

LH2 in Marine Shipping

Borrowing technology from space



Agenda



Why hydrogen, and why liquefy it?



How is green hydrogen produced?



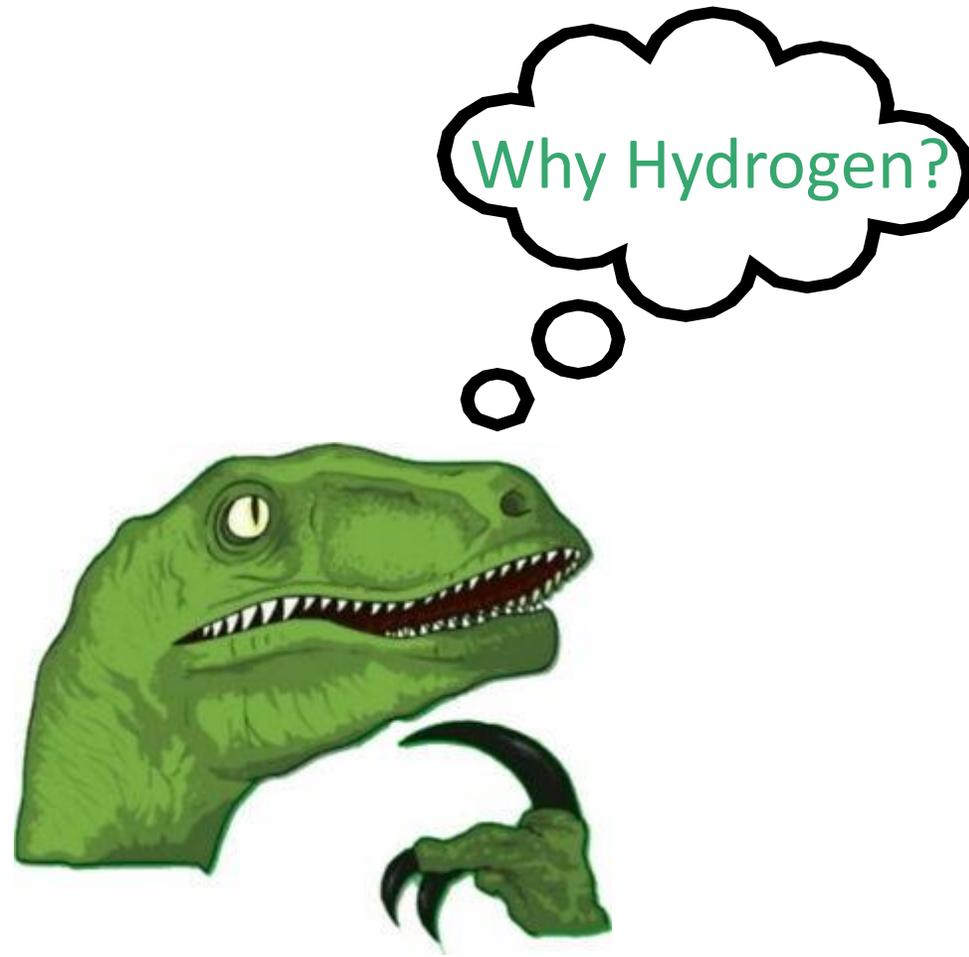
How much does hydrogen cost to produce?



Case studies



Closing recommendations



Why Hydrogen?

Advantages

- Zero Emissions
- Can be produced from multiple sources
- Can be produced emissions free
- Can be produced anywhere
- High mass energy density
- Modular consumption

Disadvantages

- Low volume energy density

Challenges

- Limited existing infrastructure
- High production cost
- Challenging to transport

Opportunities

- Valid solution across many industries

Why Liquefy Hydrogen?

Advantages

- Higher energy density by volume

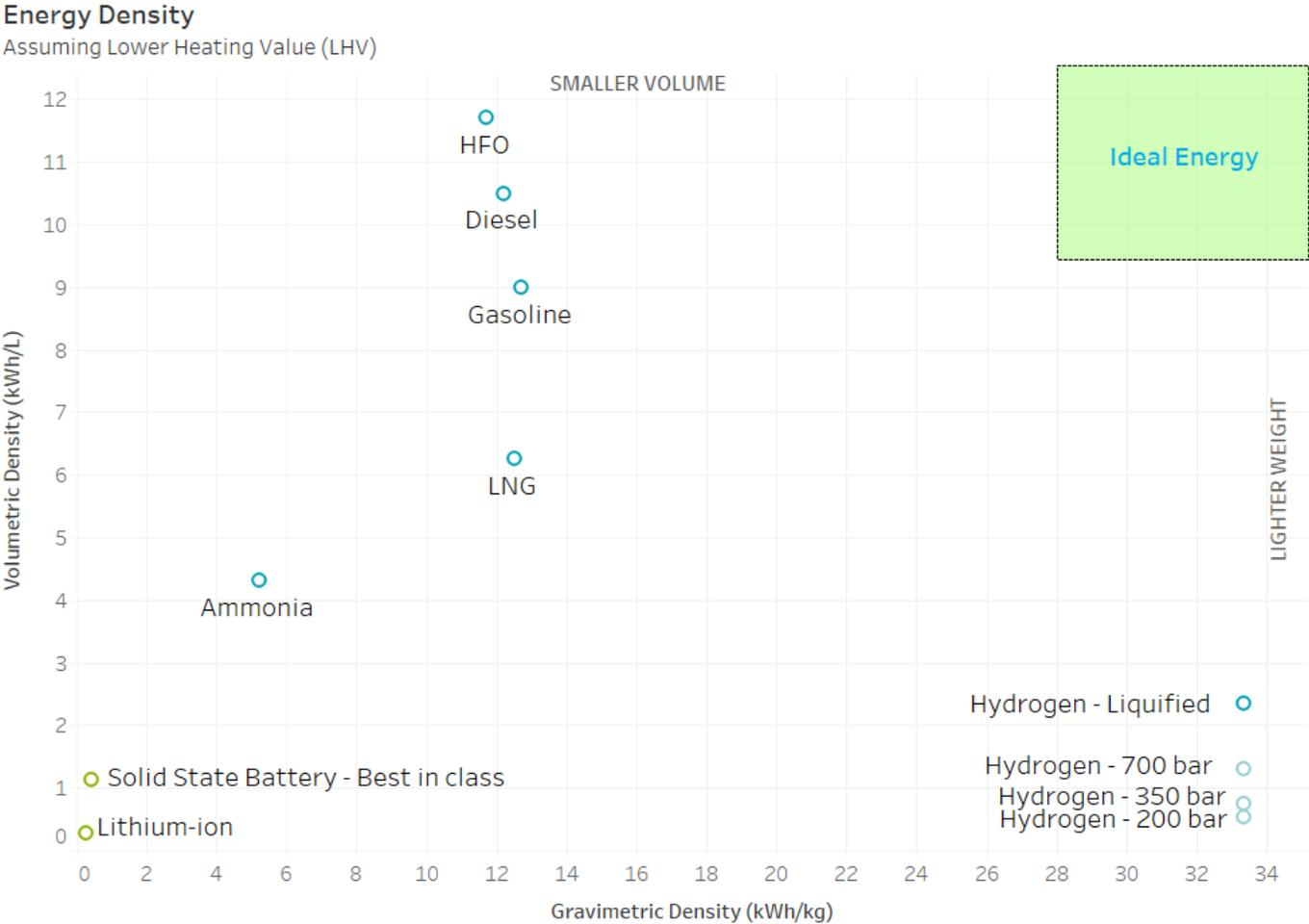
Disadvantages

- Higher energy consumption

Challenges

- Limited existing infrastructure
- Higher production cost
- Challenging to transport

