Thursday, November 19, 2024

Hydrogen

Thema: C - Aufbau der Wasserstoffwirtschaft


# TECHNO ECONOMIC ASSESSMENT OF HYDROGEN AND DERIVATES IMPORT

Techno-ökonomische Bewertung von Technologien und Importoptionen für erneuerbar erzeugte Wasserstoffderivate

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# 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: energy pillar?

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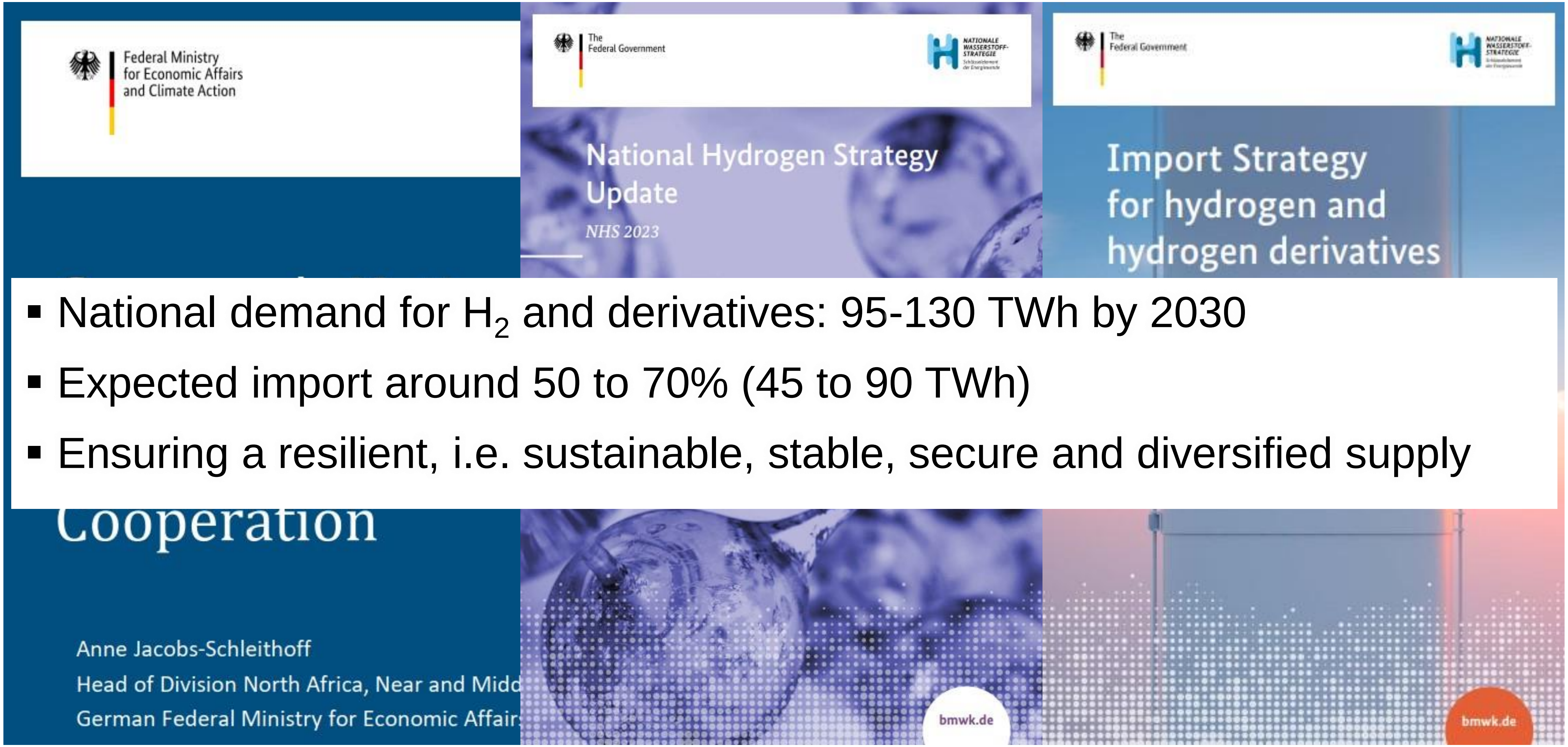


- National demand for $H_2$ and derivatives: 95-130 TWh by 2030
- Expected import around 50 to 70% (45 to 90 TWh)
- Ensuring a resilient, i.e. sustainable, stable, secure and diversified supply

