Power-to-Al: Techno-economics of Aluminium as an Energy Carrier

Hüseyin Ersoy[1], Manuel Baumann[1], Linda Barelli[2], Marcel Weil[1,3], Stefano Passerini[3]

[1] Institute for Technology Assessment and System Analysis (ITAS), KIT, Karlsruhe, Germany
[2] University of Perugia (UNIPG), Perugia, Italy
[3] Helmholtz Institute Ulm for Electrochemical Energy Storage (HIU), KIT, Ulm Germany

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Agenda

- Introduction
- Energy Carriers & Comparison
- Integration of Aluminium as an alternative energy carrier
- Techno-economics
- Conclusion & Outlook

Introduction: Demand on alternative energy carriers

- Hydrogen is the most promising energy carrier, but…
  - The green H_2 will be 2 or even 3 times more expensive,
  - H_2 storage requires very large volumes, and it is expensive,
  - Europe will highly depend on the synthetic fuel imports from MENA region,
  - Inefficiencies due to conversion (i.e, Ammonia path)
- Natural gas crisis that we are facing today, and increasing energy prices.

Energy Carriers

Hydrogen as main renewable energy carrier

- Lack of dedicated infrastructure
- Lack of value recognition
- Low growth rate of H_2 refueling stations
- Electrolyser capacity is only 135 MW (as November 2021, EU Target: 6 GW by 2024) [2]

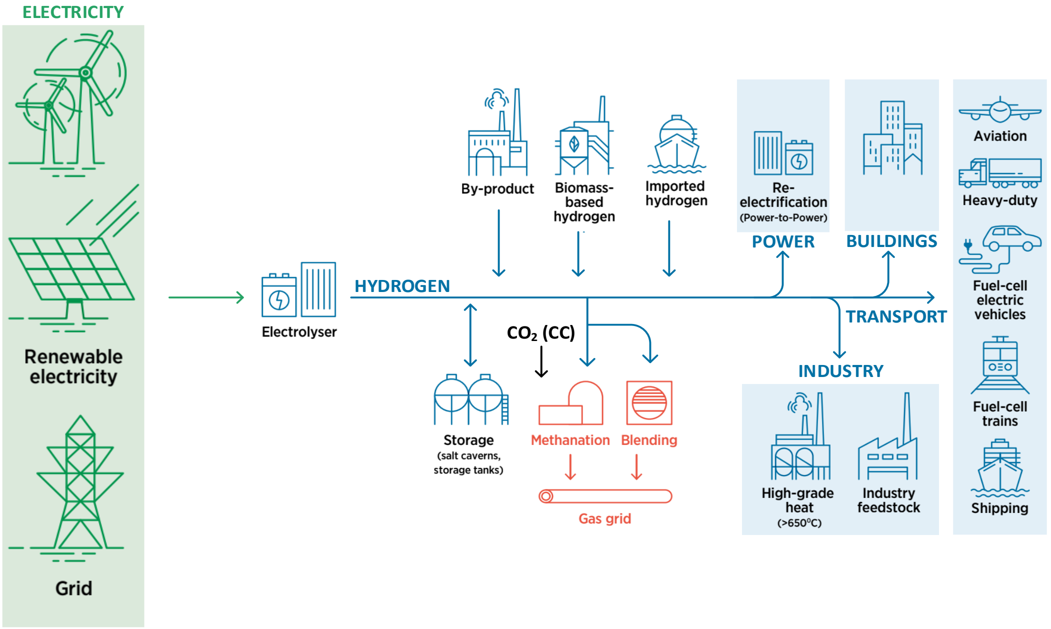
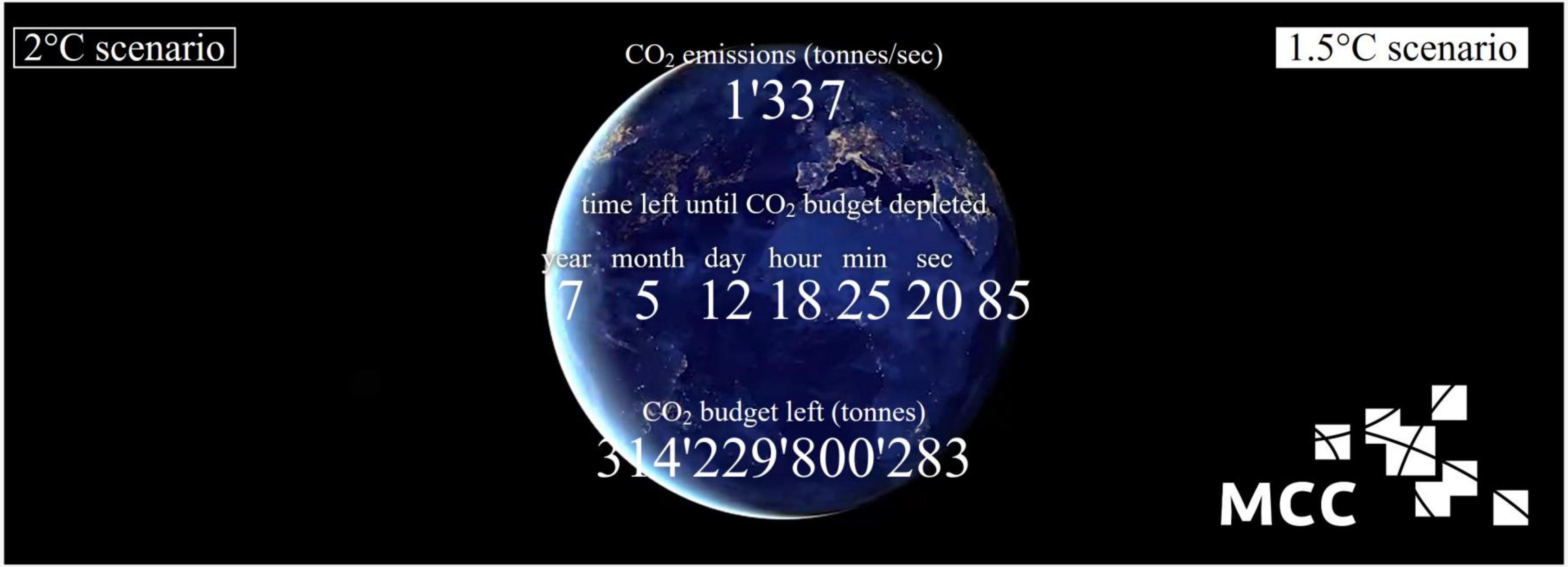