Comparison of Energy Carriers

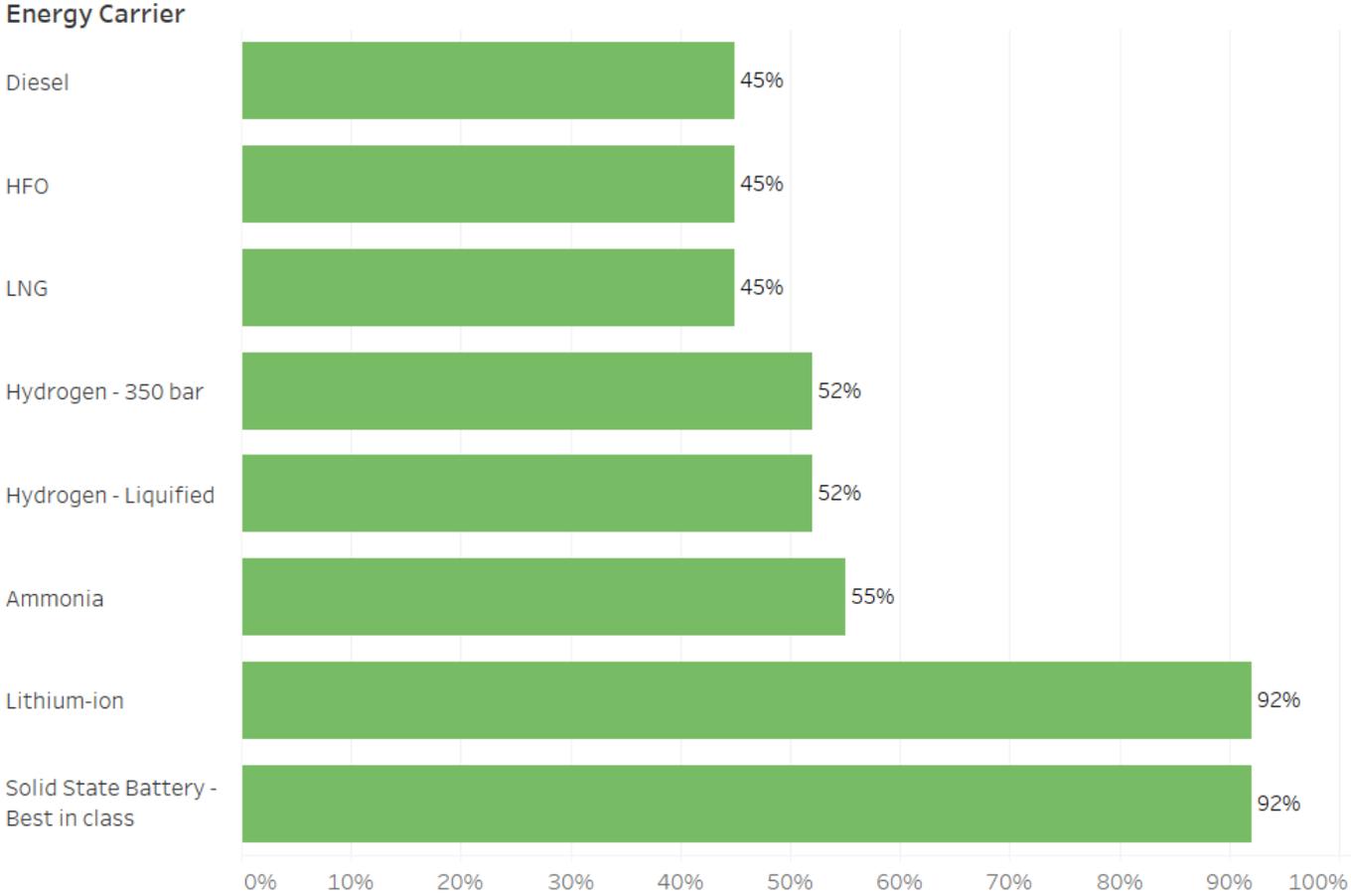


Category
■ Liquid ■ Gas ■ Battery



Comparison of Energy Carriers: Efficiency

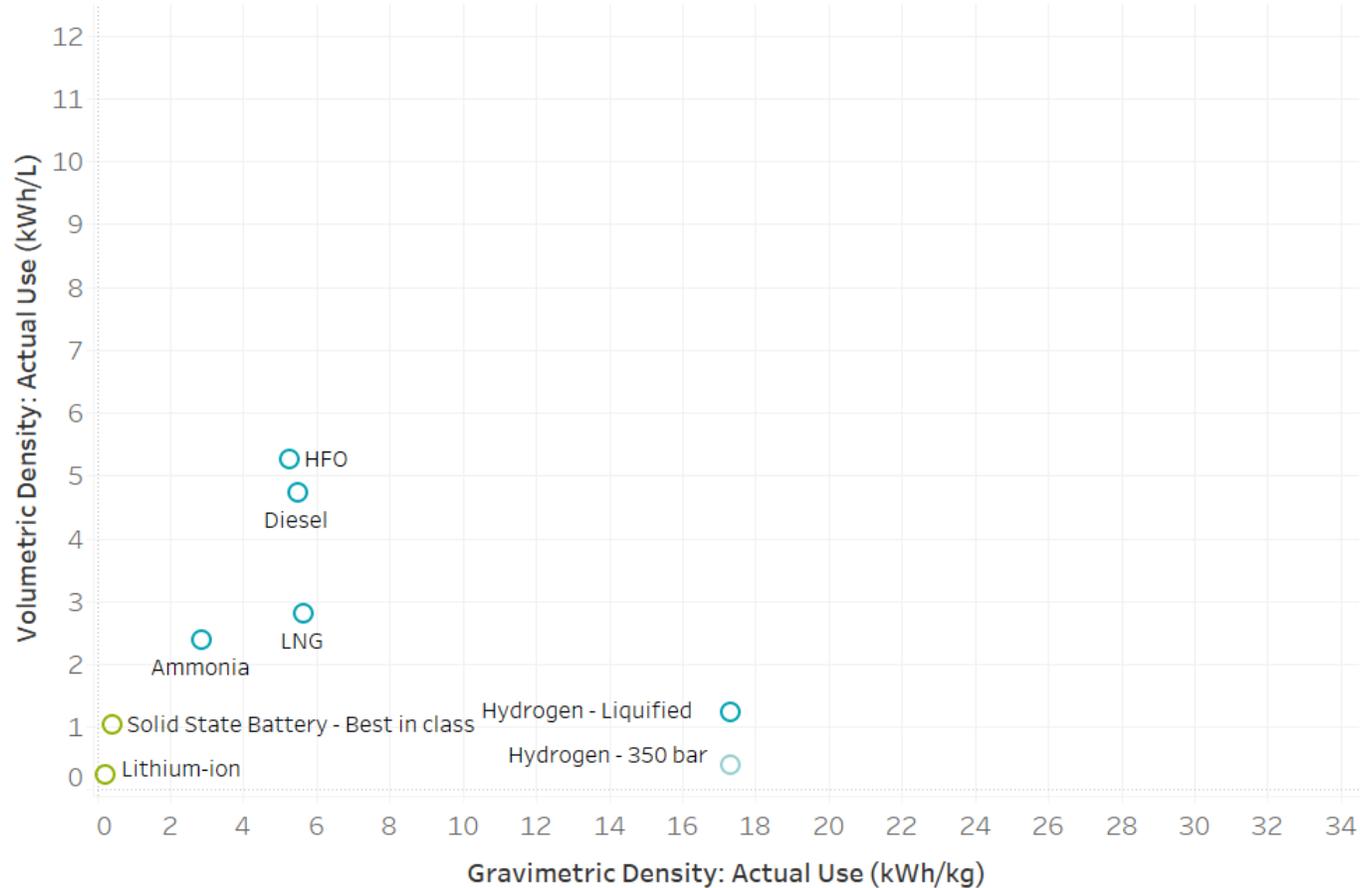
Energy Carrier Peak Efficiency Comparison
In percentage kWh produced of total kWh available



Comparison of Energy Carriers: In Reality

Energy Density in Reality

Assuming Lower Heating Value (LHV)