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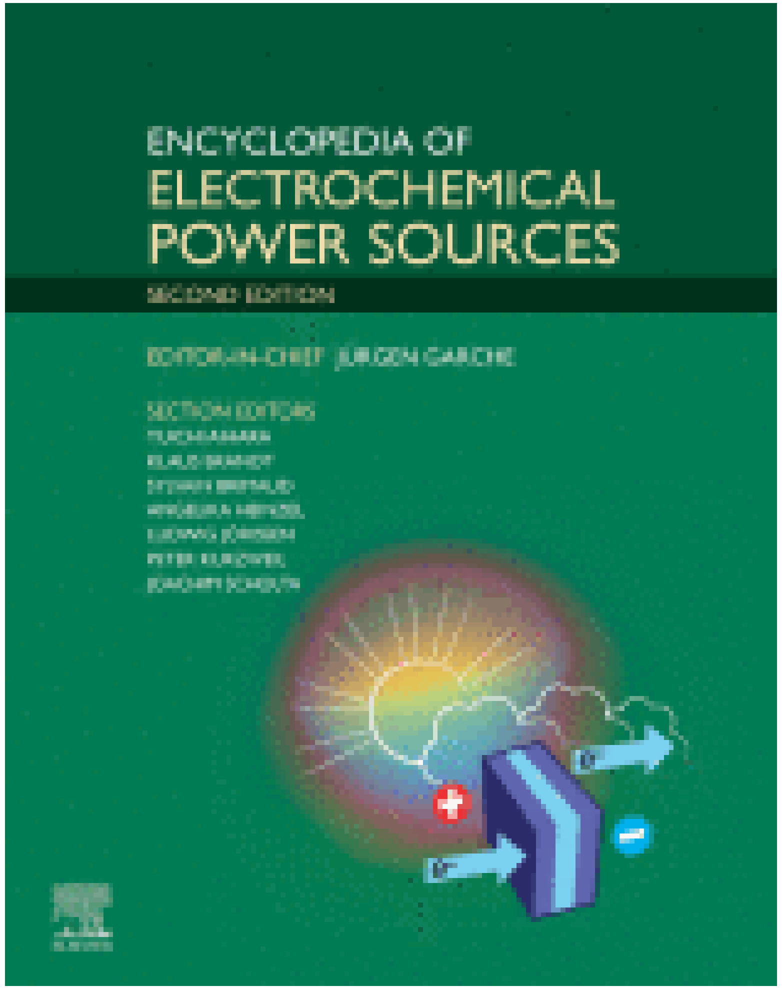
**Goal: $CO_2$ reduction @ minimized GHG-Abatement cost**