Figure source: [1]

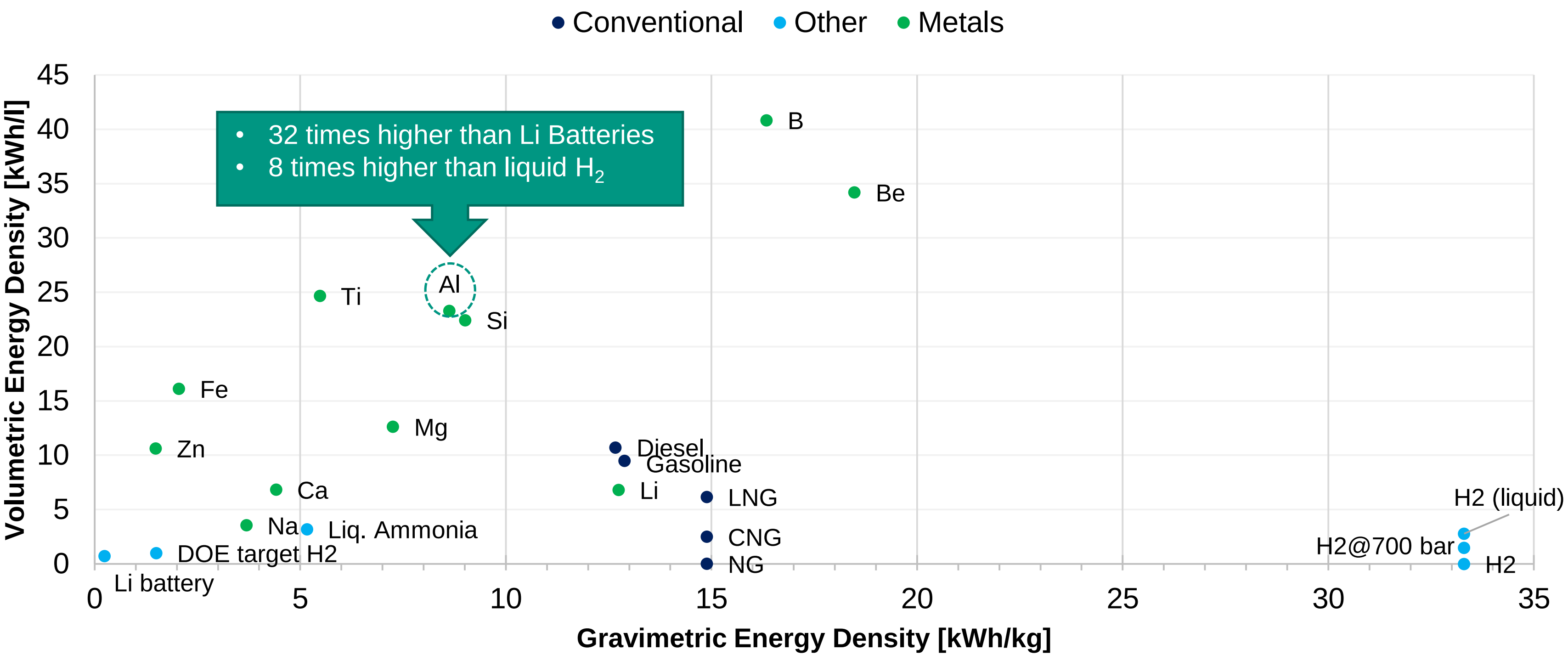
And in the meanwhile…



Quelle: https://www.mcc-berlin.net/fileadmin/data/clock/carbon_clock.htm

Bearbeiten

Energy Densities Comparison



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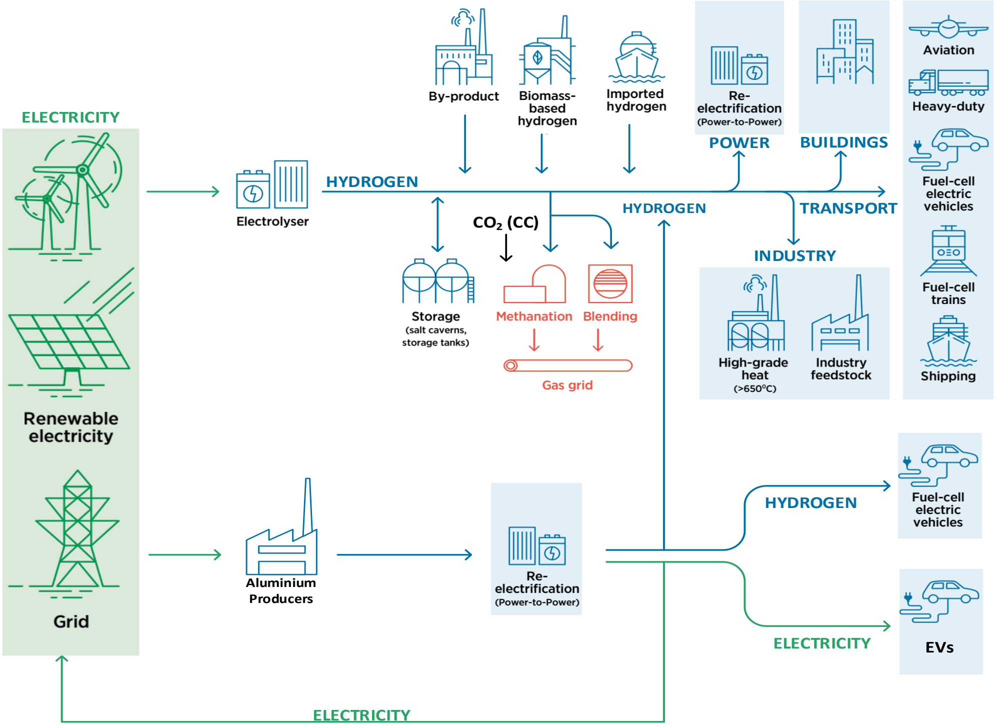
Integration of Aluminium as an alternative