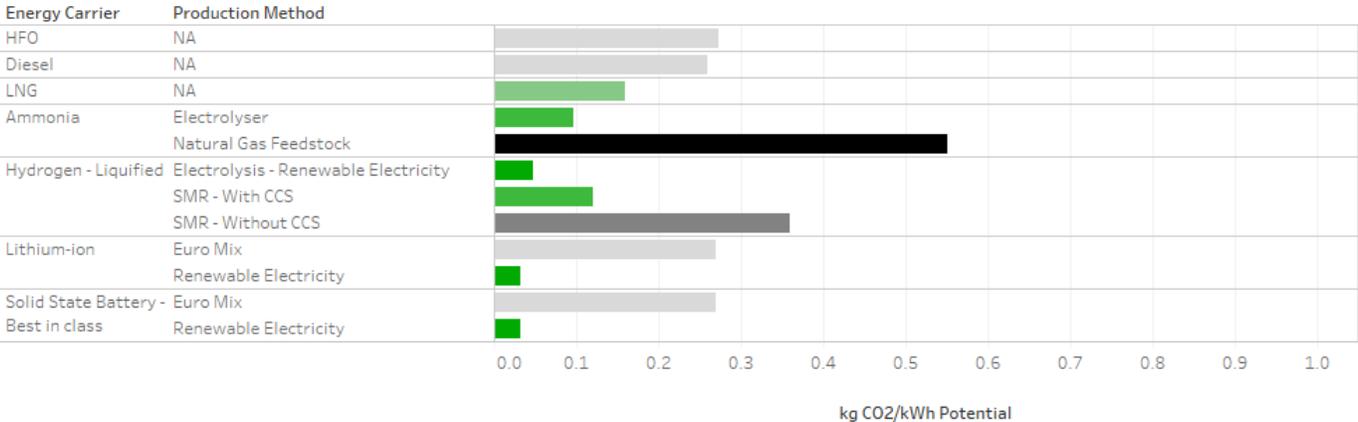


Category
■ Battery ■ Gas ■ Liquid

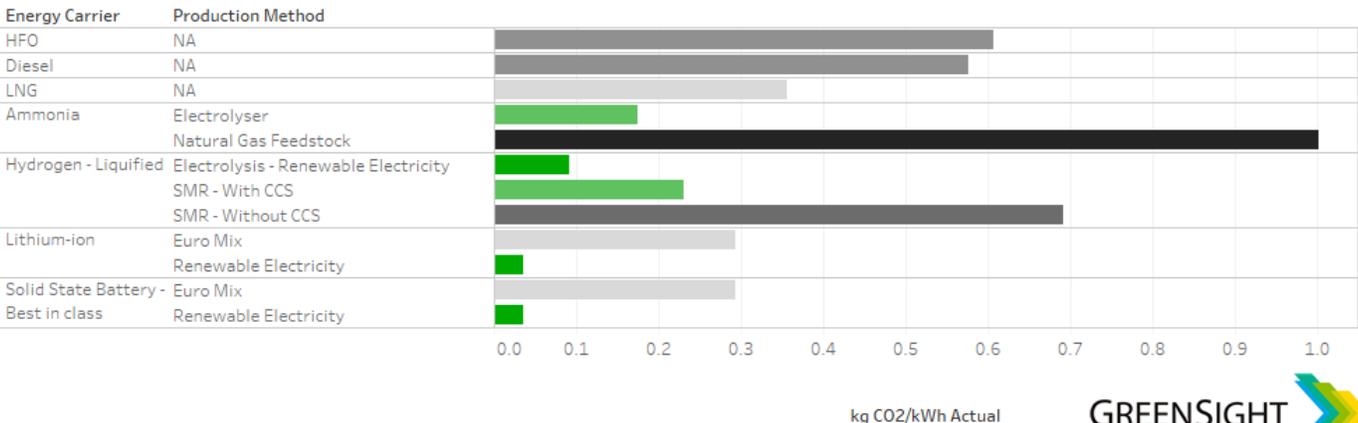


Comparison of Energy Carriers: Emissions

CO2 Emissions per kWh Potential
Based on theoretical energy available



CO2 Emissions per kWh Actual
Based on actual fuel consumption efficiency

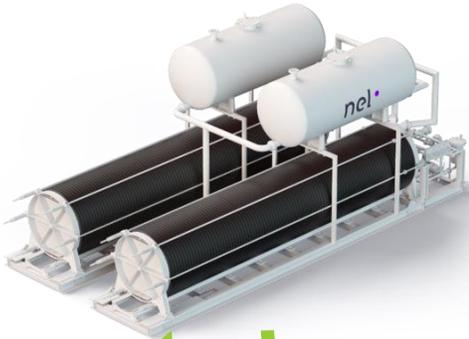


Source to Propeller Efficiency

Electricity Production



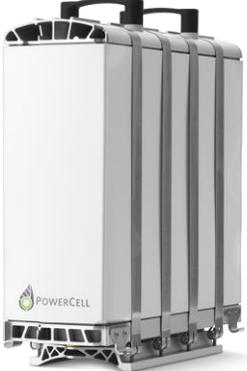
Hydrogen Production