**Question: Where to invest? How much? When?**

**Standardized methodology for LCA and TEA required!**

# Assessment of remote PtX production and transport [1]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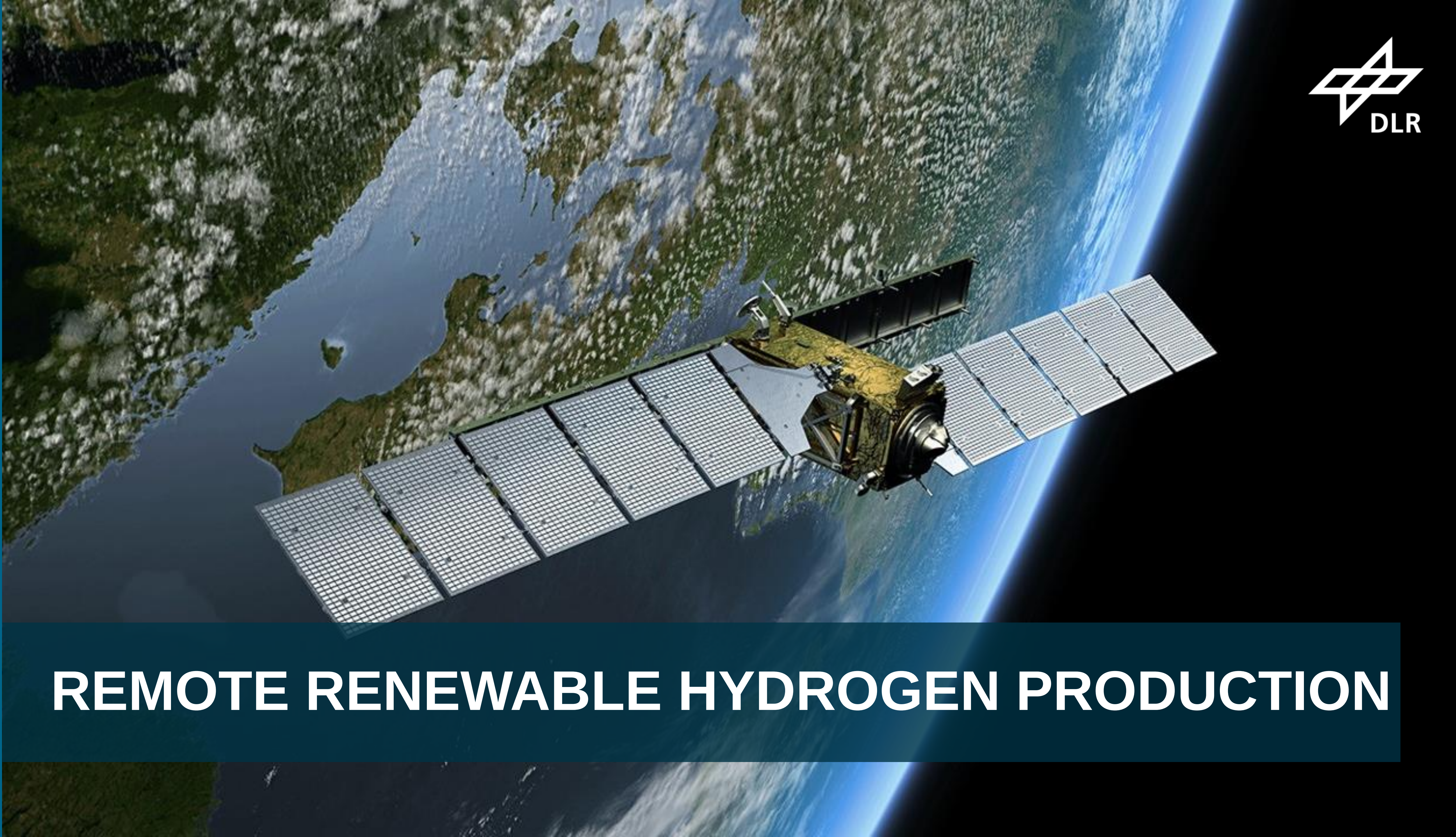
[1] Dietrich et. al (2025). Hydrogen Non-Conventional Storage Options. In: Encyclopedia of Electrochemical Power Sources, Second edition. Volume 6, Chapter: Fuels – Introduction, p. 199-231, https://doi.org/10.1016/B978-0-323-96022-9.00183-3