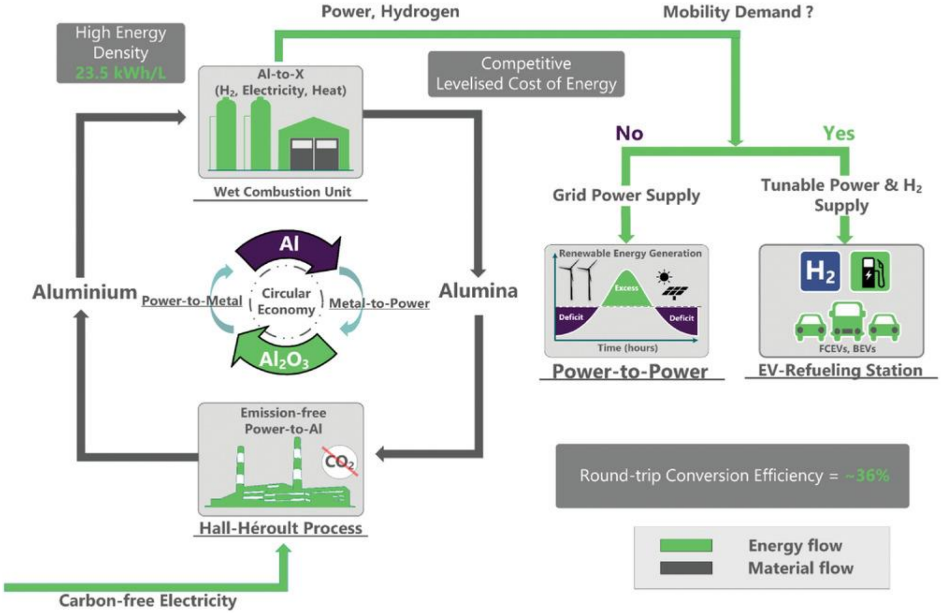
System comparison [3]:

Energy Carrier	Conversion Technology	RTE	Vol. Energy Density
Al	Hybrid System in	35.6%	23.5 kWh/L
H_2	PEM Electrolyzer / PEM Fuel Cell	30%	0.53 kWh/L
	Reversible Solid-oxide Cell	48%	0.2 kWh/L
Methanol / DME	SOE/SOFC	36.5% (26.5 with CC)	5.5 kWh/L
Gasoline	SOE/SOFC	27% (20% with CC)	8.8 kWh/L
LNG	SOE/TSA dehydration, H2 and CO2 membrane separation	28% (23% with CC)	5.8 kWh/L

Figure adapted from: [1]

Al-based Business Case for Refueling Stations

Proposed circular business case [4]:

