Thursday, September 12, 2024

Hydrogen Derivates

Thema: C - Aufbau der Wasserstoffwirtschaft

TECHNO ECONOMIC ASSESSMENT OF PTX IMPORT

Large-scale transport of renewable energy via hydrogen and derivates

Ralph-Uwe Dietrich, Sandra Adelung, Felix Habermeyer, Nathanael Heimann, Simon Maier, Moritz Raab, Yoga Rahmat
Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR)
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(DLR e.V., www.DLR.de/tt)

PtX import to Germany [1]
Agenda

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1. Motivation and activities
2. Example hotspot for RE generation
3. Standardized techno-economic assessment methodology for PtX production
4. RE transport options overseas
5. Hydrogen derivate options comparison
6. Conclusion and outlook

[1] Dietrich et. al (2024). Encyclopedia of Electrochemical Power Sources, Second edition. Chapter: Large-scale transport of renewable energy via hydrogen and derivates

Motivation
Green H_2 import a German energy pillar?

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Federal Ministry for Economic Affairs and Climate Action

Germany's National Hydrogen Strategy and International Cooperation

Anne Jacobs-Schleithoff
Head of Division North Africa, Near and Middle East
German Federal Ministry for Economic Affairs and Climate Action

Germany provides targeted funding instruments to support green hydrogen projects worldwide

Germany's H2 funding schemes

- H2Global: Auction-based promotion of international green hydrogen projects
- **H2Uppp:** Provision of supporting services to small private-sector projects
- **Green Hydrogen Fund**
- National **Funding Guideline** for bilateral hydrogen projects in non-EU countries
- **Individual project funding** (e.g., grants for projects in Saudi-Arabia and Chile in Dec. 2020)

Source: Guidehouse, March 2024 based on BMWK 2022 & BMWK 2023; Icons by flaticon.com

Federal Ministry for Economic Affairs and Climate Action

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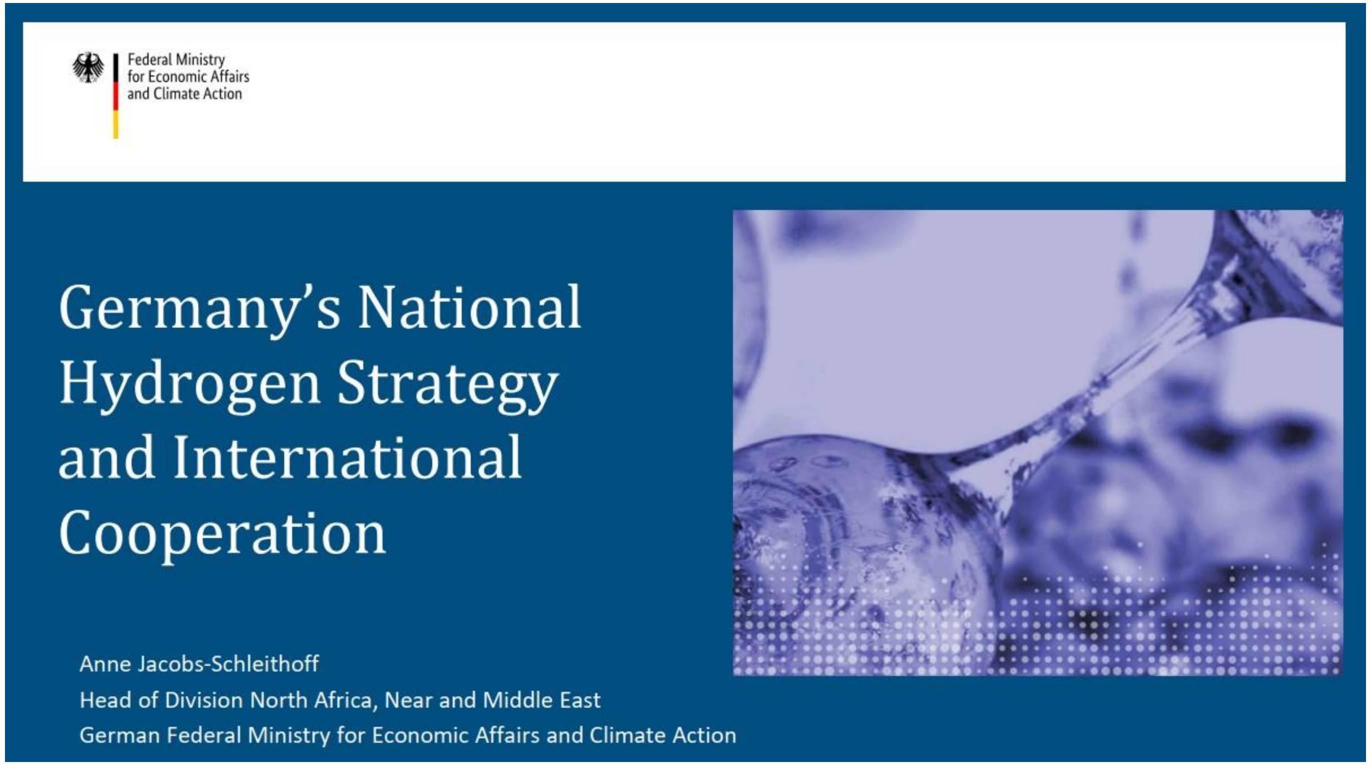
Motivation
Green H_2 import a German energy pillar?