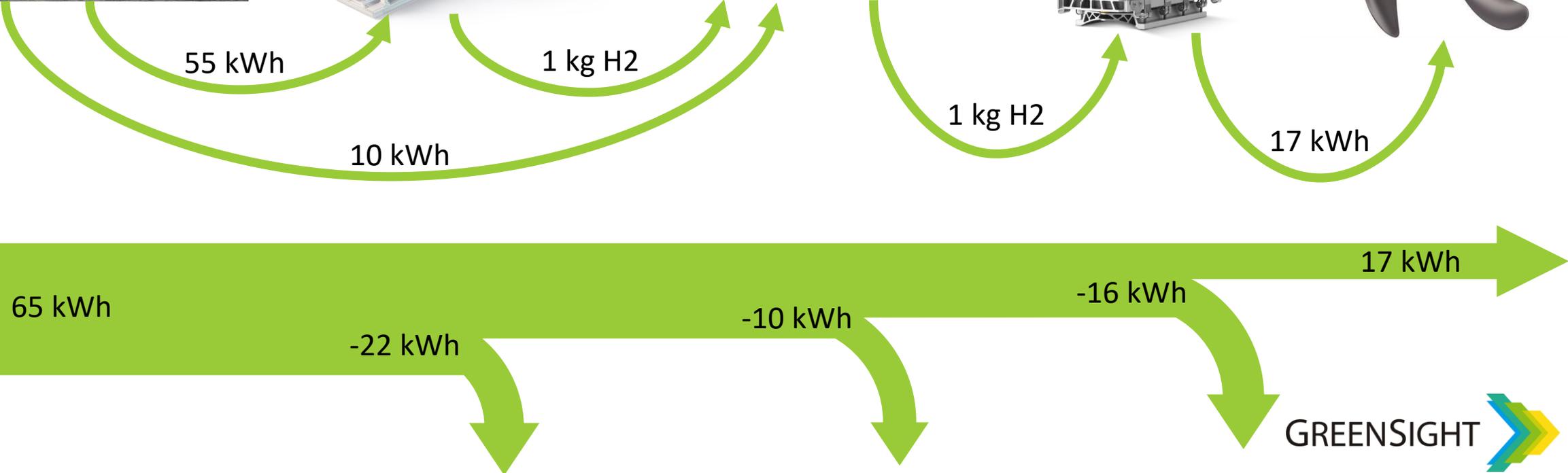
Liquefaction



Fuel Cell

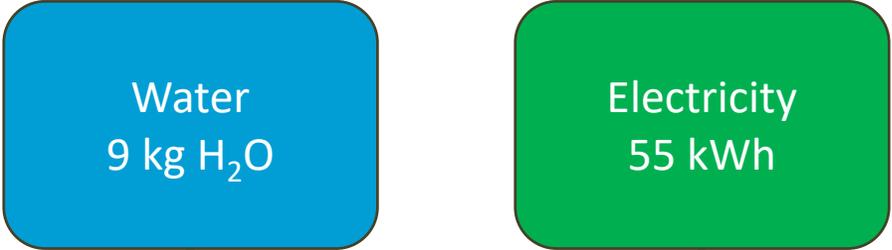


Propeller

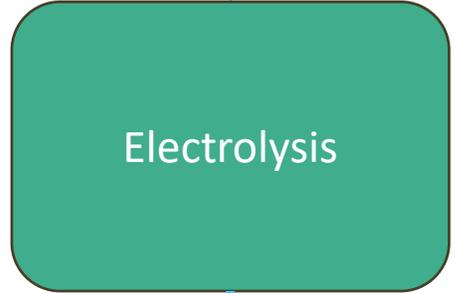


Hydrogen Production: Inputs & Outputs

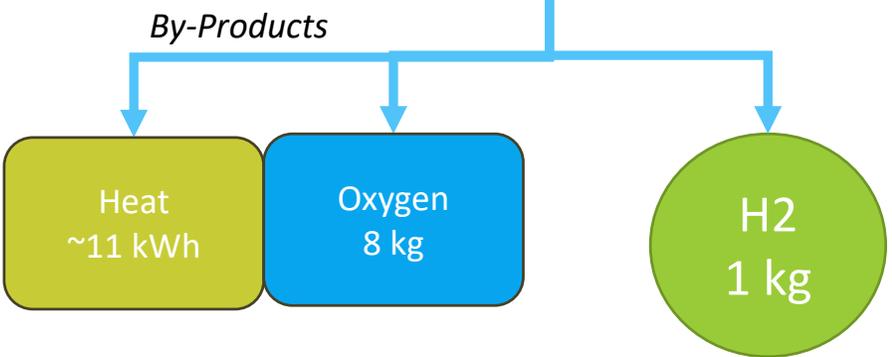
Inputs



Processes

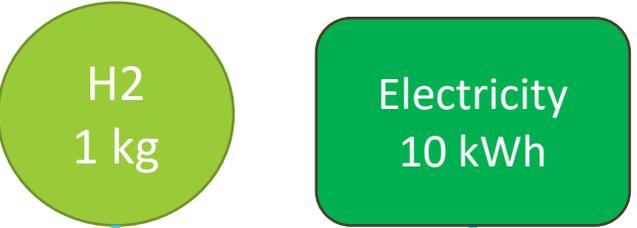


Outputs



Hydrogen Liquefaction: Inputs & Outputs

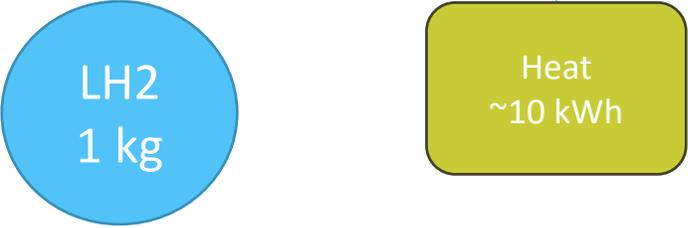
Inputs



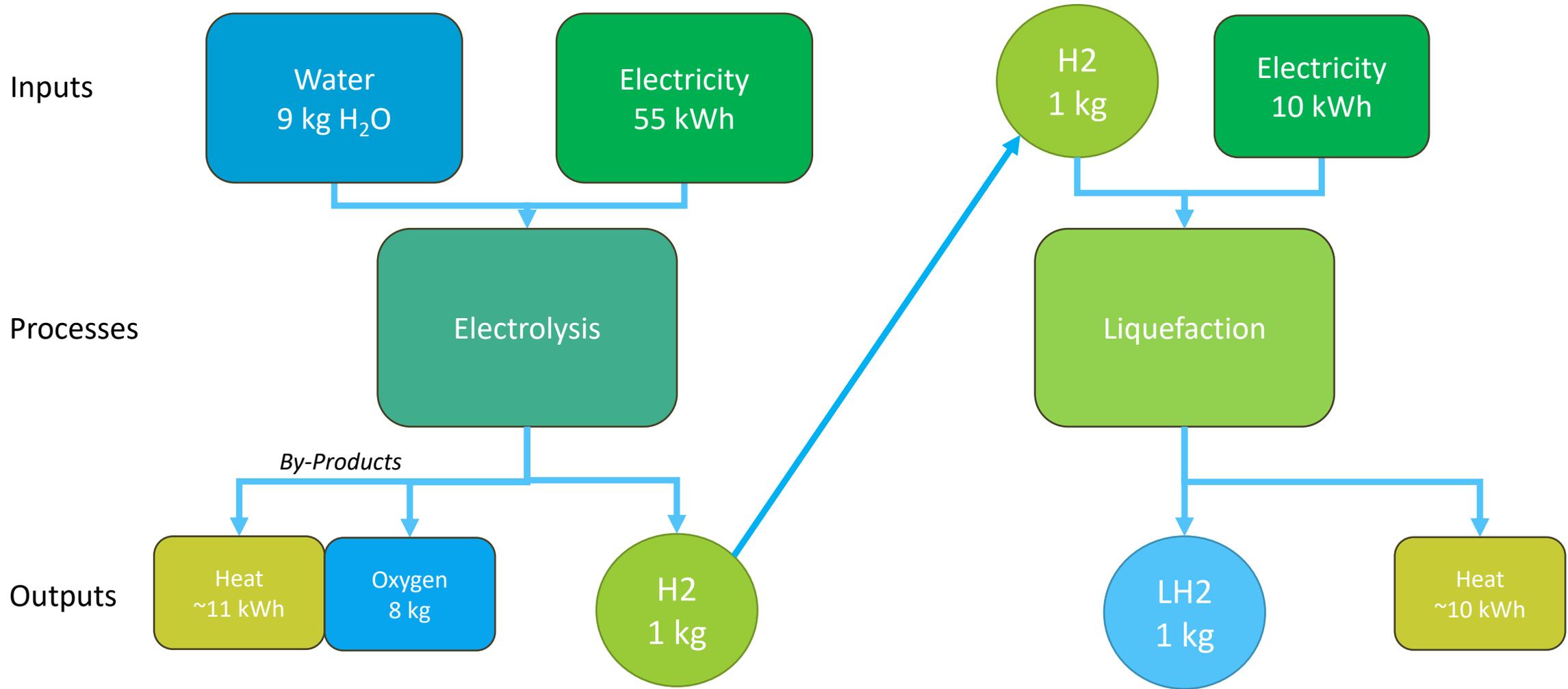
Processes



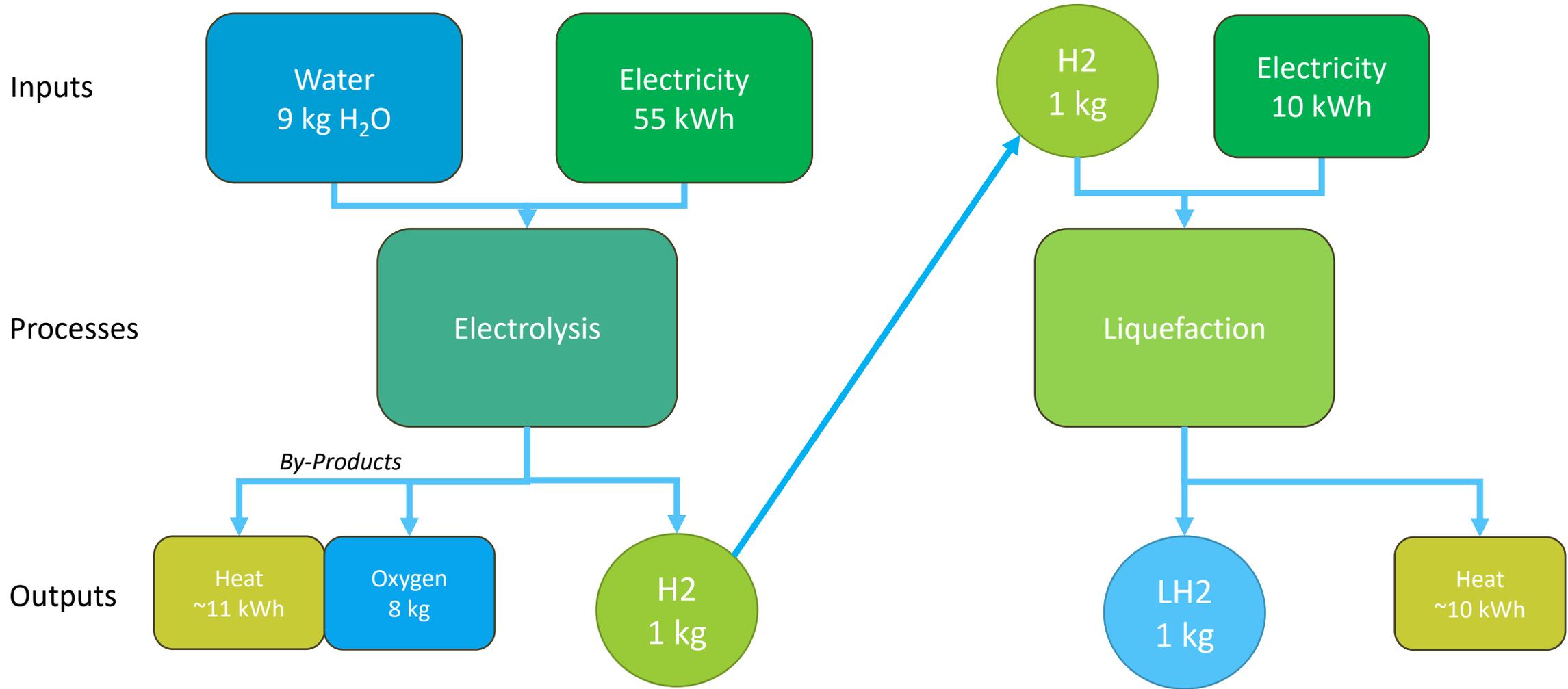