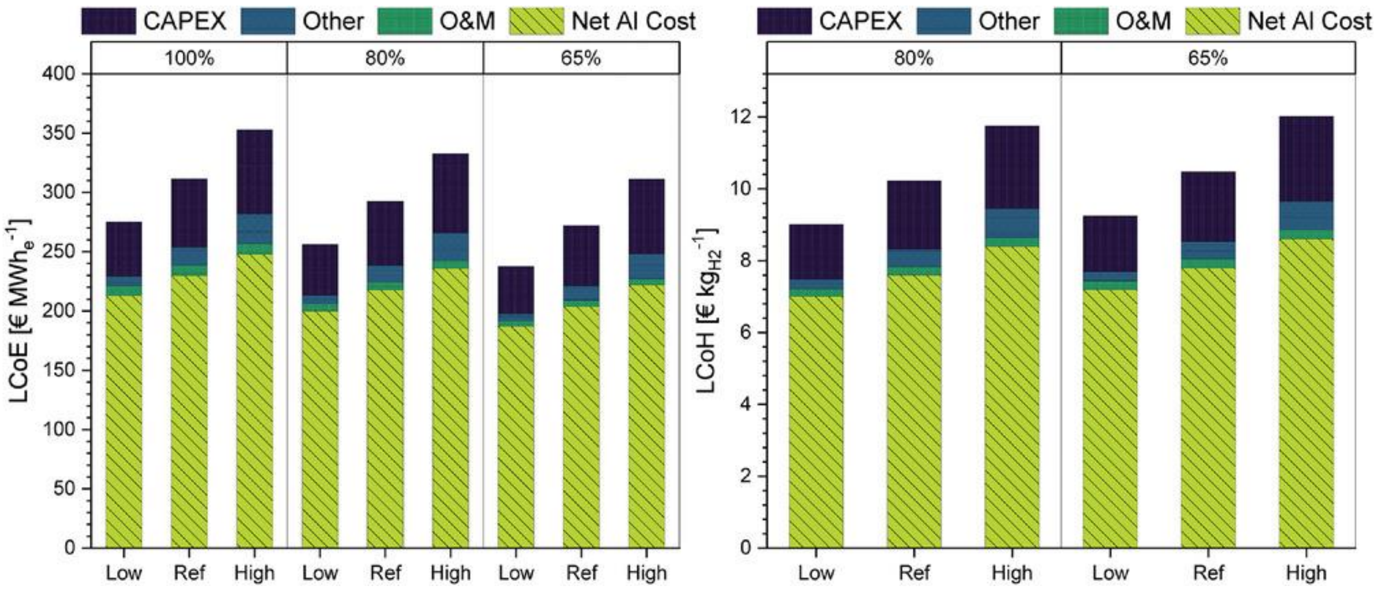


- Technical aspects [4]

Partial Loads	Power	Hydrogen	$\eta_{Al\text{-}to\text{-}Power}$
100%	~4 MW	-	35.6%
80%	3.1 MW	28 kg/h	38.8%
65%	2.6 MW	46.8 kg/h	40.7%

- Al flow rate: 0.275 kg/s
- Specific investment: 4200–6200 €/kW

Estimated LCOH and LCOE Values (Base case)



LCoE and LCoH estimations for the base case, i.e., 4000 FLHs and electricity price of 50 € MWhe^{-1}. (Low: lower end, Ref: reference, and High: higher end.) The H_2 kWh equivalent is estimated based on the higher heating value of 39.4 kWh kg^{-1}. [4]