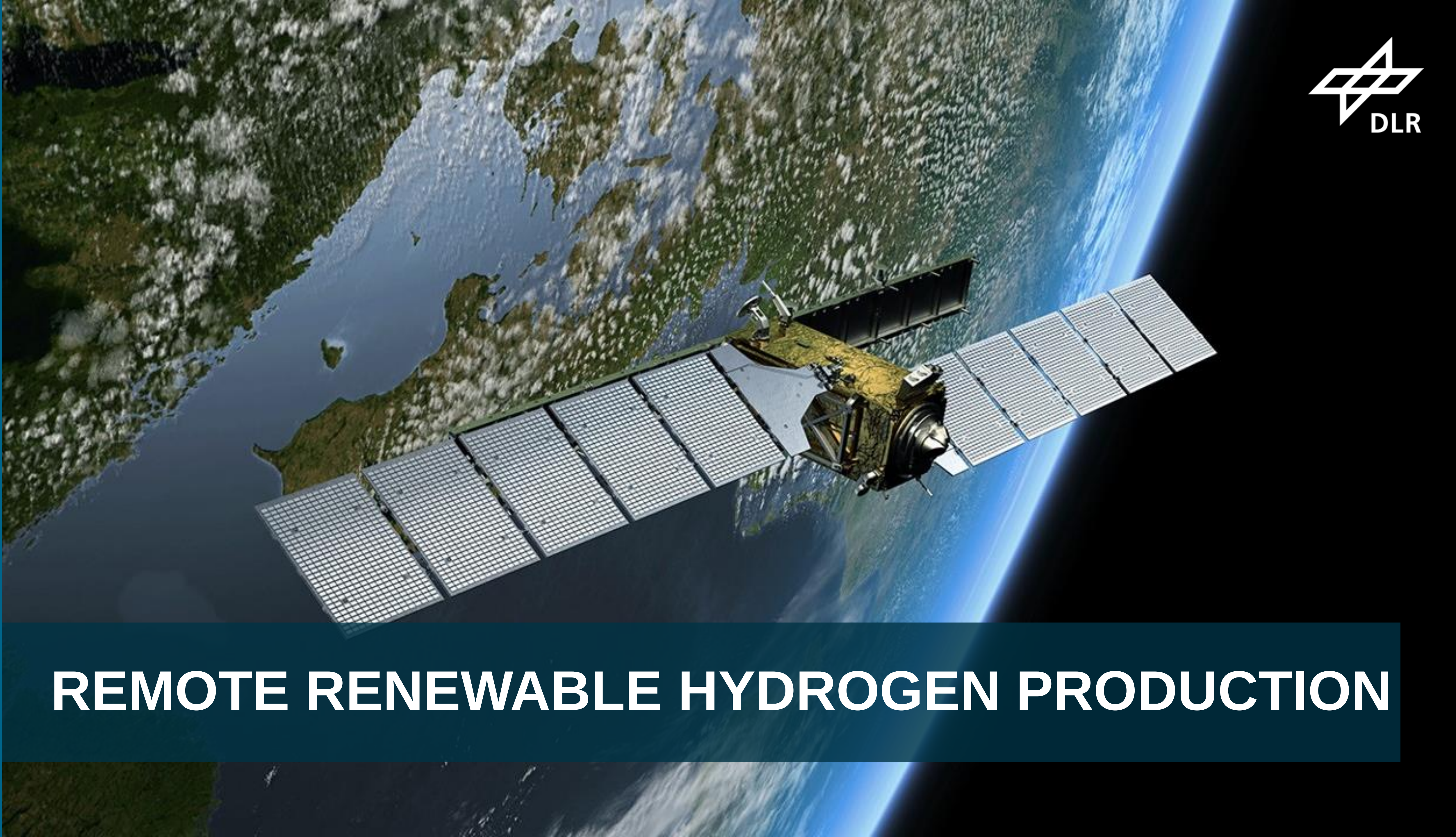
GREEN H2

Germany earmarks up to $3,8 bln for future green hydrogen imports

February 22, 2024 · 3 min read

Goal: CO_2 reduction @ <u>minimized GHG-Abatement cost</u>

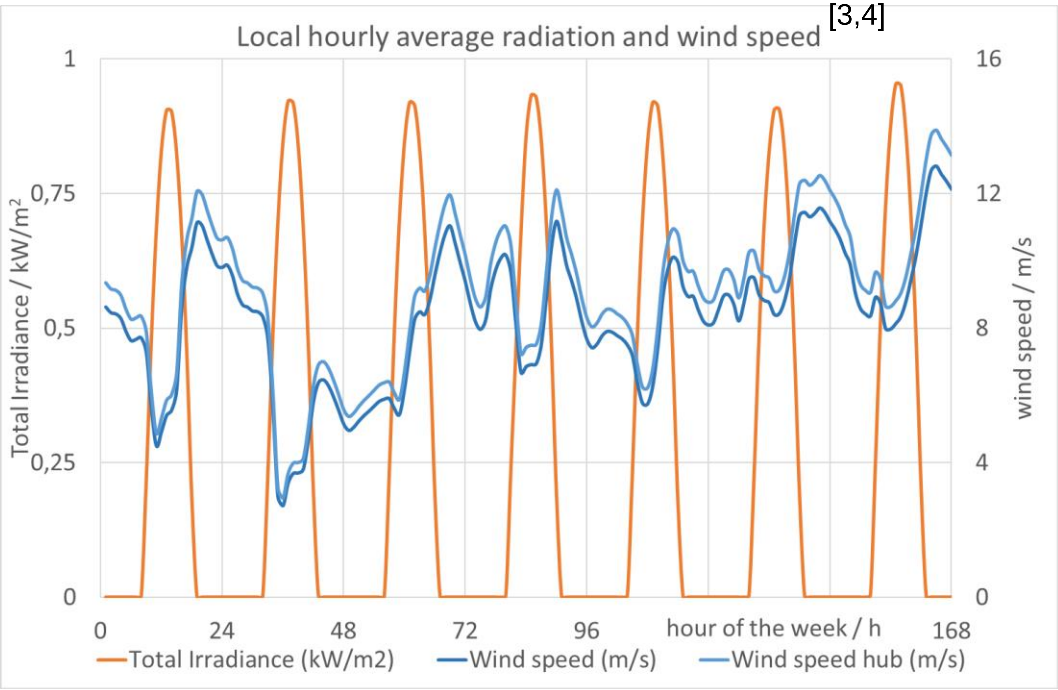
Standardized methodology for LCA and TEA required!

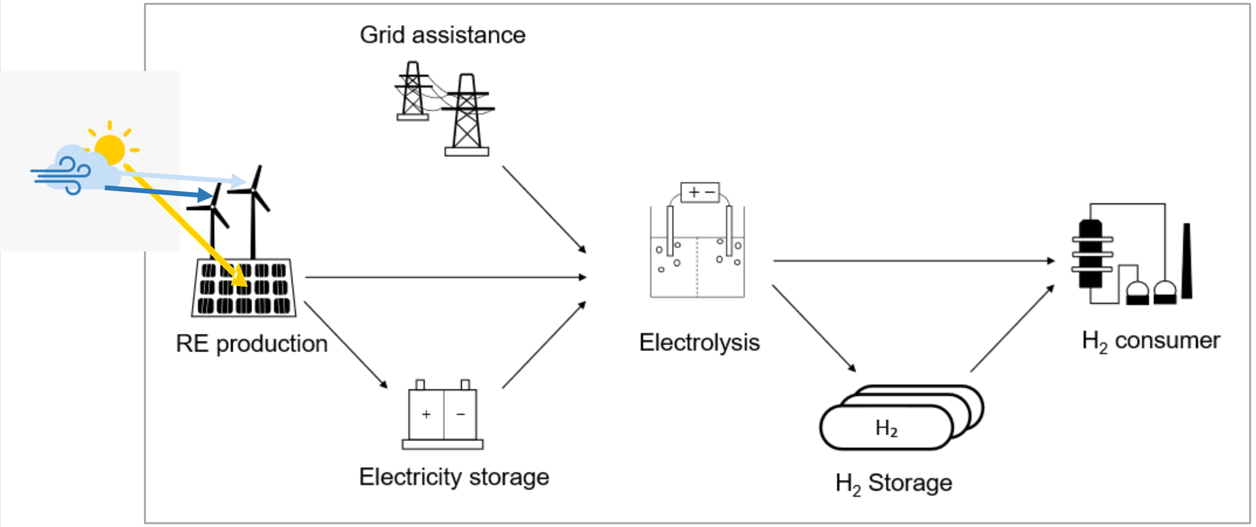


REMOTE RENEWABLE HYDROGEN PRODUCTION

Local RE-H_2 production
Namibia: cheap, stabile PV-based H_2?[1]

- 1 GW H_2: Tsau Khaeb National Park, Namibia (latitude -26.8, longitude 15.3)[2]



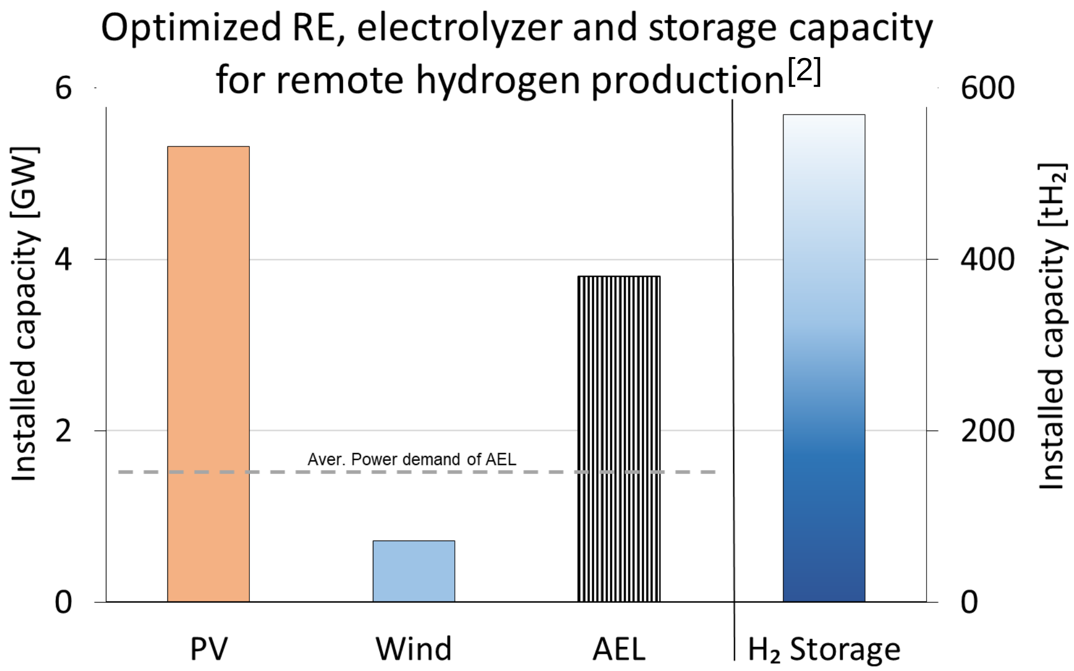


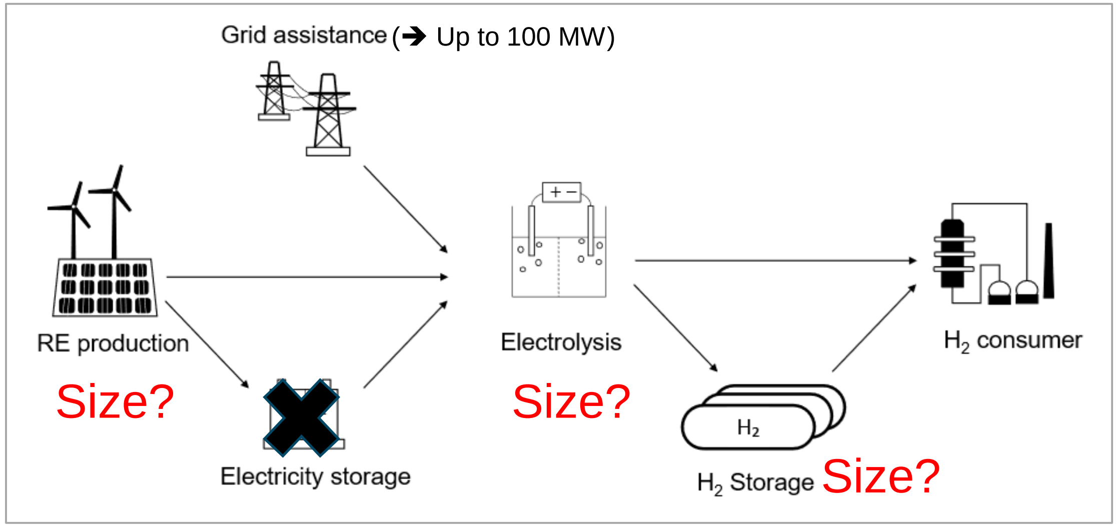
[1] according to Franzmann, D. et al. (2023) Green hydrogen cost-potentials for global trade, International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2023.05.012.
[2] Dietrich et. al (2024). Encyclopedia of Electrochemical Power Sources, Second edition. Chapter: Large-scale transport of renewable energy via hydrogen and derivates
[3] Pfenninger, S. and Staffell, I. (2016). Long-term patterns of European PV output. Energy 114, pp. 1251-1265. doi: 10.1016/j.energy.2016.08.060
[4] Staffell, I. and Pfenninger, S. (2016). Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239. doi:10.1016/j.energy.2016.08.068