Outputs



Electrolyser Production + Liquefaction



Electrolyser Production + Liquefaction

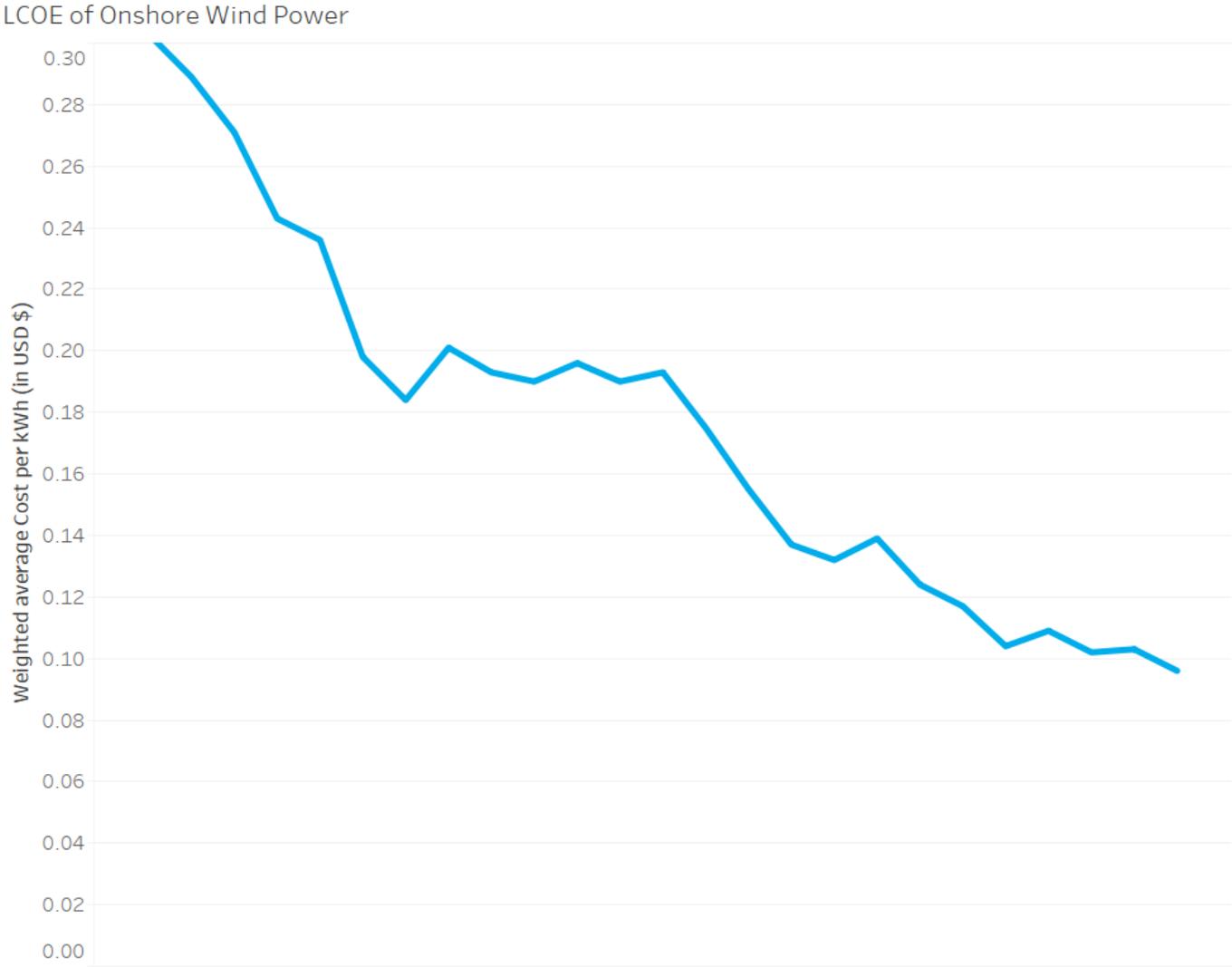


Main Input: Electricity

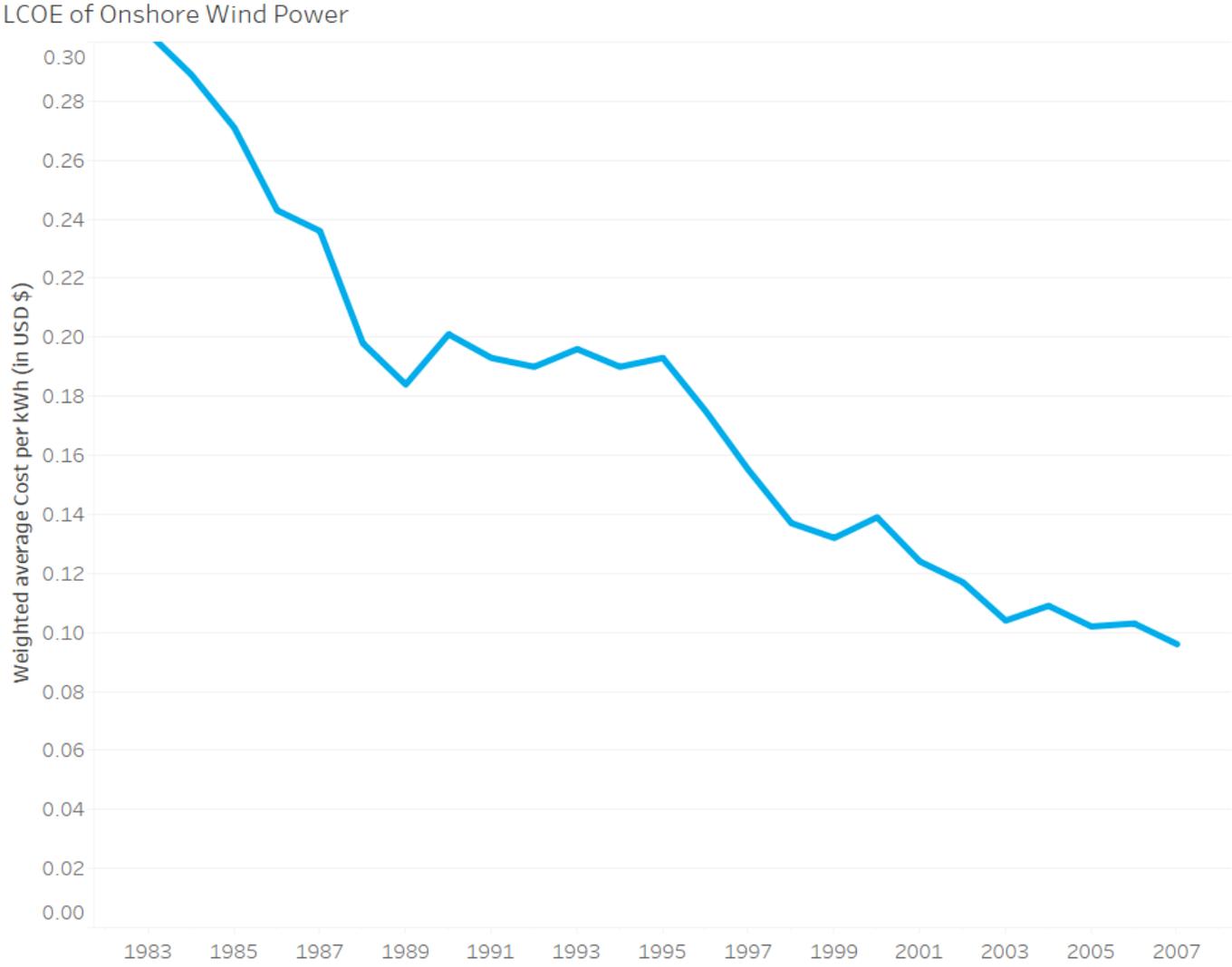
Electricity
55 kWh

Electricity
10 kWh

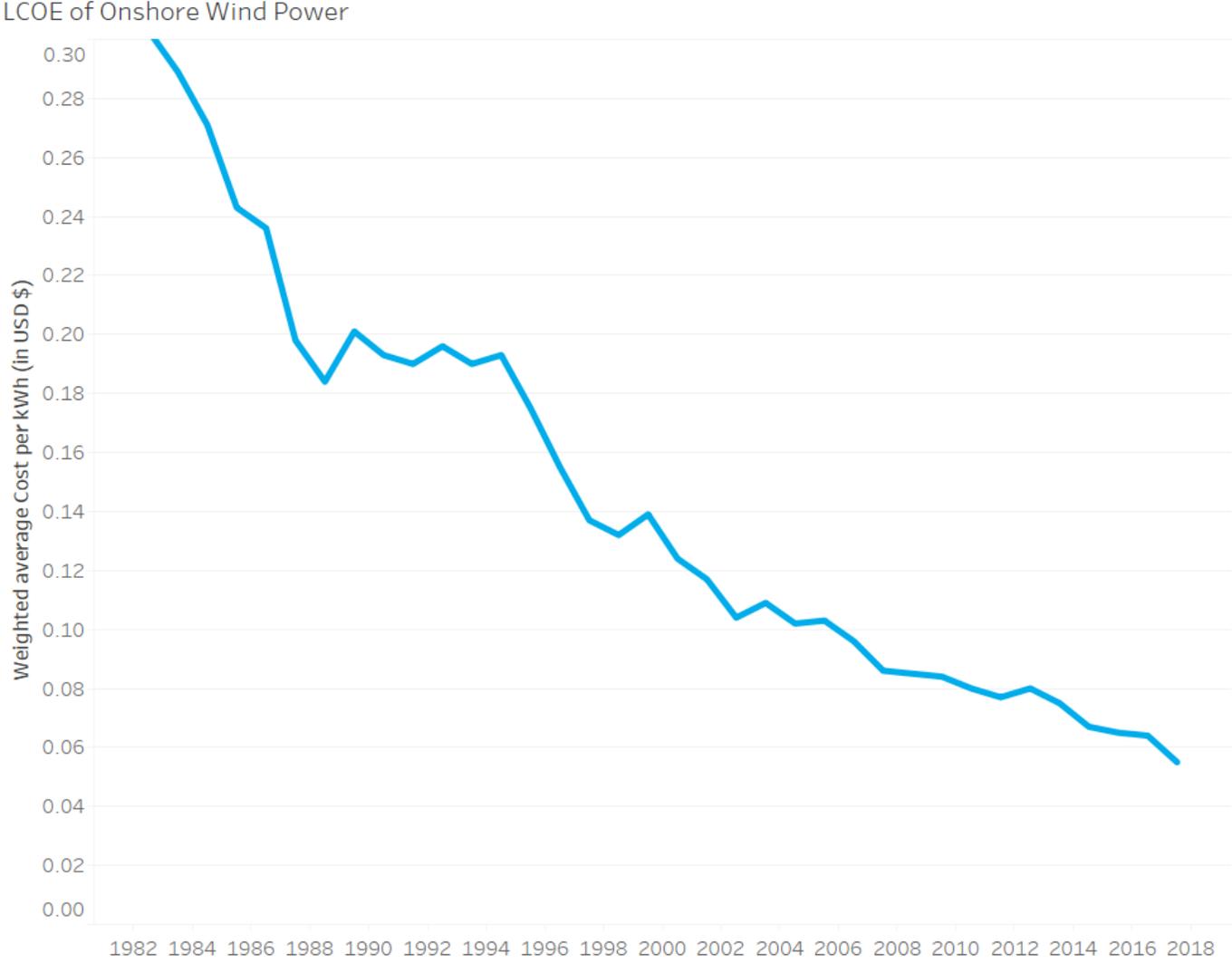
Cost of Electricity: Wind Power



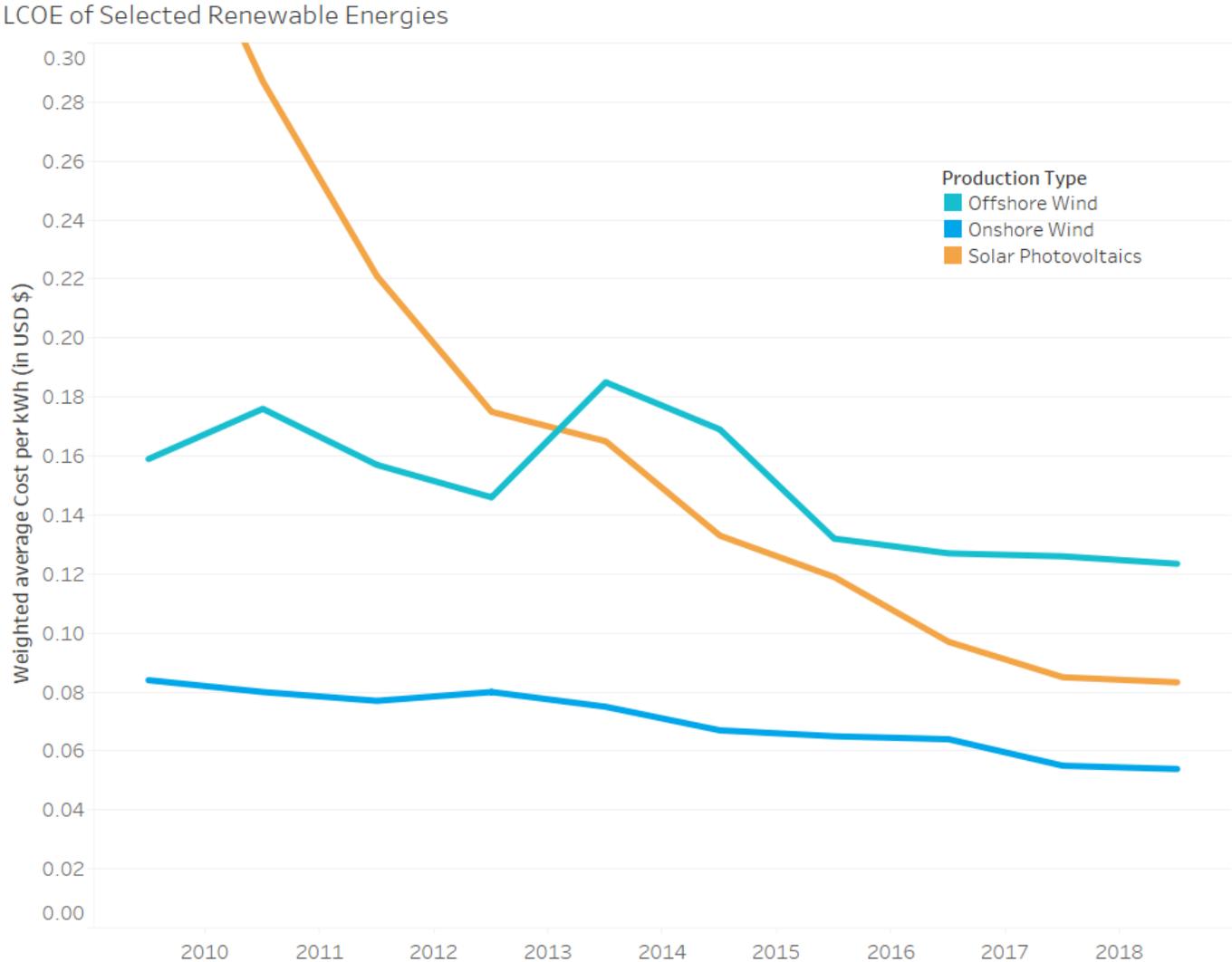
Cost of Electricity: Wind Power



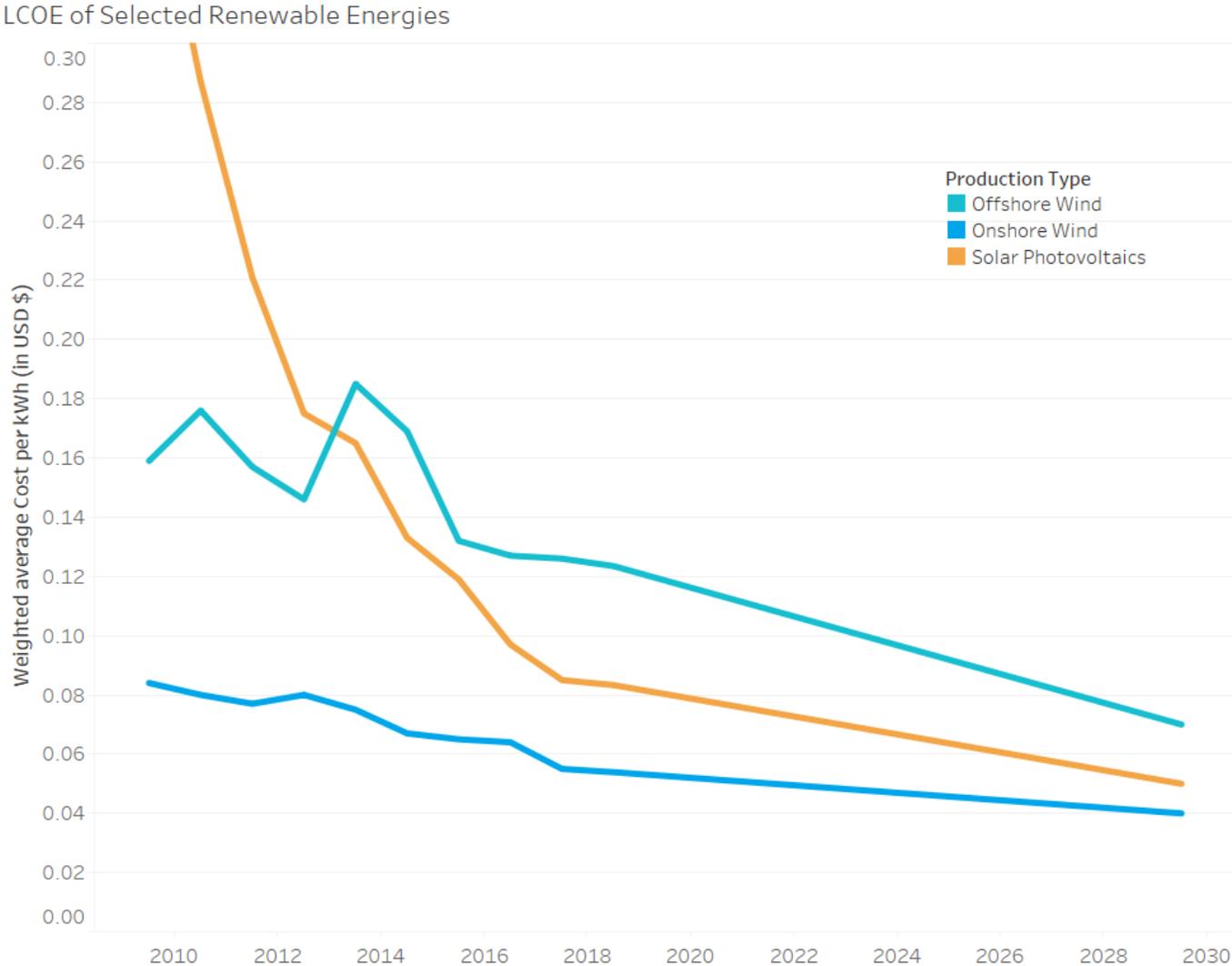
Cost of Electricity: Wind Power



