factor or 2 GW operating at regular capacity





Source: IRENA, HyBRIT