Local RE-H_2 production

Namibia: cheap, stabile PV-based H_2?[1]

- 1 GW H_2: Tsau Khaeb National Park, Namibia (latitude -26.8, longitude 15.3)[2]
  - Locally cost optimized design of wind and solar power, electrolyzer, H_2 storage





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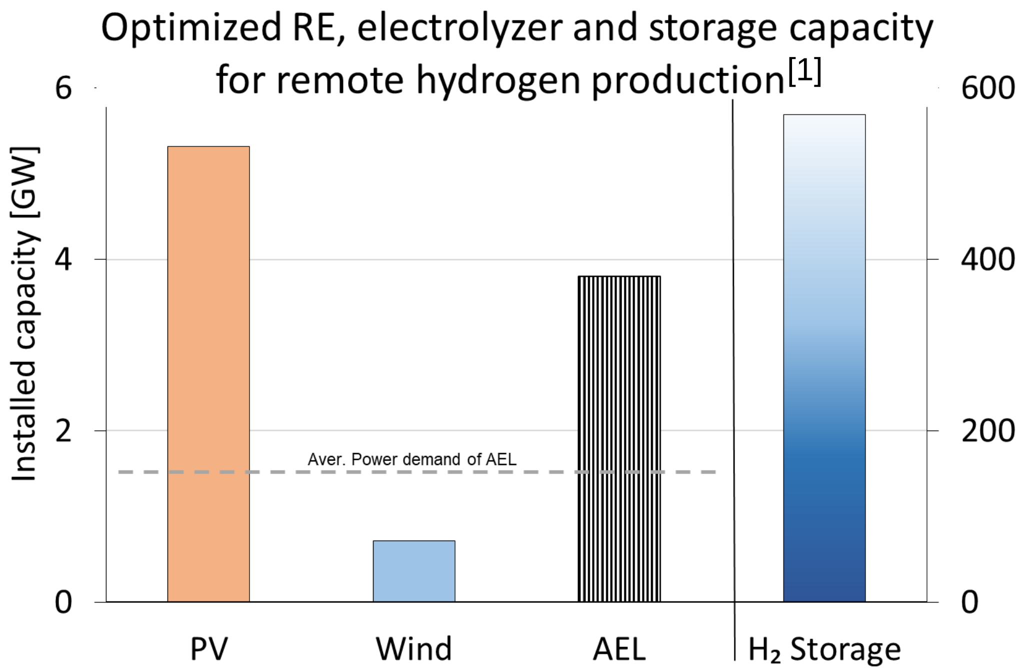
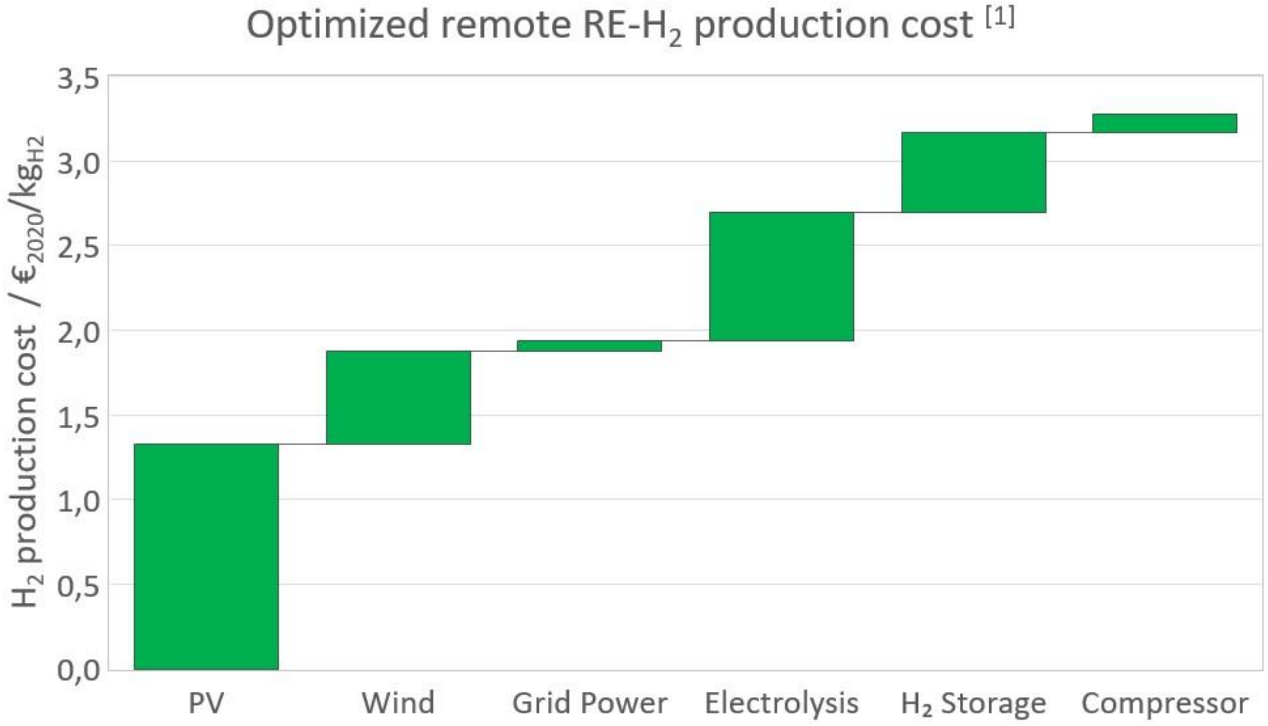
Local RE-H_2 production
Namibia: LCOH [1]

- 1 GW H_2: Tsau Khaeb National Park, Namibia (latitude -26.8, longitude 15.3)
  - cost optimized design of wind and solar power, electrolyzer, H_2 storage





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Local RE-H_2 production remarks

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- Assumption: no restrictions regarding available space, local man power, renewable carbon, water consumption, pollution, grid interaction, regulation, …
- Perspective cost and performance data for 2030 have to be conformed

Component	Cost type	Lang factor	Value	Unit	Source
PV farm	FCI	1	492*	$€_{2021} kW_{Peak}^{-1}$	[16]
Wind turbine	FCI	1	1’573*	$€_{2021} kW_{Peak}^{-1}$	[20]
AEL	EC	1.62	160*	$€_{2021} kW^{-1}$	[16]

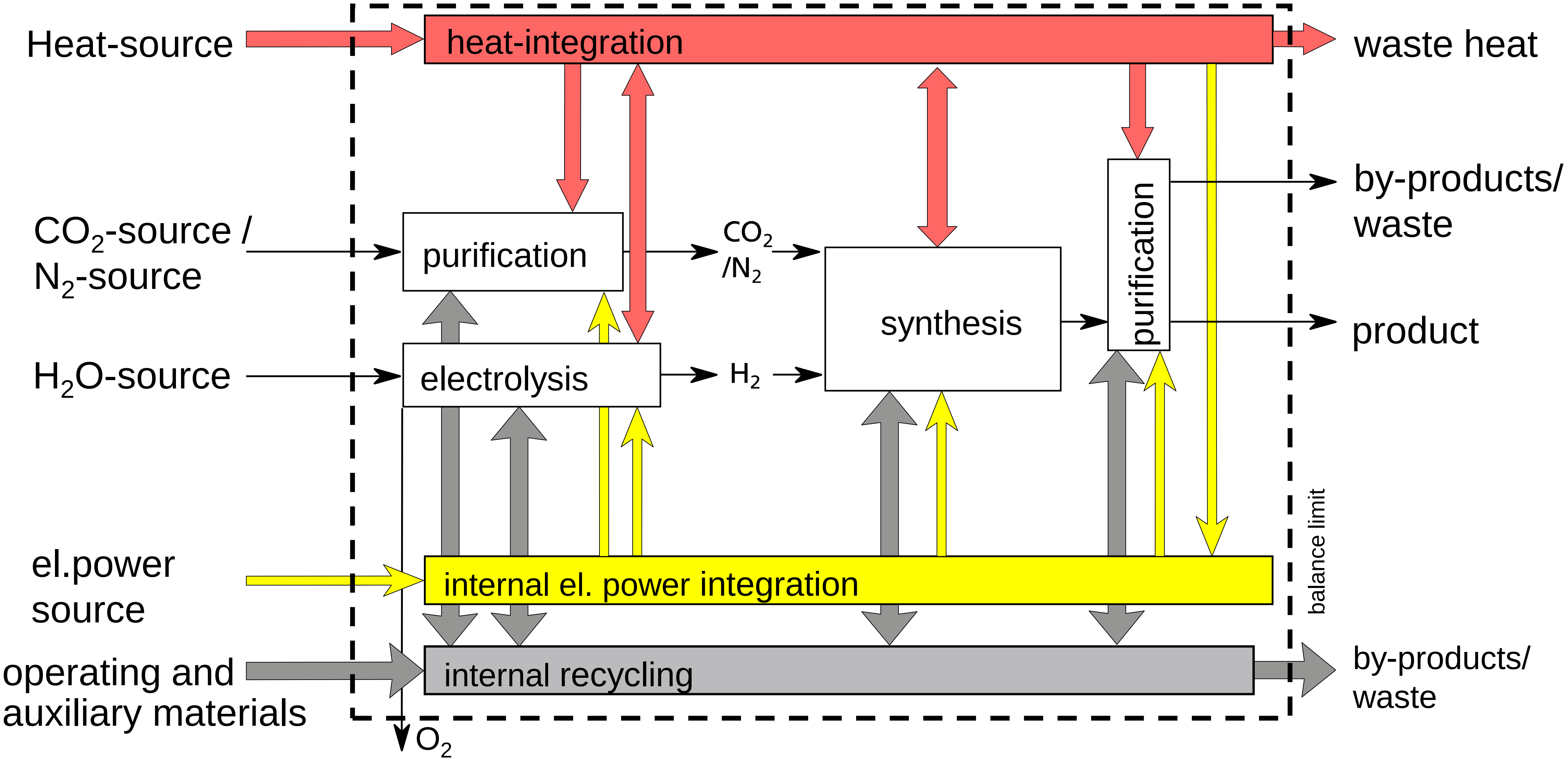
*Perspective data for 2030 according to source