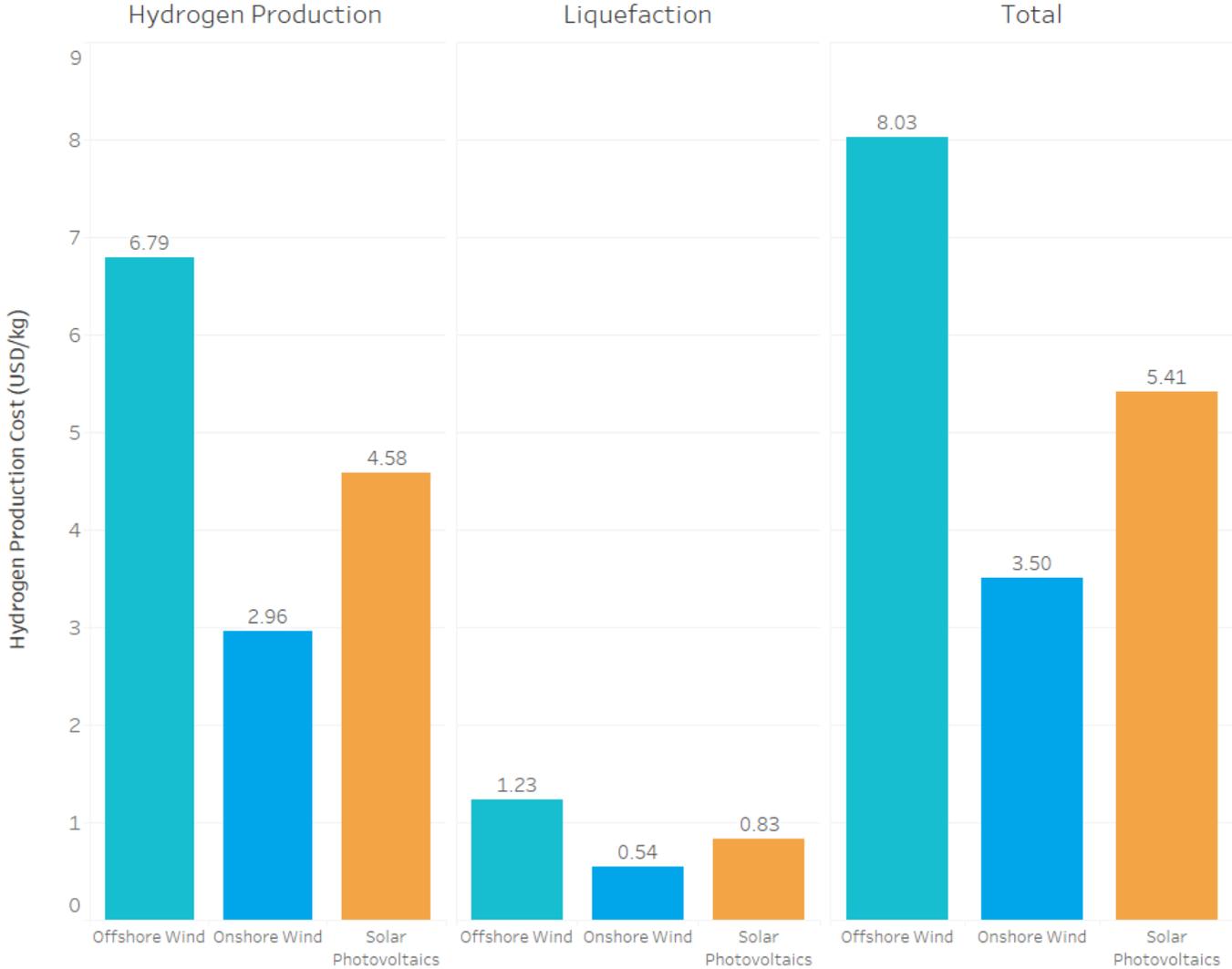
Cost of Electricity: Today



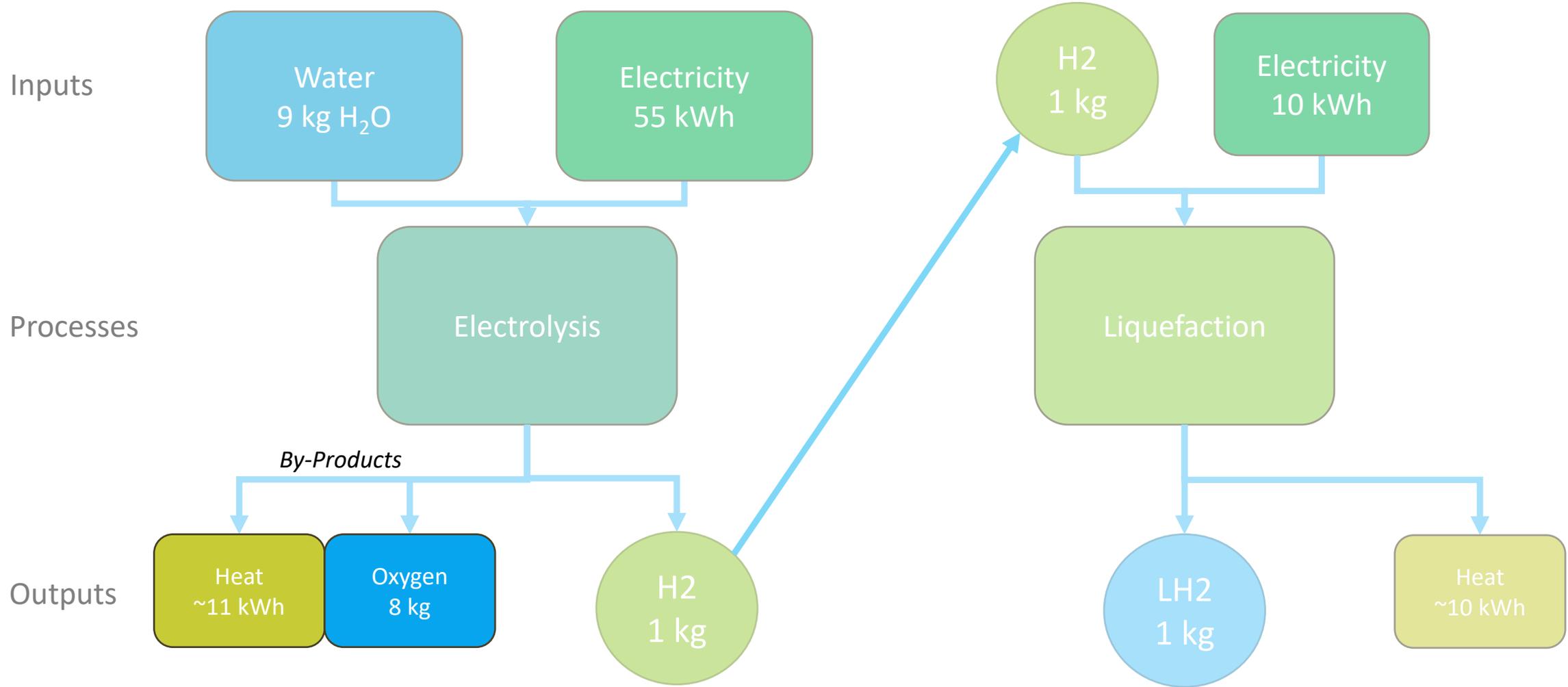
Cost of Electricity: Forecast



Production Cost: H2 / LH2



Use of By-Products



Use of By-Products

Heat
~11 kWh

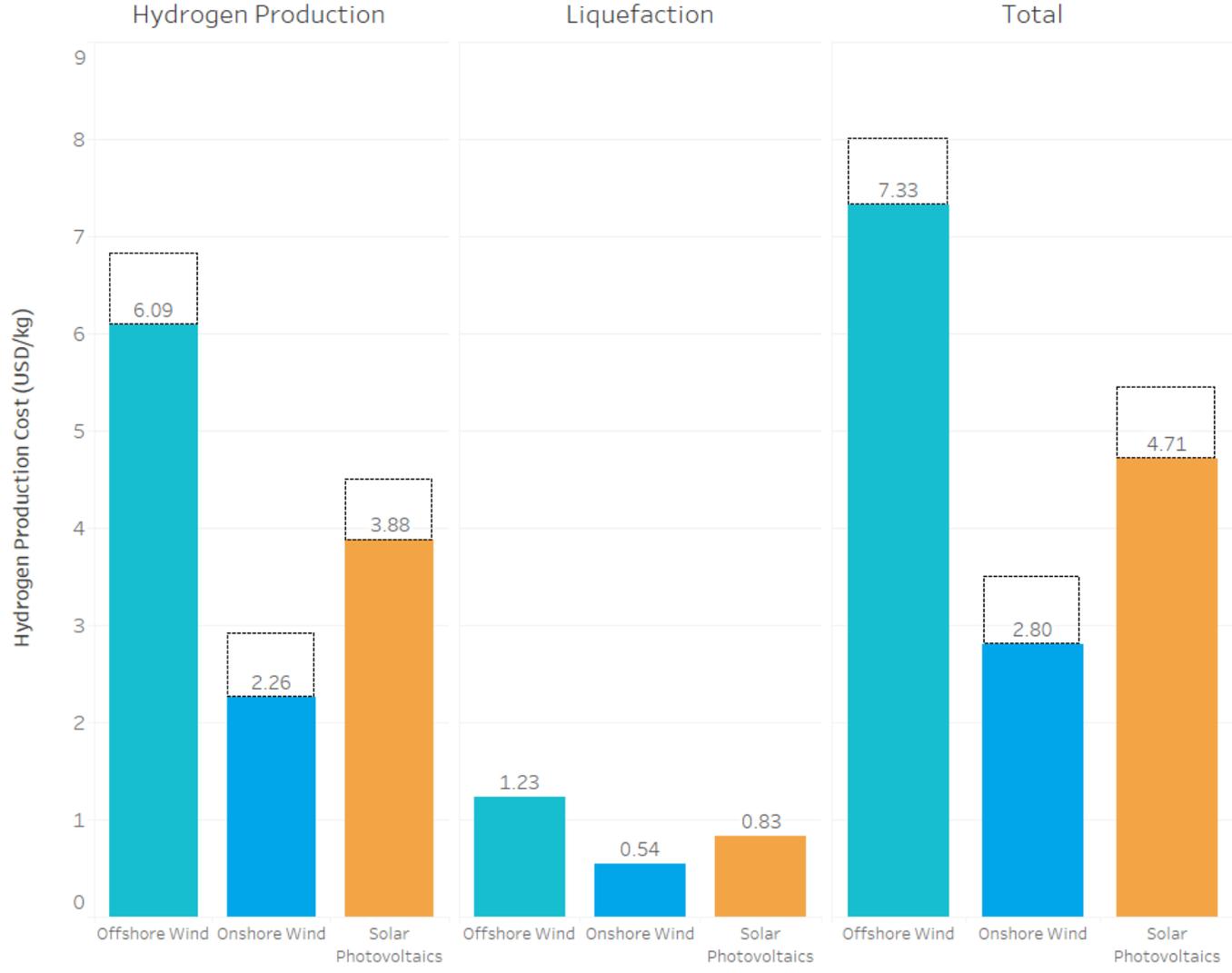
Oxygen
8 kg

Hydrogen Production	Electricity Used (kWh)	Heat By-Product (kWh)	Sale Price of Heat (50% discount)	Additional Income
1 kg	55,00	11,00	0,04	0,39
1 kg	55,00	11,00	0,04	0,46
1 kg	55,00	11,00	0,03	0,30