Scenarios

As the aluminium cost is the most cost sensitive element in economics, following scenarios are developed [4]:

Scenario	Al Price [€/kg Al]	Al_2O_3 Price [€/kg Al eq.]	Energy Intensity [kWh/kg Al]	Electricity Price [€/MWh]
Scenario – I	1.44 – 1.86 (μ=1.65)	0.52-0.93 (μ=0.67)	14.25	50
Scenario – II	1.06 – 1.48 (μ=1.26)	0.52-0.93 (μ=0.67)	11	30
Scenario – III	0.73 – 1.15 (μ=0.93)	0.52-0.93 (μ=0.67)	11	0

Levelized Cost of Hydrogen (LCOH)

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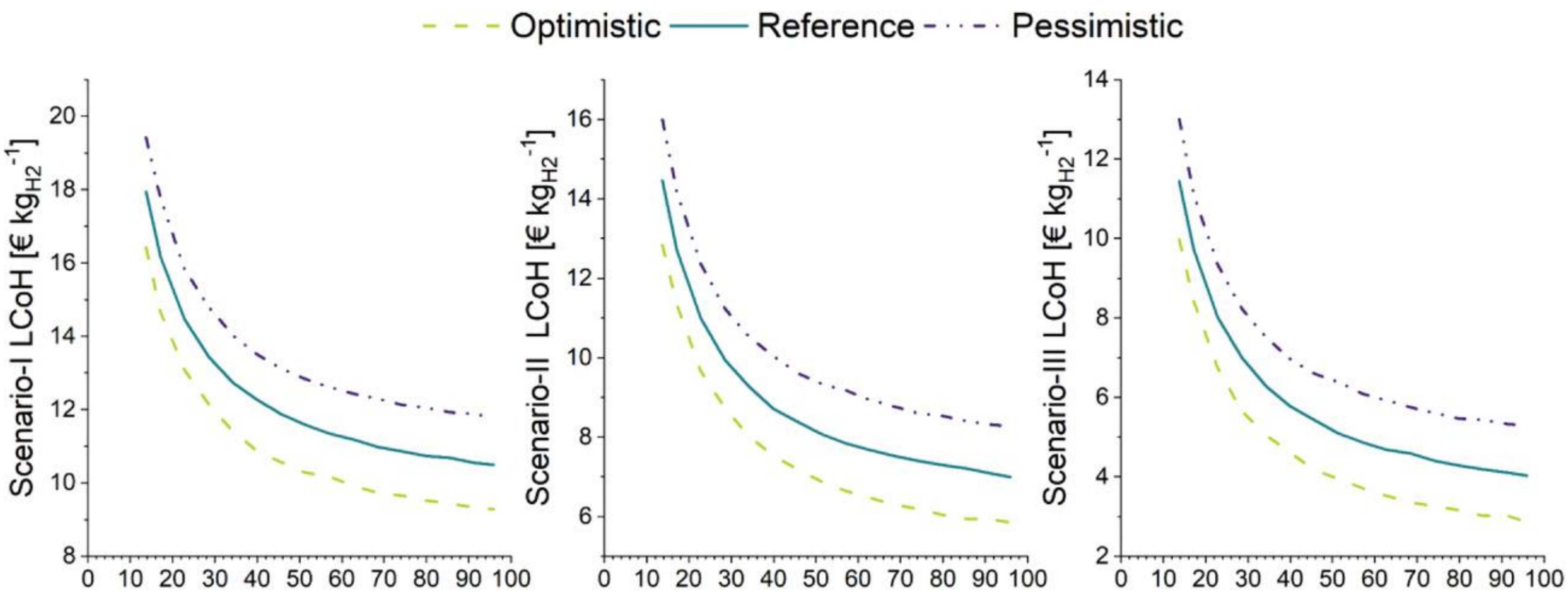