- Generalized WACC* need to be locally adjusted (standard: 7.5 % interest rate)

[16] Raab, M., Körner, R. and Dietrich, R.-U.(2021) Techno-economic assessment of renewable hydrogen production and the influence of grid participation. International Journal of Hydrogen Energy, 2022. 47(63): p. 26798-26811
[20] Taylor, M., et al.,(2021) Renewable Power Generation Costs in 2020. https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020
* WACC - Weighted Average Cost of Capital

HYDROGEN DERIVATE PRODUCTION

Derivate production
Generalized assessment [1]



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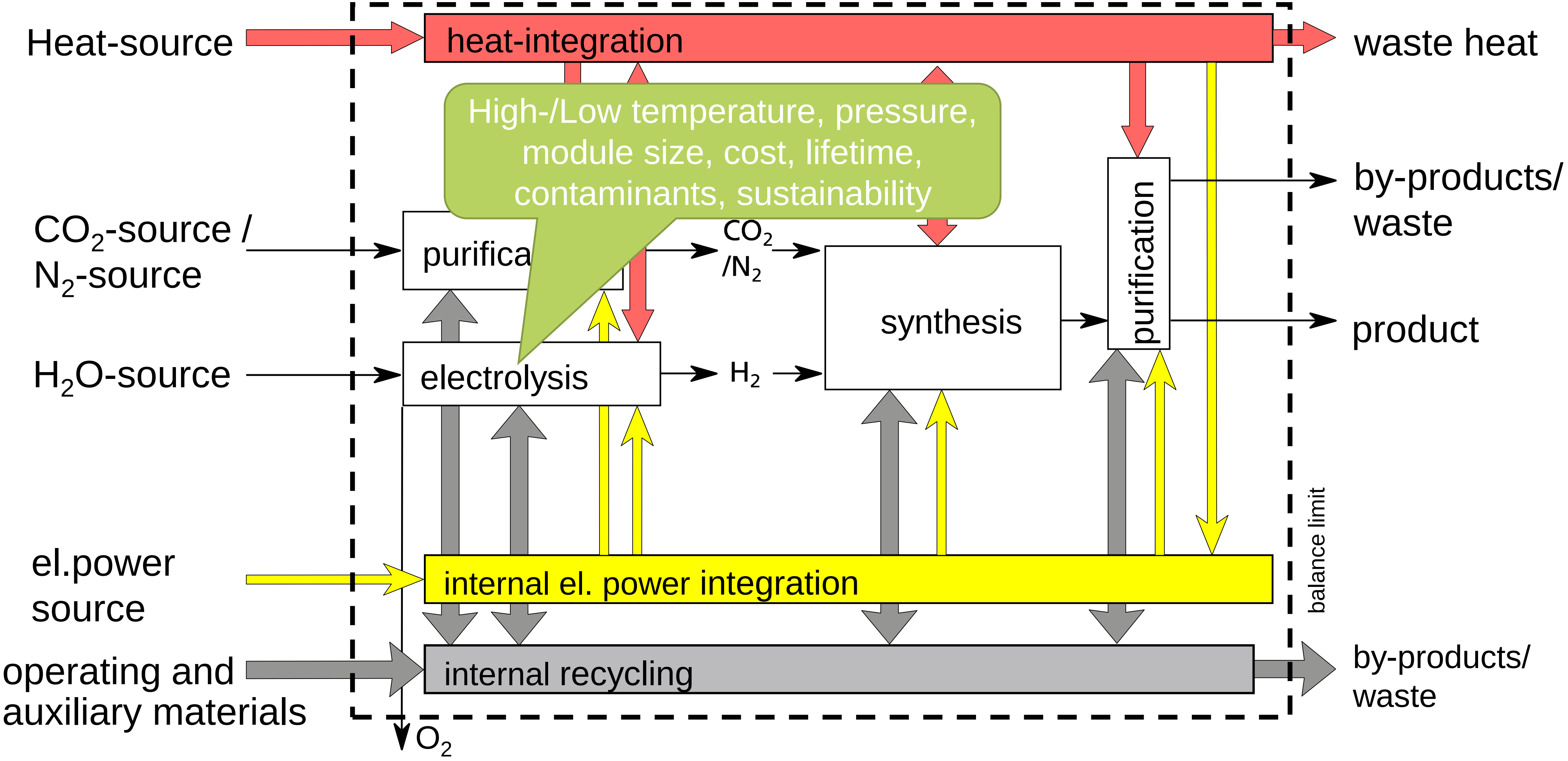
Derivate production

Generalized assessment [1]



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Derivate production

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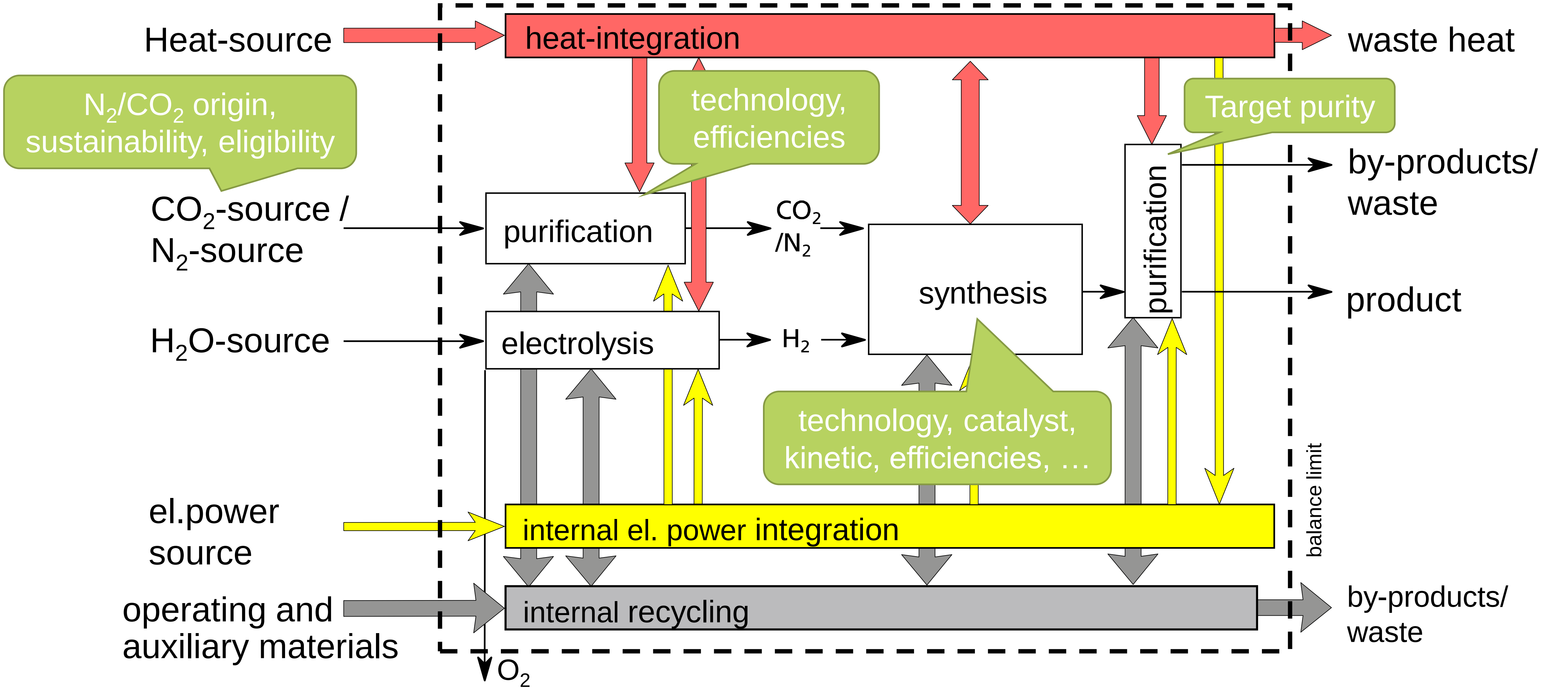