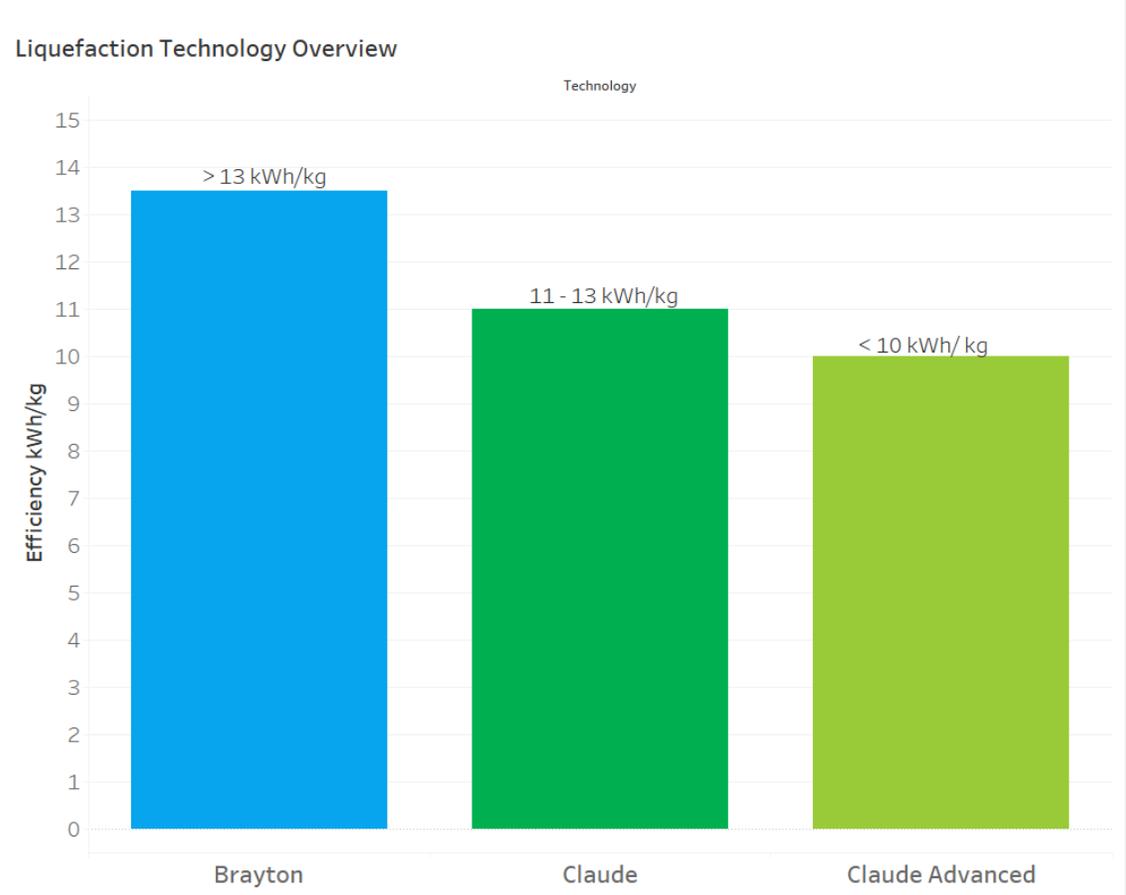
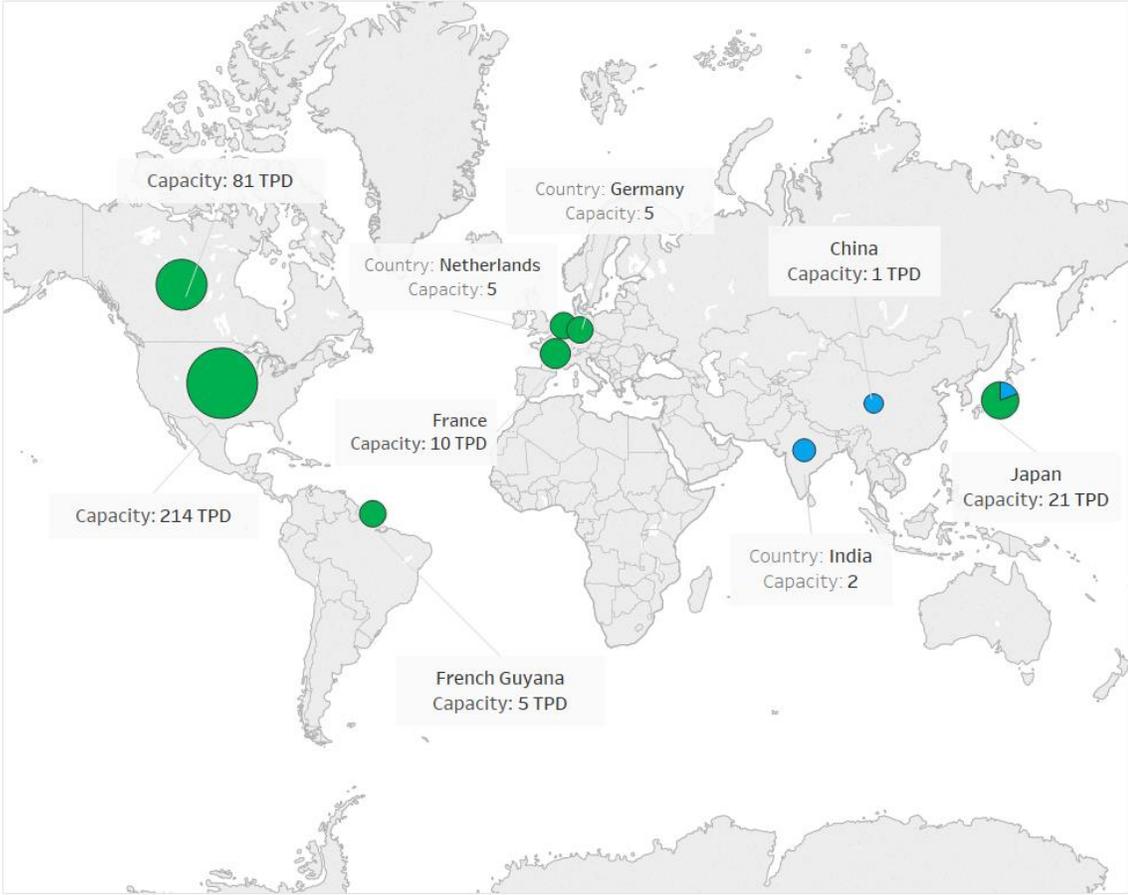
Units Hydrogen	Units O2 Produced	Available for Sale	Sale Price of O2 (Market)	Additional Income
1 kg	8 kg	8 kg	0,05	0,40

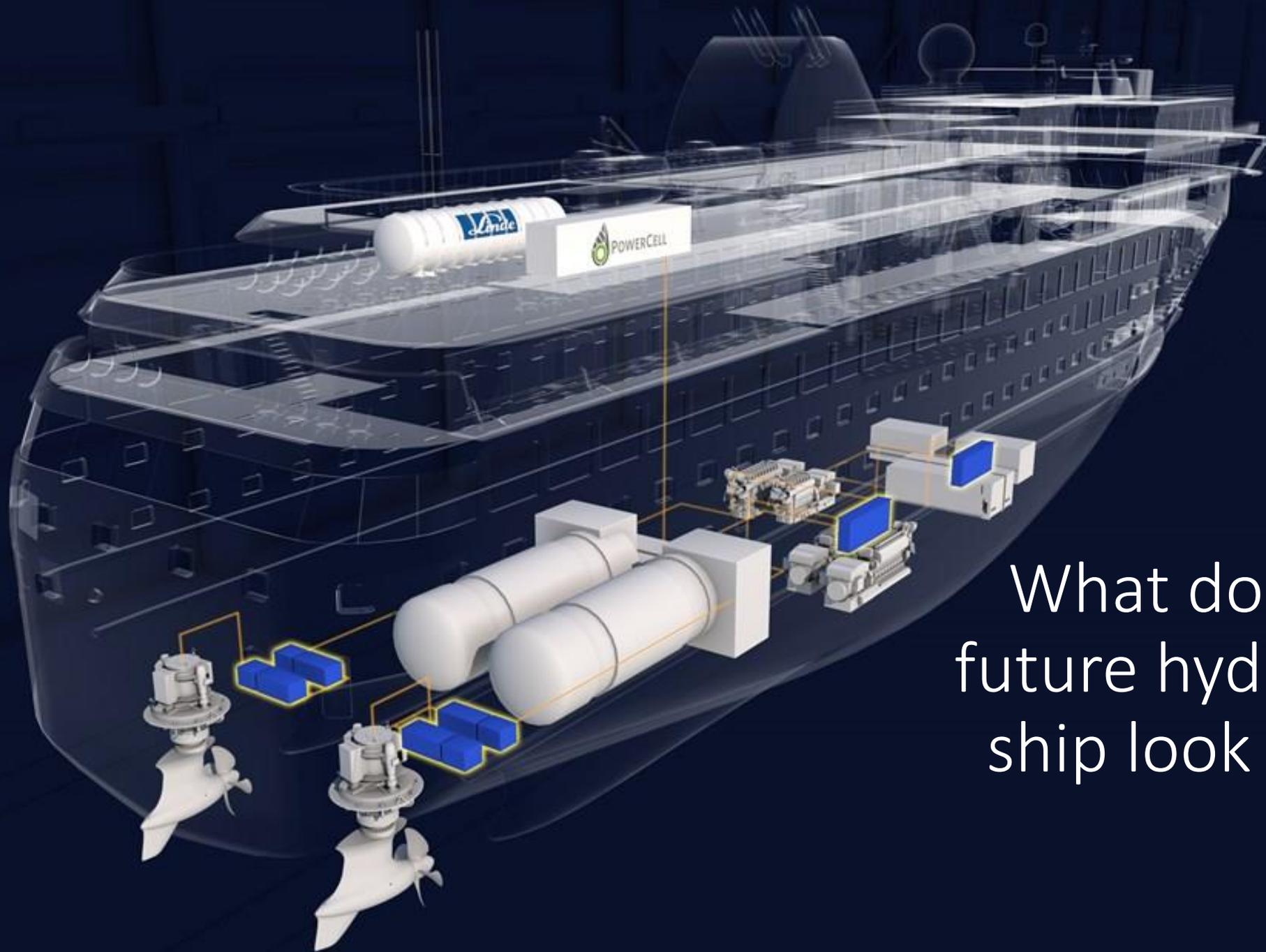
Additional Income				0,70 - 0,86
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Production Cost: H2 / LH2



LH2: Global Production





What does a future hydrogen ship look like?