Figure source: [4]

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Levelized Cost of Electricity (LCOE)

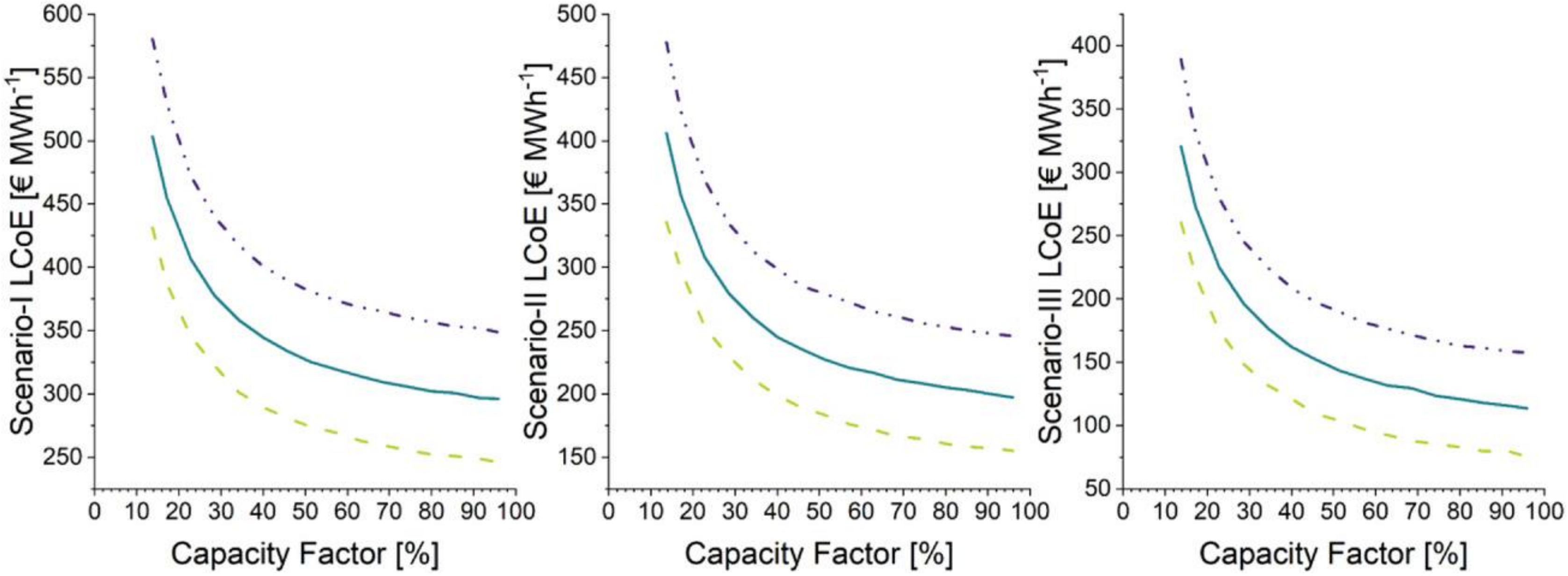

Figure source: [4]