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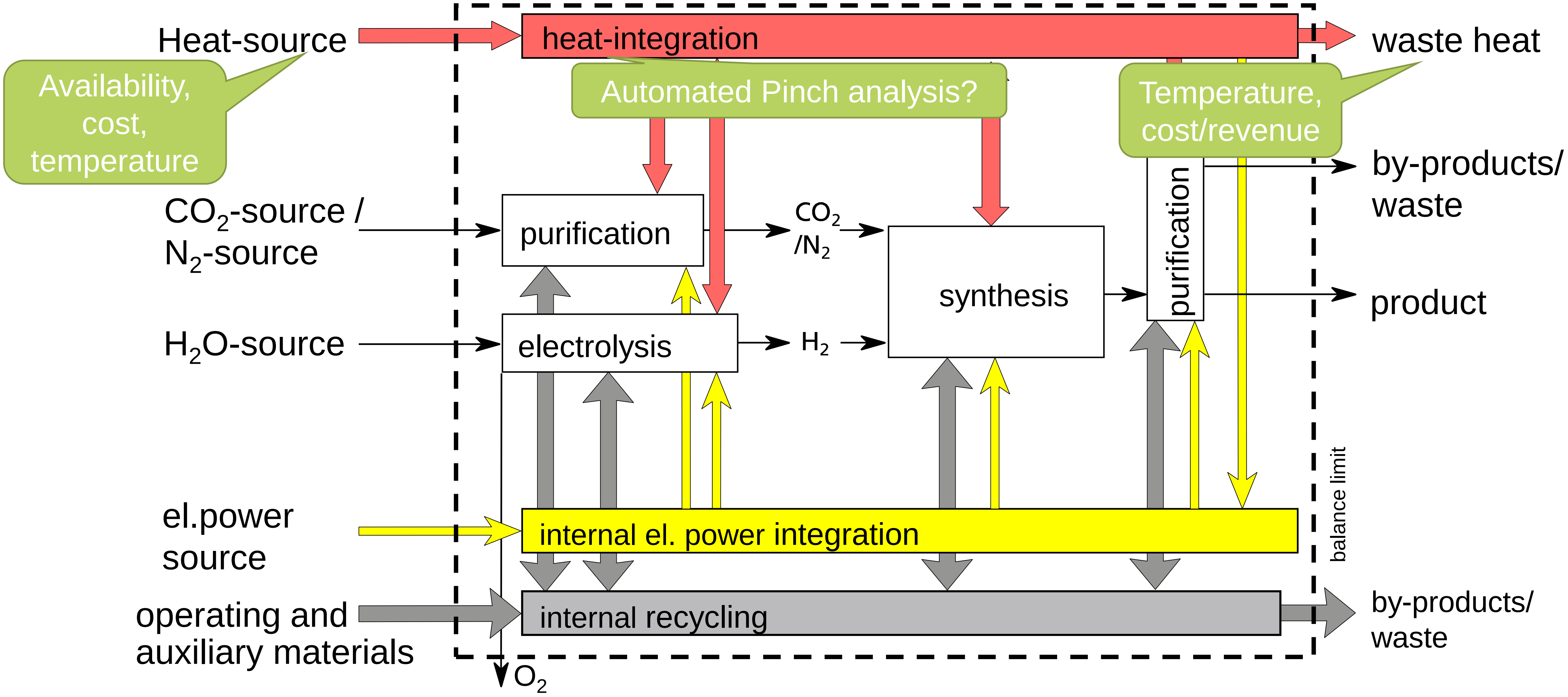

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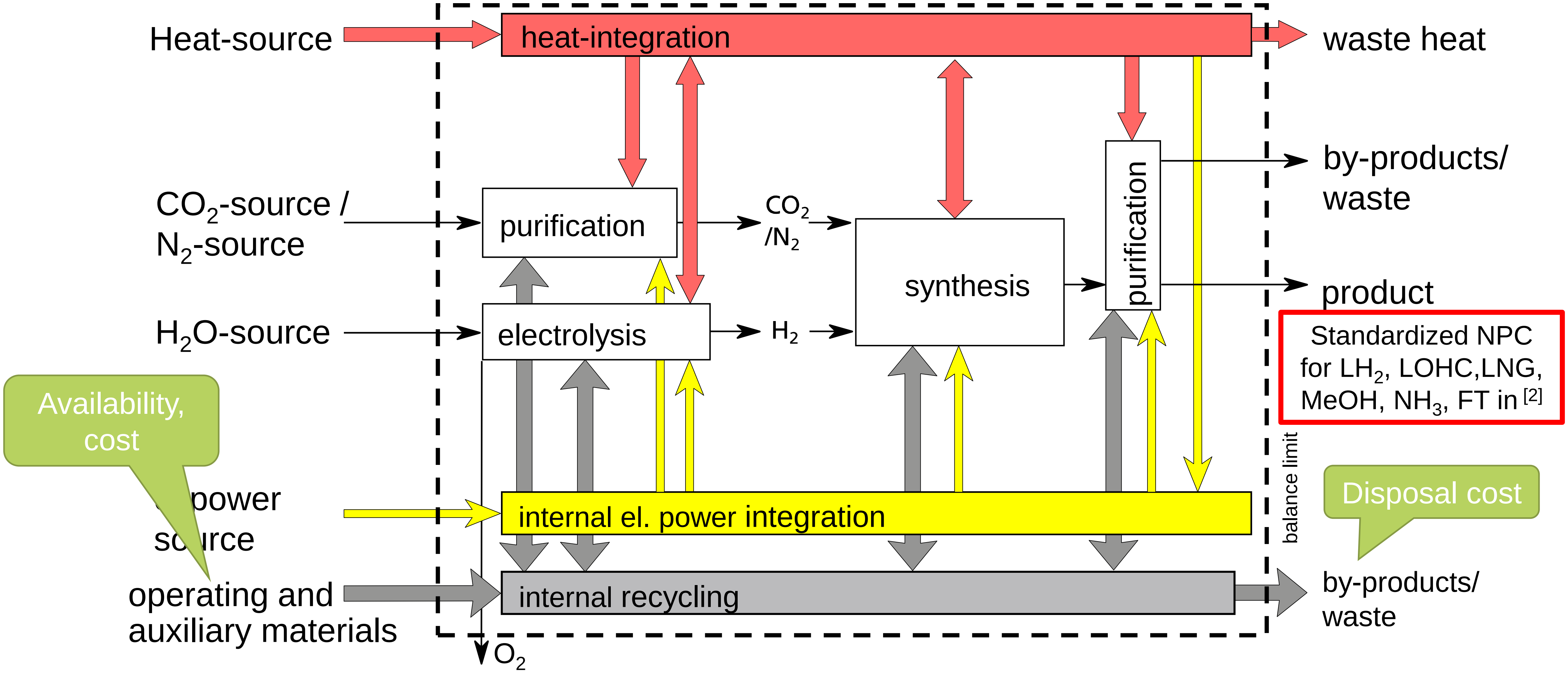

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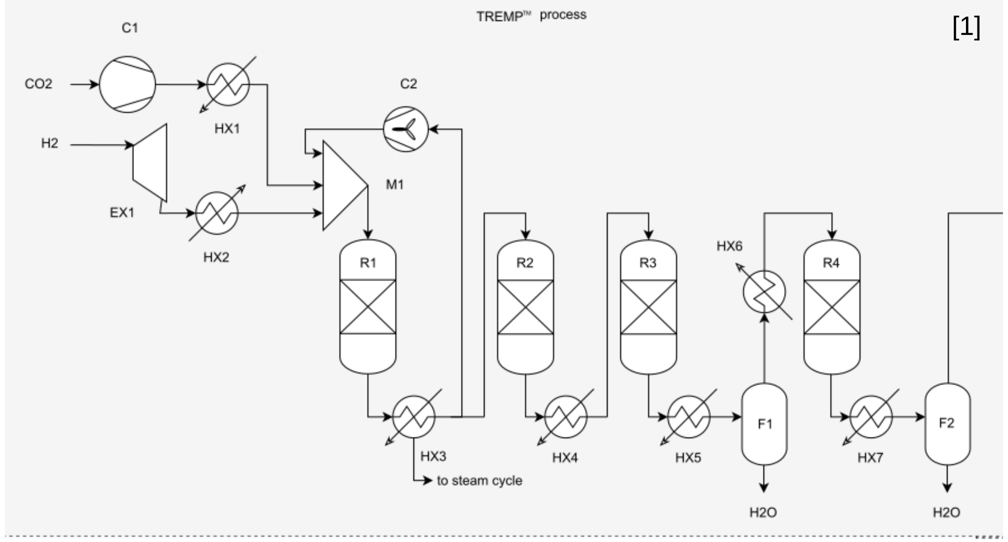
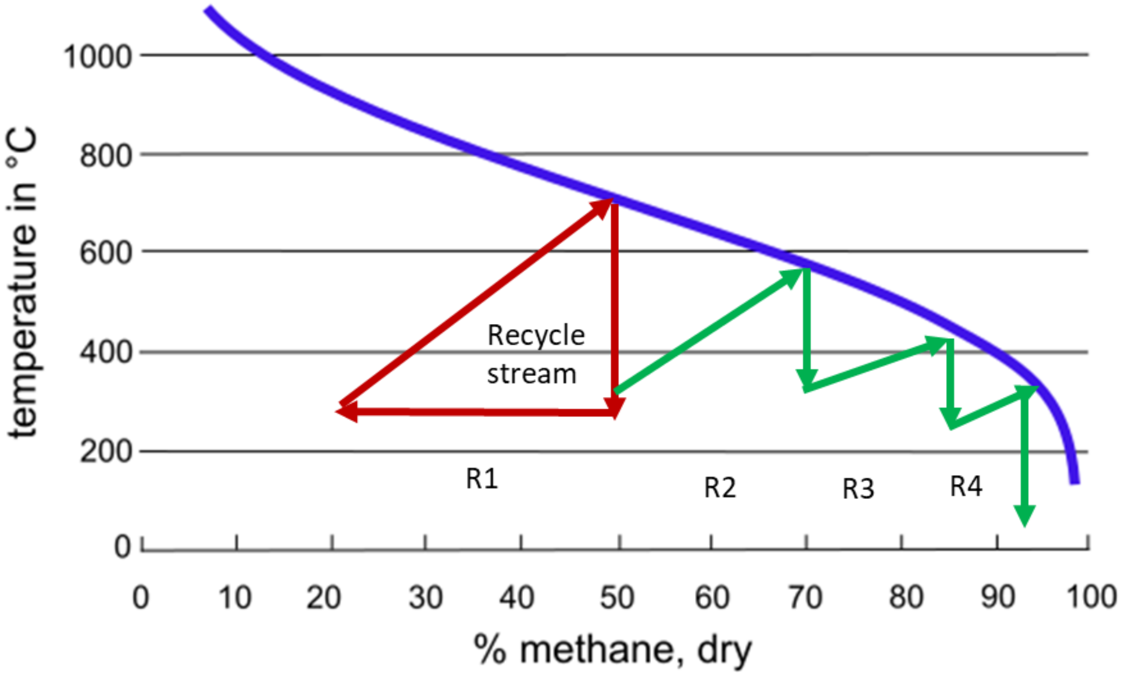
Derivate production
Example: LNG production