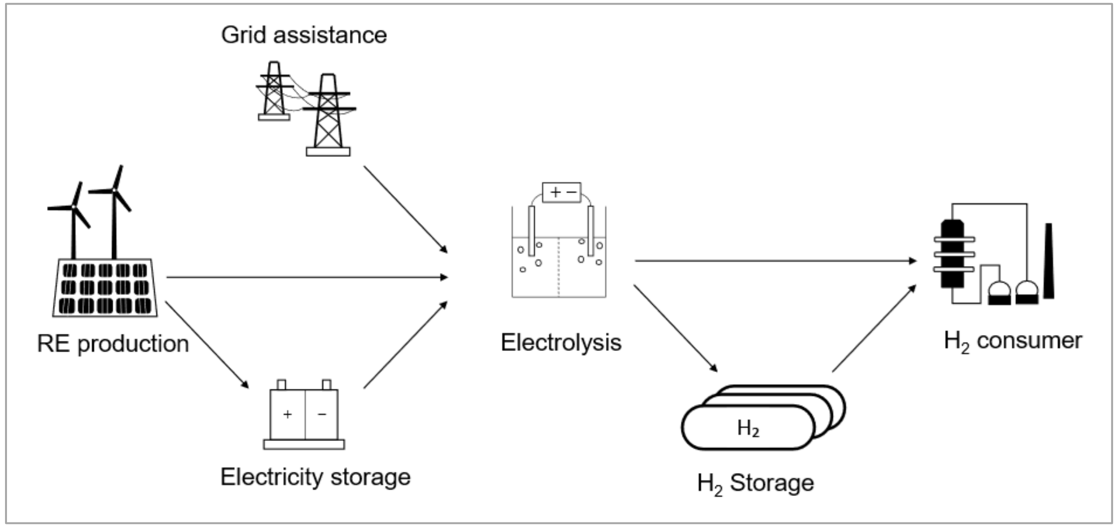


# REMOTE RENEWABLE HYDROGEN PRODUCTION

# Local RE-$H_2$ production

## Namibia: cheap, green $H_2$?[1]

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

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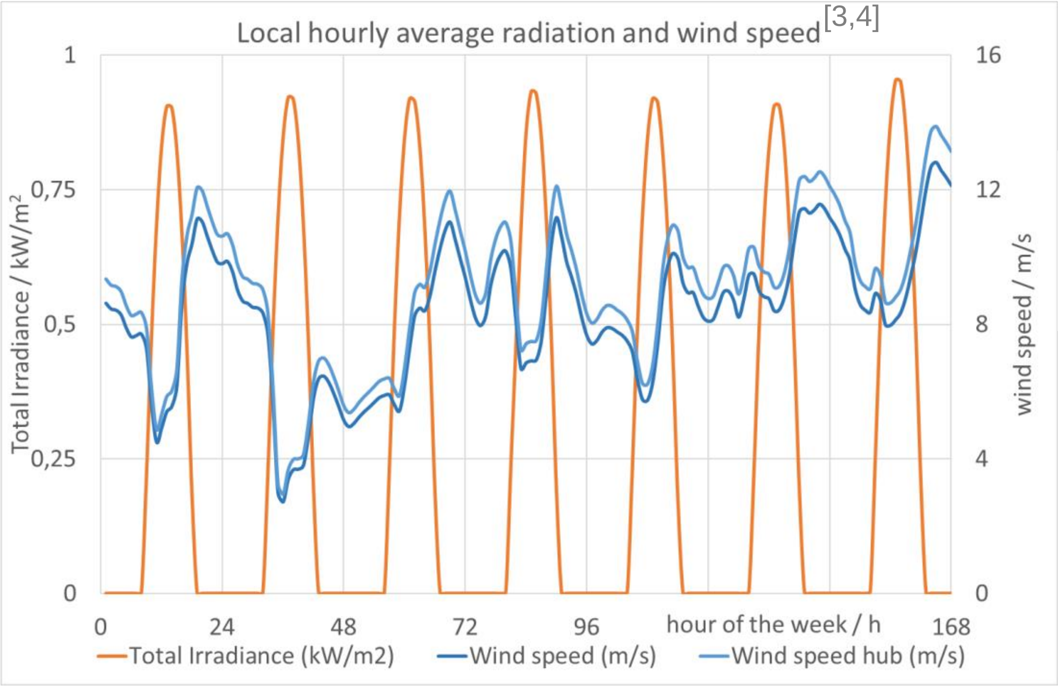


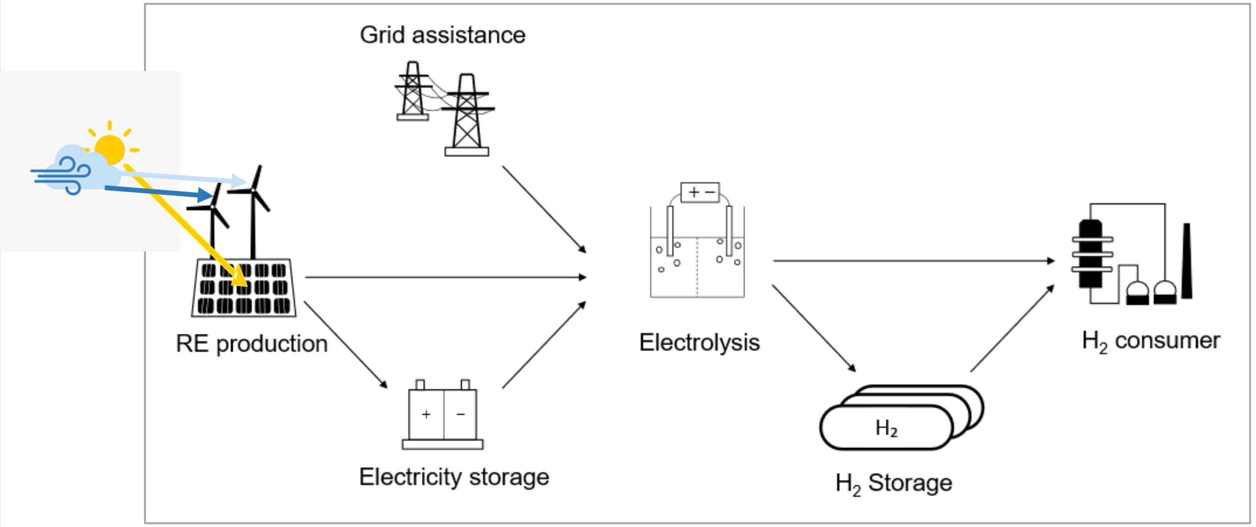


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[3] Pfenninger, S. and Staffell, I. (2016). Long-term patterns of European PV output. Energy 114, pp. 1251-1265. doi: 10.1016/j.energy.2016.08.060
[4] Staffell, I. and Pfenninger, S. (2016). Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239. doi:10.1016/j.energy.2016.08.068