The Route: Malaysia – Egypt

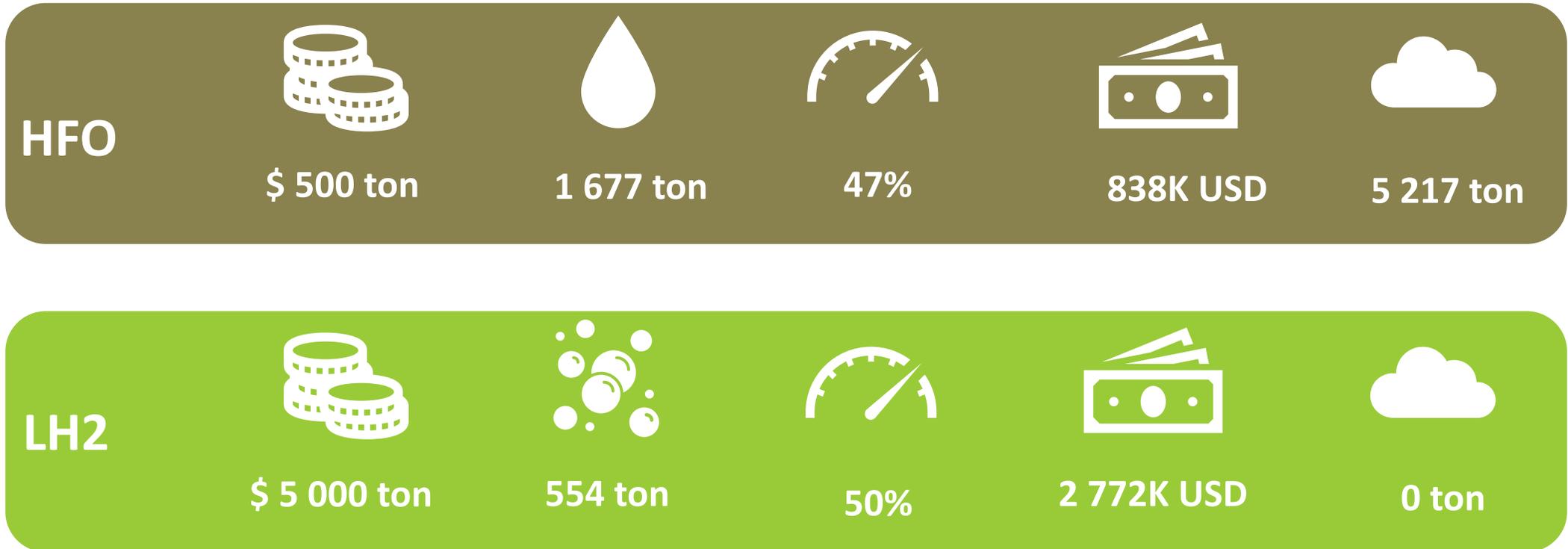
Emma Maersk

The Distance: ~5000 nm
Capacity: 11 000 TEU
Energy Used: 9 240 MWh
Possible LH2: Yes



Emma Maersk: Comparison

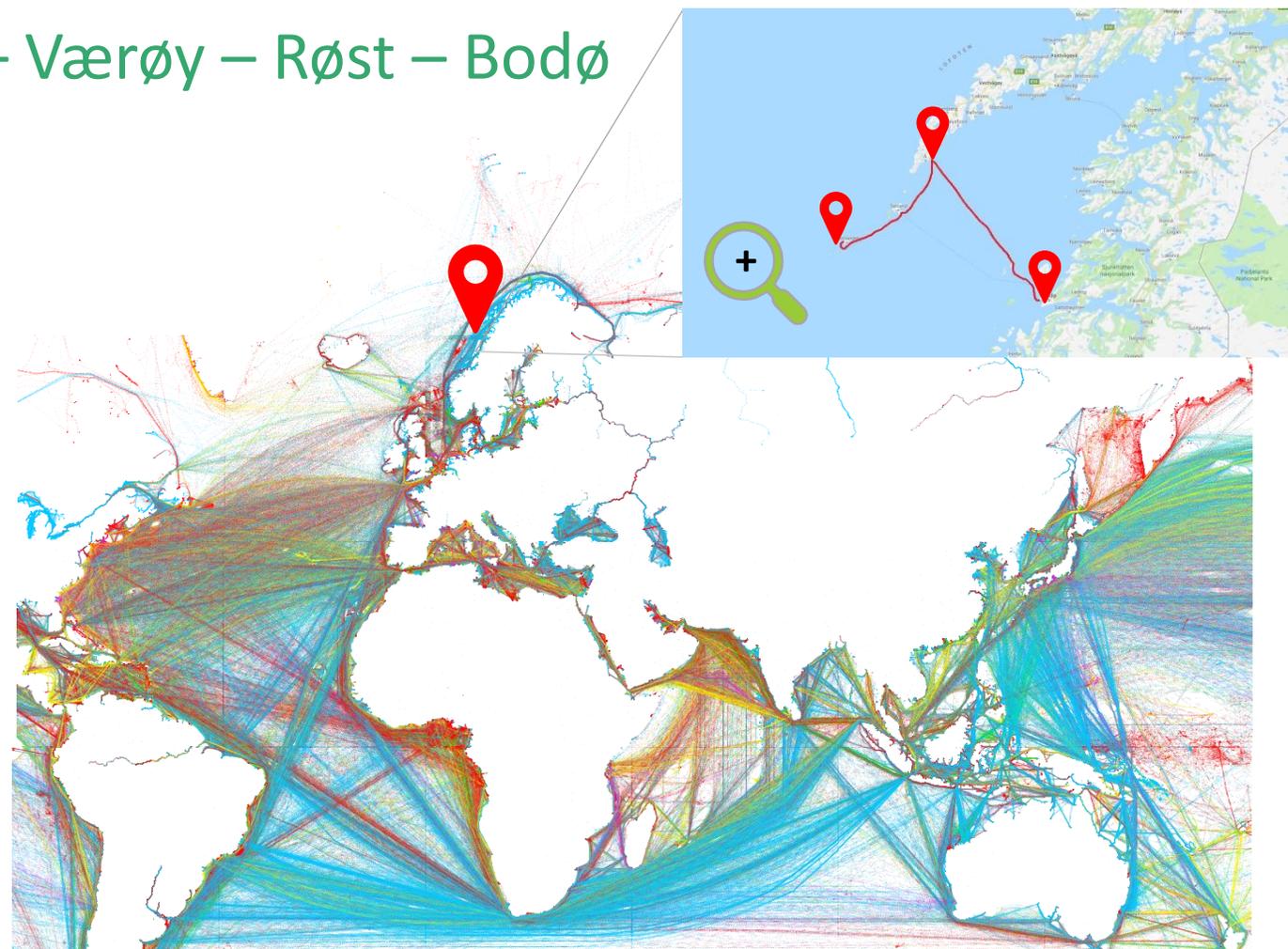
Malaysia - Egypt



The Route: Bodø - Moskenes - Værøy - Røst - Bodø

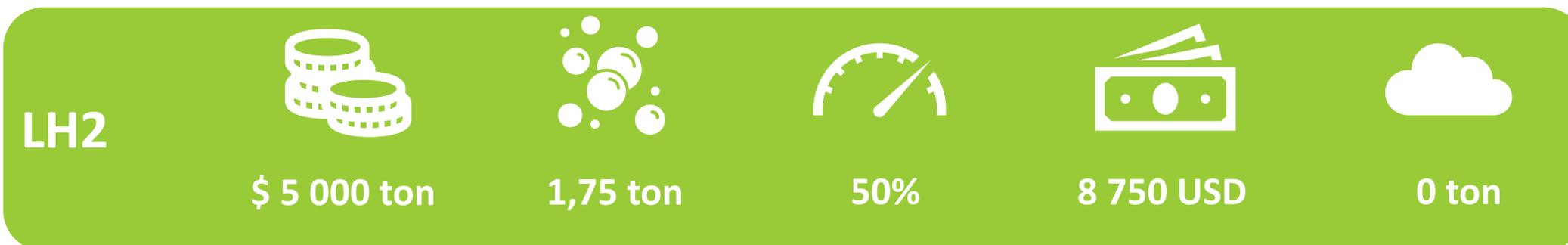
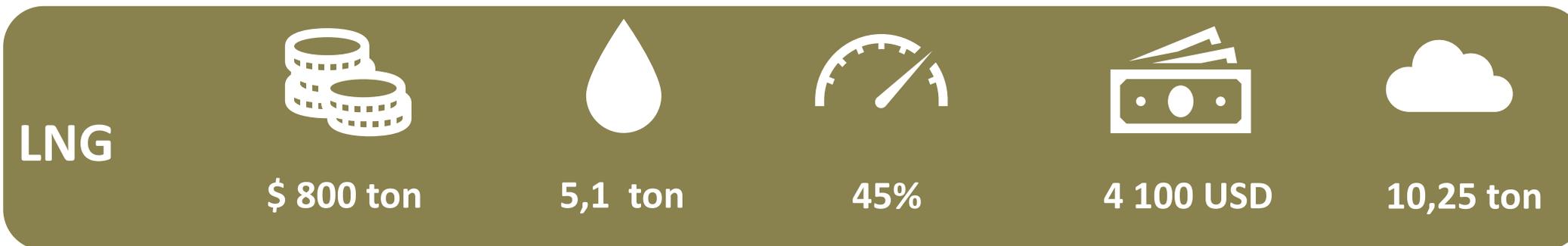
MF Værøy

The Distance: ~155 nm
Capacity: 390 passengers
Capacity cars: 120
Energy Used: 28,9 MWh
Possible LH2: Yes



MF Værøy Comparison

Bodø - Moskenes – Værøy – Røst – Bodø



Closing Recommendations



START SMALL – BUT NOT TOO SMALL



FIND THE WILLINGNESS TO PAY



FOCUS ON SPECIFIC PORTS/ROUTES
A – B –A



USE FUNDING WHERE AVAILABLE: IN NORWAY:
PILOT E, ENOVA, NOX FUND



WORK TOGETHER
ECONOMIES OF SCALE WILL YIELD SIGNIFICANT RESULTS



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