Advanced TREMP™-process



Simulation assumptions:
- No impurities
- No side reactions

- High temperature in R1
  - ➢ Steam cycle
  - ➢ Superior efficiency



[1] Rönsch, S., et al., 2016
[2] Heimann, N. et al (2023), Standardized tea of sCNG and HCNG, to be submitted
[3] Bin Omar, M.N.(2016) Thermodynamic and Economic Evaluation on Existing and Perspective Processes for Liquefaction of Natural Gas in Malaysia. Ph.D. Thesis, TU Berlin

Derivate production
Example: LNG production

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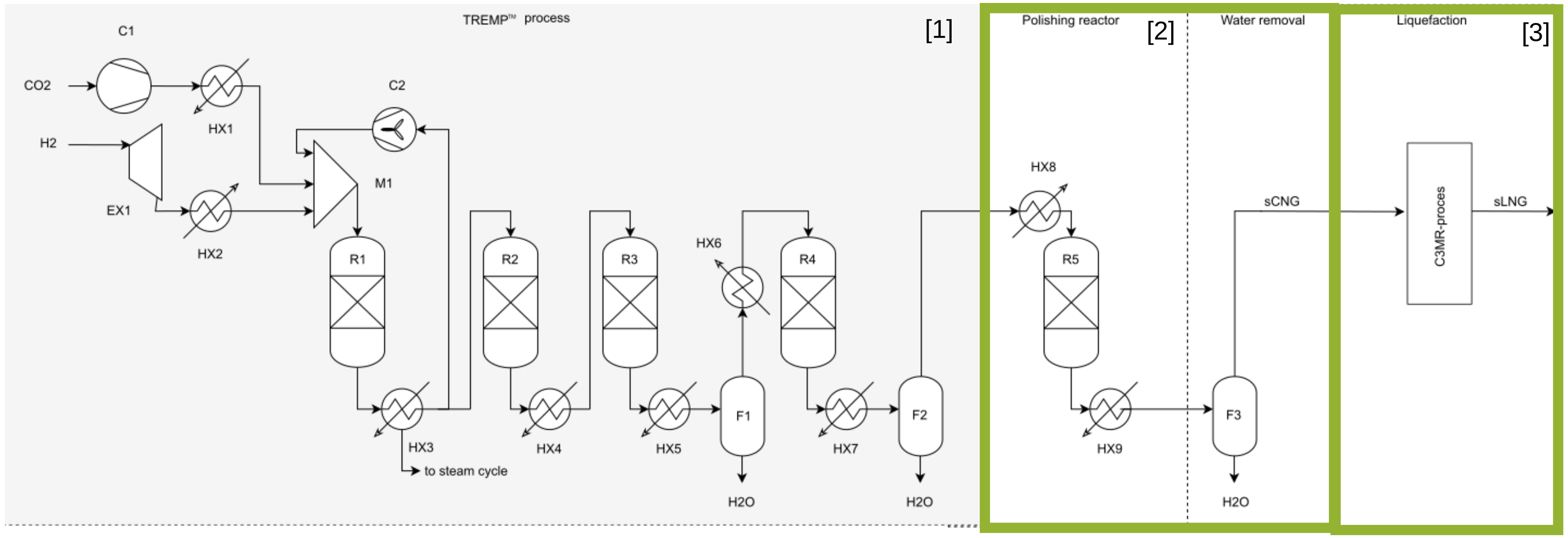

- High temperature in R1
  - Steam cycle
  - Superior efficiency
- Adjustment for LNG export
  - Composition [2]
    DIN EN 16723-2:2017-10
    ➔ Polishing reactor &
    ➔ Water removal
  - Liquefaction [3]

Simulation assumptions:
- No impurities
- No side reactions

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[2] Heimann, N. et al (2023), Standardized tea of sCNG and HCNG, to be submitted
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Derivate production [1]
Example: LNG production

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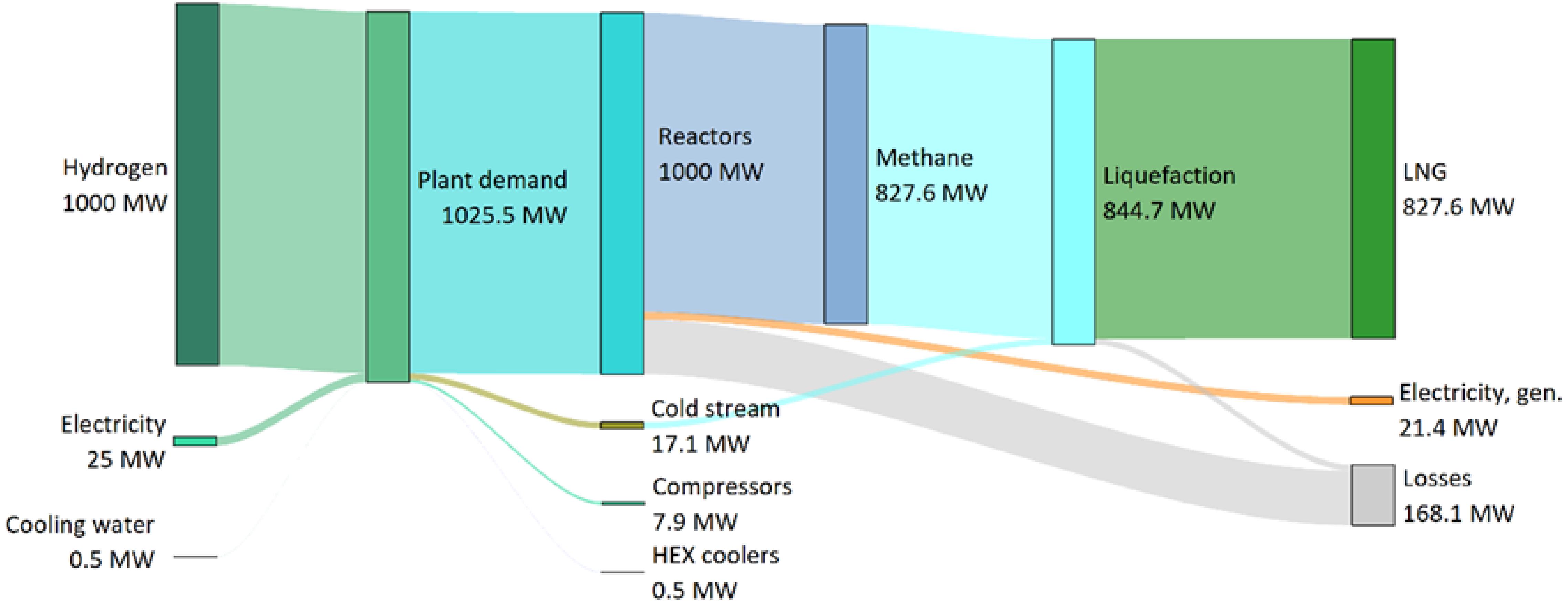
- Energy flow diagram of the optimized LNG production process