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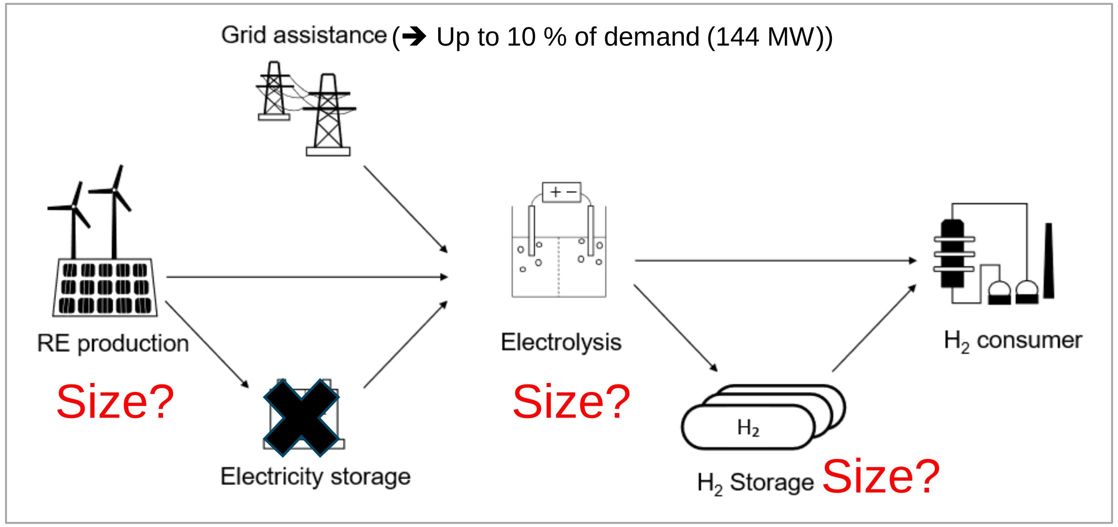




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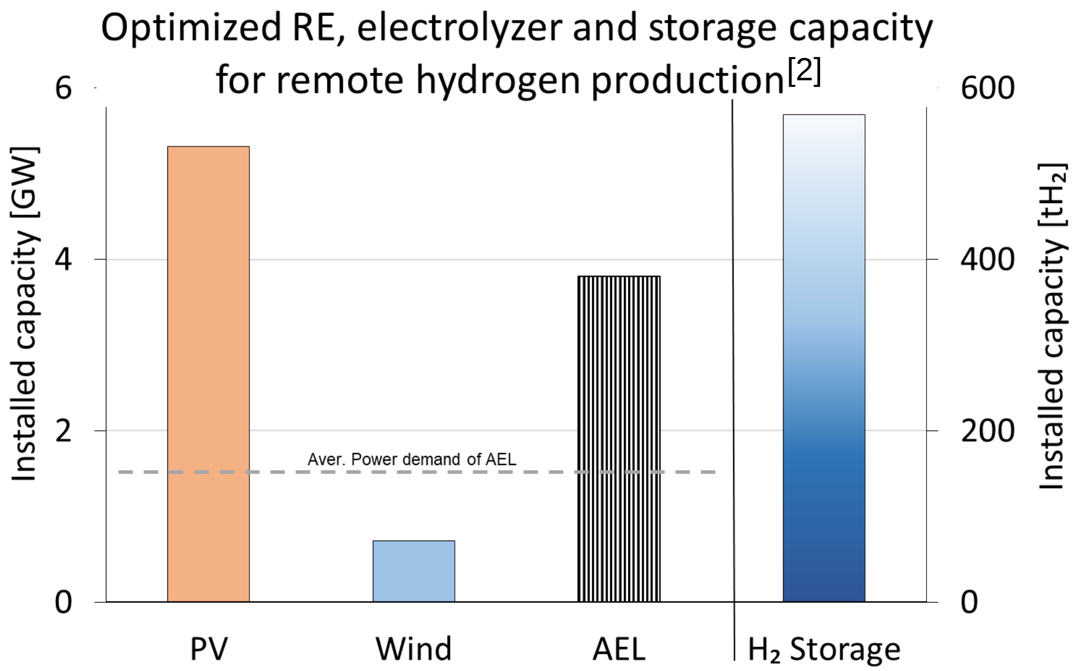