Comparison

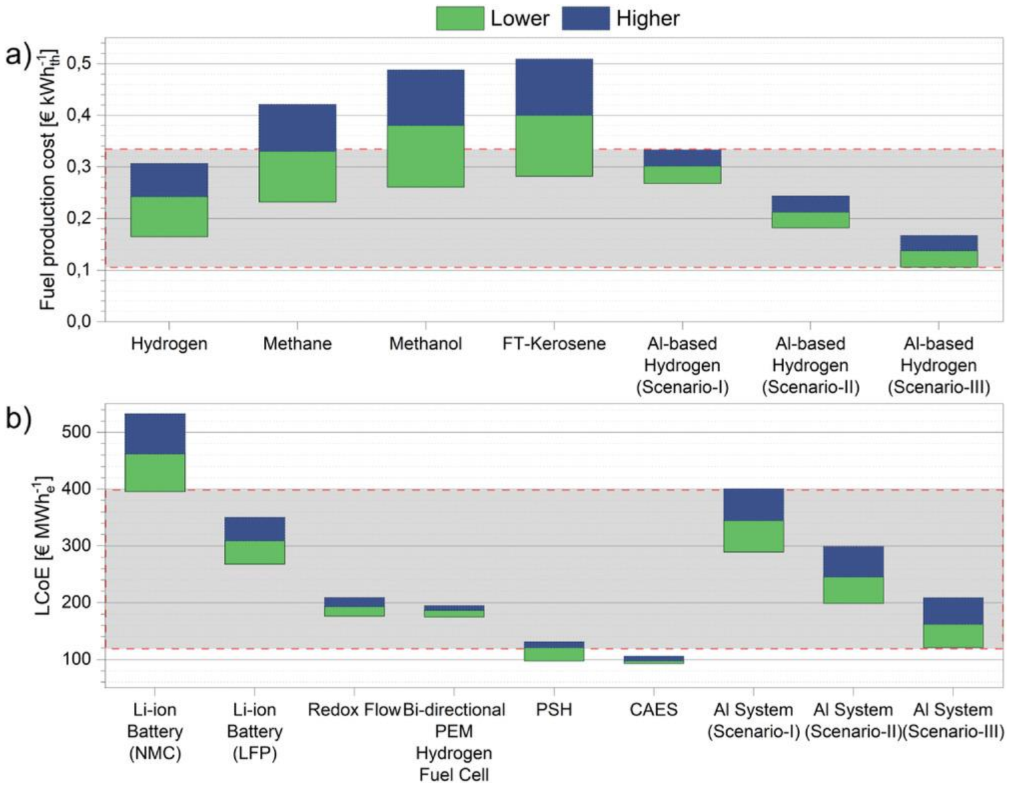

Figure source: [4]

Conclusion & Outlook

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- Overall carbon-neutrality of the proposed concept depends mainly on one step namely the “Hall-Héroult process”. (i.e., inert anodes, wettable cathodes)
- Experimental demonstrations are needed.
- The levelized cost estimations imply high economic competitivity.
- Especially, on-site H_2 generation helps to avoide the burdens for costly H_2 storage and transmission.
- In the Power-to-Power context Al proves similar economic performance to bi-directional PEM H_2 conversion system (with cavern storage), which refers to the cheapest possible concept with a complex energy conversion chain.

Conclusion & Outlook

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For the Aluminium combustion:

- Development of a pilot system,
- Techno-economic evaluation of other business cases.

Further use of aluminium as an energy carrier:

- Development and investigation of a mechanically rechargeable Al-air battery for within Power-to-X context for seasonal energy storage. (KIT Future Fields Project Stage - II: ALU-STORE)

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Thank you for your attention!

ITAS
Institute for Technology Analysis and System Analysis
Karlstraße 11, Karlsruhe
Germany
http://www.itas.kit.edu/

Research for Sustainable Energy Technologies (RESET)

Manuel Baumann
manuel.baumann@kit.edu
Tel: +49 721 608-23215

Hüseyin Ersoy
hueseyin.ersoy2@kit.edu
Tel: +49 721 608-26019

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