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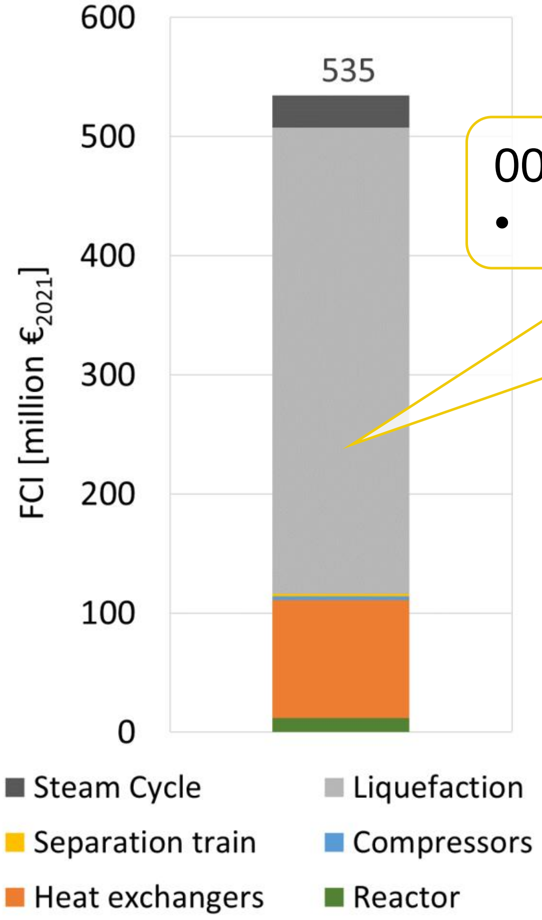
Derivate production [1]
Example: LNG production

- FCI and NPC breakdown of LNG plant in Namibia [1]



00-05-C1 - LNG liquefication (single train)
- 391.25 M€$_{2021}$

[1] Dietrich et. al (2021). Encyclopedia of Electrochemical Power Sources, Second edition. Chapter: Large-scale transport of renewable energy via hydrogen and derivates

Derivate production [1]
Example: LNG production

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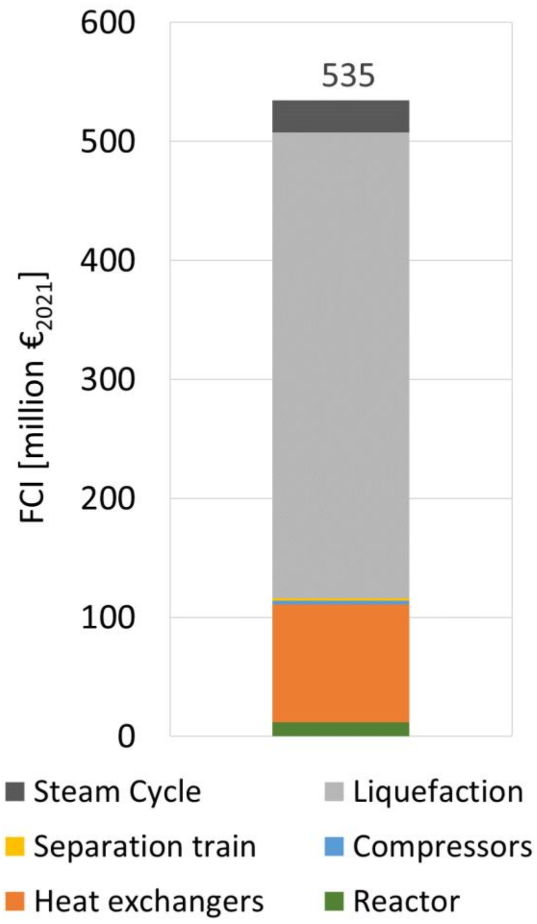

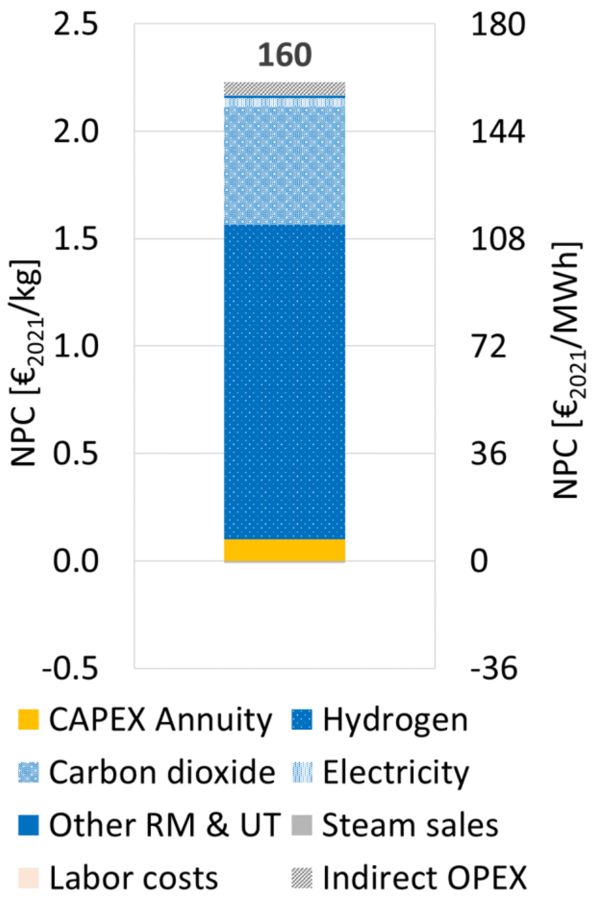

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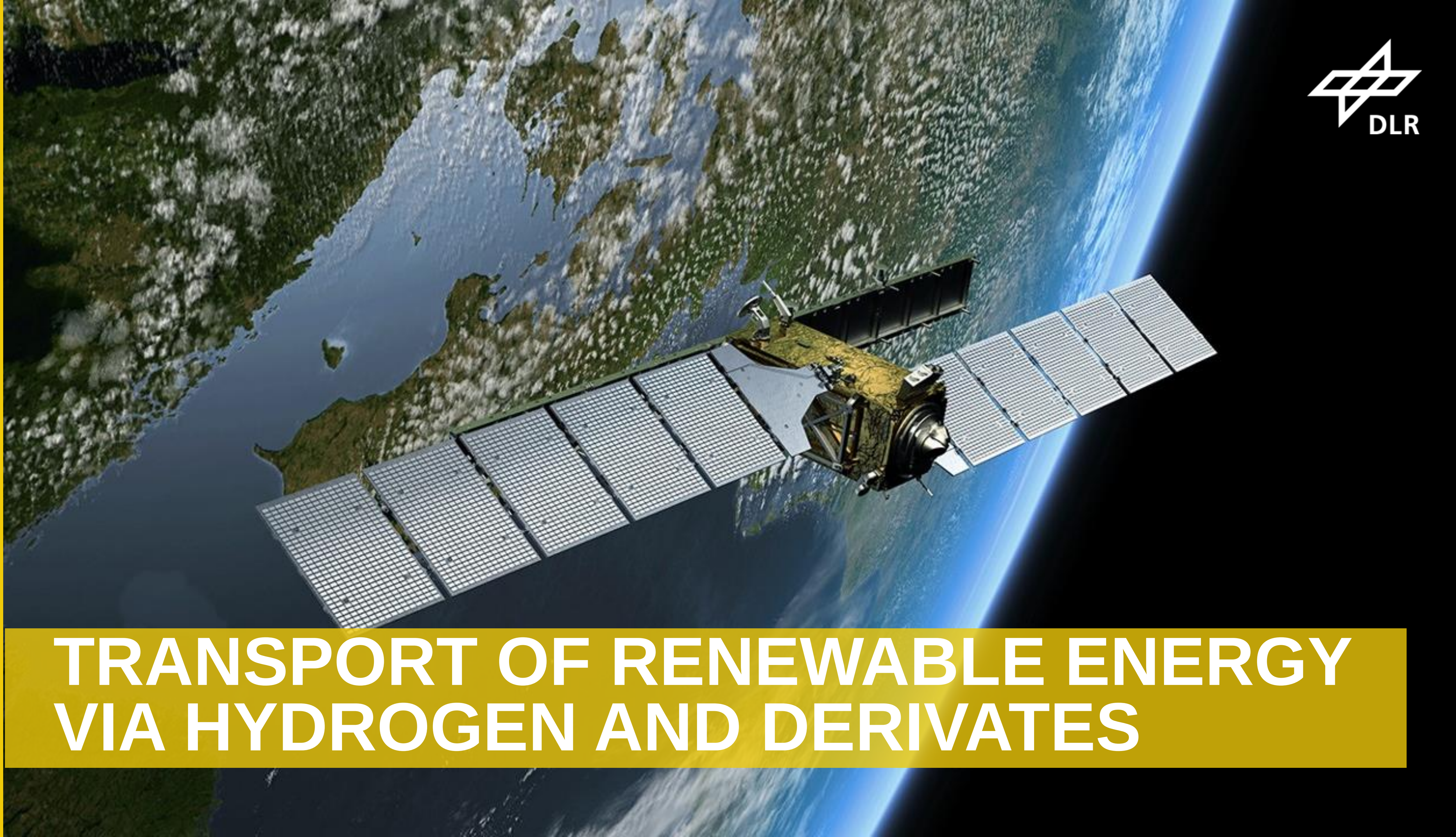
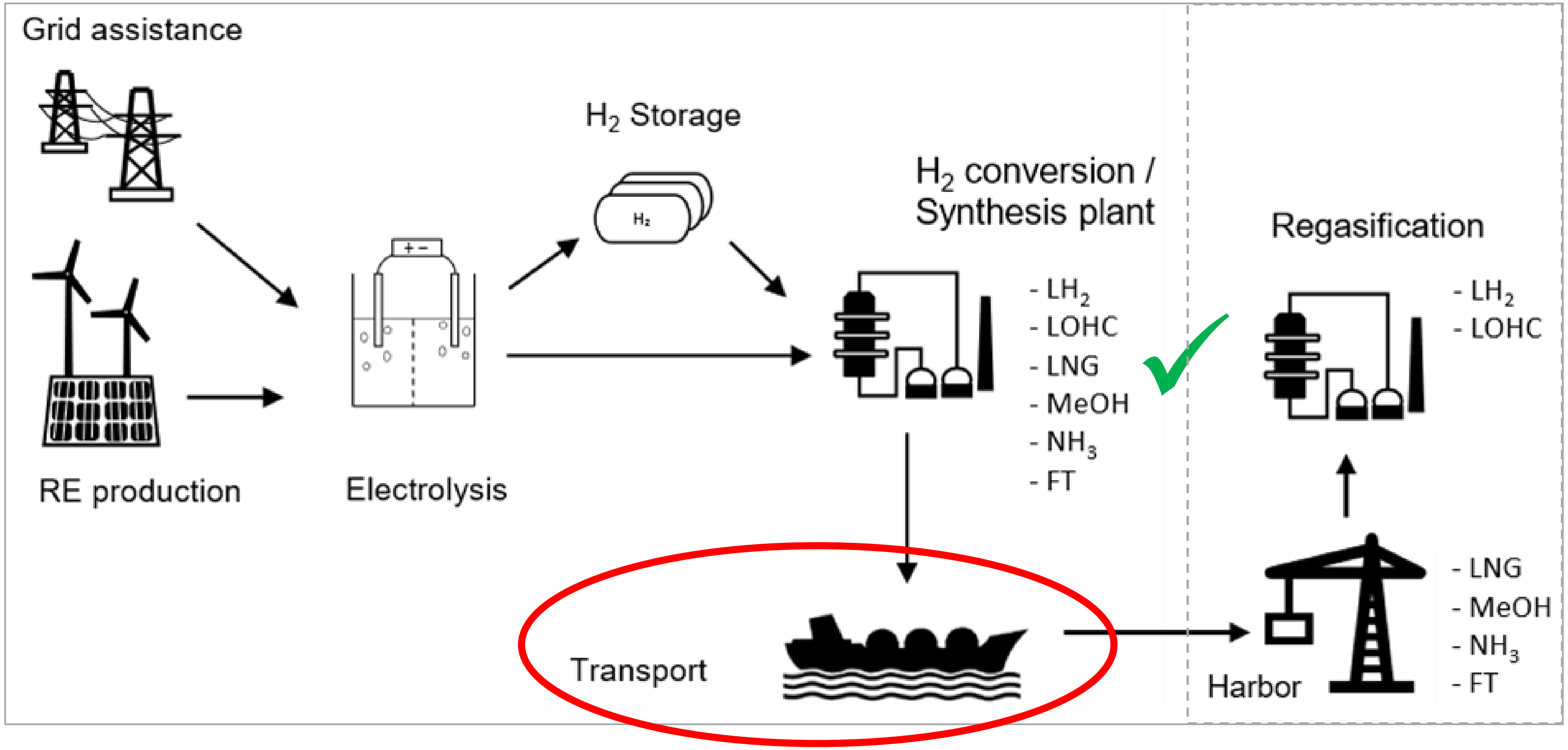


TRANSPORT OF RENEWABLE ENERGY VIA HYDROGEN AND DERIVATES

Large Scale RE transport overseas [1]

- Example: Tsau Khaeb National Park, Namibia
- Destination: WHV, Germany



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Large Scale RE transport
See transport options

- See transport options – different scale, fuel consumption, TRL, …

© Kawasaki Heavy Industries


Q-Max LNG carrier Al Mafyar (Image: Nakilat)


ULCC TI Europe (Image: Euronav)

- 160 Tm³ LH2 by mid-2020, commercial in early ´30s [1]
- 160 Tm³ LH2 = 0.4 TWh_{LHV} = 2.9 ktoe

- 265 Tm³ commercial Q-Max LNG carrier fleet [2]
- 265 Tm³ LNG = 1.6 TWh_{LHV} = 80.7 ktoe

- Up to 500 Tm³ commercial Ultra Large Crude Carrier fleet [3]
- 500 Tm³ FT-Crude = 4.9 TWh_{LHV} = 250 ktoe

[1] Kawasaki Obtains AIP for Large,160 Tm3 Liquid Hydrogen Carrier. https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20220422_3378
[2] https://en.wikipedia.org/wiki/Q-Max
[3] https://en.wikipedia.org/wiki/TI-class_supertanker

Large Scale PtX import options [1]

At the gate cost comparison

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	Unit	LH_2	LOHC – H12-BT	LNG	MeOH	NH_3	FT - diesel
Production rate	$t\ h^{-1}$	29.5	469.6	59.6	145.0	158.5	84
η_{HtF}	% $(GW_{LHV,F}\ GW_{LHV,H}^{-1})$	98.4	97.3*	82.8	80.1	81.8	63.9
η_{PtF}	% $(GW_{LHV,F}\ GW_{el}^{-1})$	60.6	55.4*	57.3	54.7	53.6	43.3
P demand	$GW_{el}\ GW_{LHV,F}^{-1}$	1.65	1.80*	1.74	1.83	1.86	2.31
η_C	%	-	-	98.5	95.2	-	95.5

Technical performance given in efficiencies

- Hydrogen efficiency
- Energetic efficiency
- Carbon efficiency

[2] https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050
[3] IGU World LNG report - 2022 Edition
[4] Methanol Price|Methanol Institute|www.methanol.org (Rotterdam)
[5] Mineral Commodity Summaries 2022 - Nitrogen (usgs.gov)
[6] Spritpreis-Entwicklung: Benzin- und Dieselpreise seit 1950 (adac.de) (German market prices minus taxes)

* Including LOHC regasification |** Based on H2 content only |*** FCI of HPP excluded |**** 30 €/MWh assumed for regasification heat

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At the gate cost comparison

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P demand	$GW_{el}\,GW_{LHV,F}^{-1}$	1.65	1.80*	1.74	1.83	1.86	2.31
η_C	%	-	-	98.5	95.2	-	95.5
NPC	$€_{2021}\,kg^{-1}$	5.00	3.55**	2.20	1.10	0.71	3.38
	$€_{2021}\,MWh_{LHV,F}^{-1}$	150	107**	160	199	141	283
Fossil sales price	$€_{2021}\,MWh_{LHV,F}^{-1}$	43.1 – 56.5[2]	43.1 – 56.5[2]	43.34[3]	77.2[4]	86.2[5]	69.0[6]
Renewable/fossil		3.48-2.65	2.48-1.89**	3.69	2.58	1.64	4.10

Net production costs are **not sales prices**!!!

- Comparison with fossil commodity prices show **factors** of price increase

[2] https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050
[3] IGU World LNG report - 2022 Edition
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Large Scale PtX import options [1]

At the gate cost comparison

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Transport and regasification efforts are not neglectable

- Transport safety
- Harbor capacity
- Regulation
- …

	Unit	LH_2	LOHC – H12-BT	LNG	MeOH	NH_3	FT - diesel
Production rate	$t\ h^{-1}$	29.5	469.6	59.6	145.0	158.5	84
ηHtF	% ($GW_{LHV,F}\ GW_{LHV,H}^{-1}$)	[illegible]	97.3*	82.8	80.1	81.8	63.9
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P demand	$GW_{el}\ GW_{LHV,F}^{-1}$	1.65	1.80*	1.74	1.83	1.86	2.31
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Renewable/fossil		3.48-2.65	2.48-1.89**	3.69	2.58	1.64	4.10
Transport FCI	$M€_{2021}$	650	503	384	248	341	251
Transport cost	$€_{2021}\ MWh_{LHV,F}^{-1}$	8.4	6.6**	5.9	3.9	5.3	5.0
Regasification cost	$€_{2021}\ MWh_{LHV,F}^{-1}$	9.0	26.7***	5.4	-	-	-
Specific FCI	$€_{2021}\ kW_{LHV,F}^{-1}$	1,365	874*	656	475	347	799
OPEX	$M€_{2021}\ a^{-1}$	1,035	230*	1,059	1,084	786	1,123

* Including LOHC regasification |** Based on H2 content only |*** FCI of HPP excluded |**** 30 €/MWh assumed for regasification heat

[2] https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050
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SUMMARY & OUTLOOK

Techno Economic Assessment of P-t-X Import

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Summary

- Large-scale transport of renewable energy via hydrogen and derivates is one pillar of Germany’s and Europe’s energy strategy
- Standardized techno-economic assessment helps to identify business cases, to quantify project and roadmap validity
- Renewable energy generation at “sweet spots” has to be balanced against transformation and transport cost to become valuable for domestic energy transition ➔ CO_2 abatement cost at home!

Transparent, standardized DLR assessment methodology can support

➔ PtX technology selection and improvement,
sweet spot and feedstock search, regulation adjustment, … !

Thursday, September 12, 2024

Hydrogen Derivates

Thema: C - Aufbau der Wasserstoffwirtschaft

TECHNO ECONOMIC ASSESSMENT OF PTX IMPORT

THANK YOU FOR YOUR ATTENTION !
Questions?

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