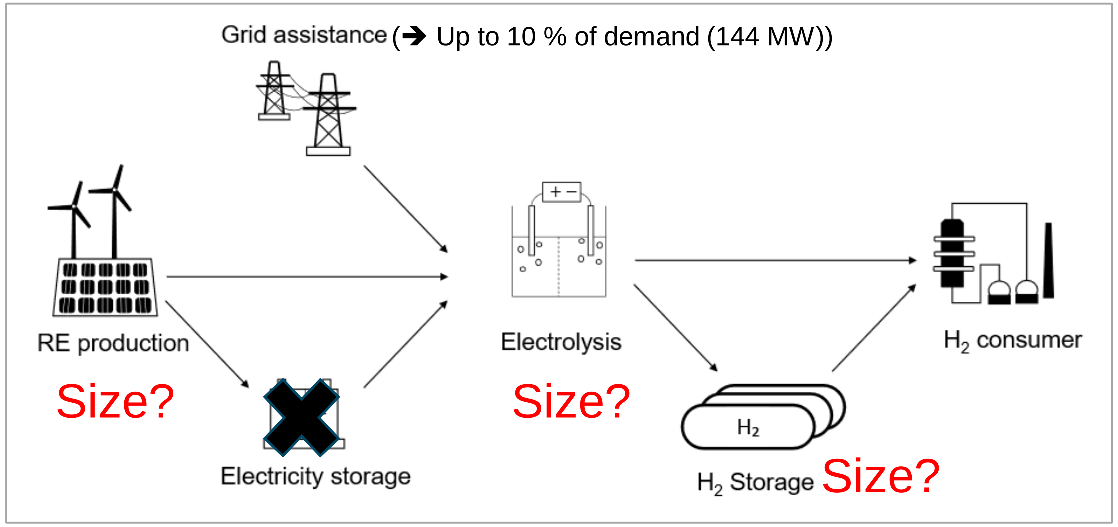




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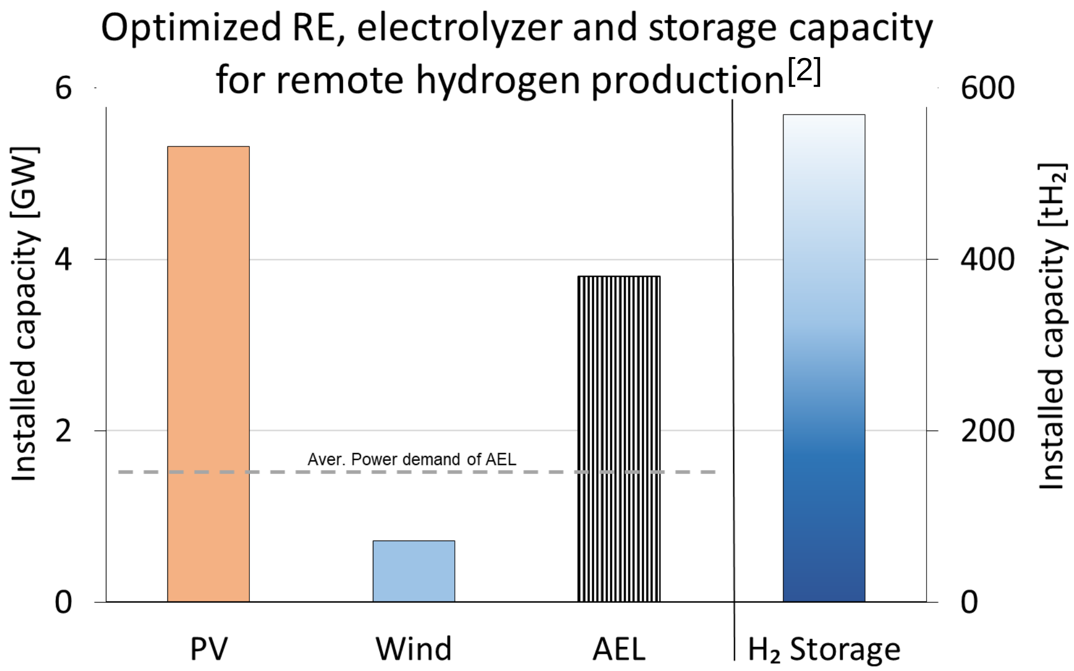


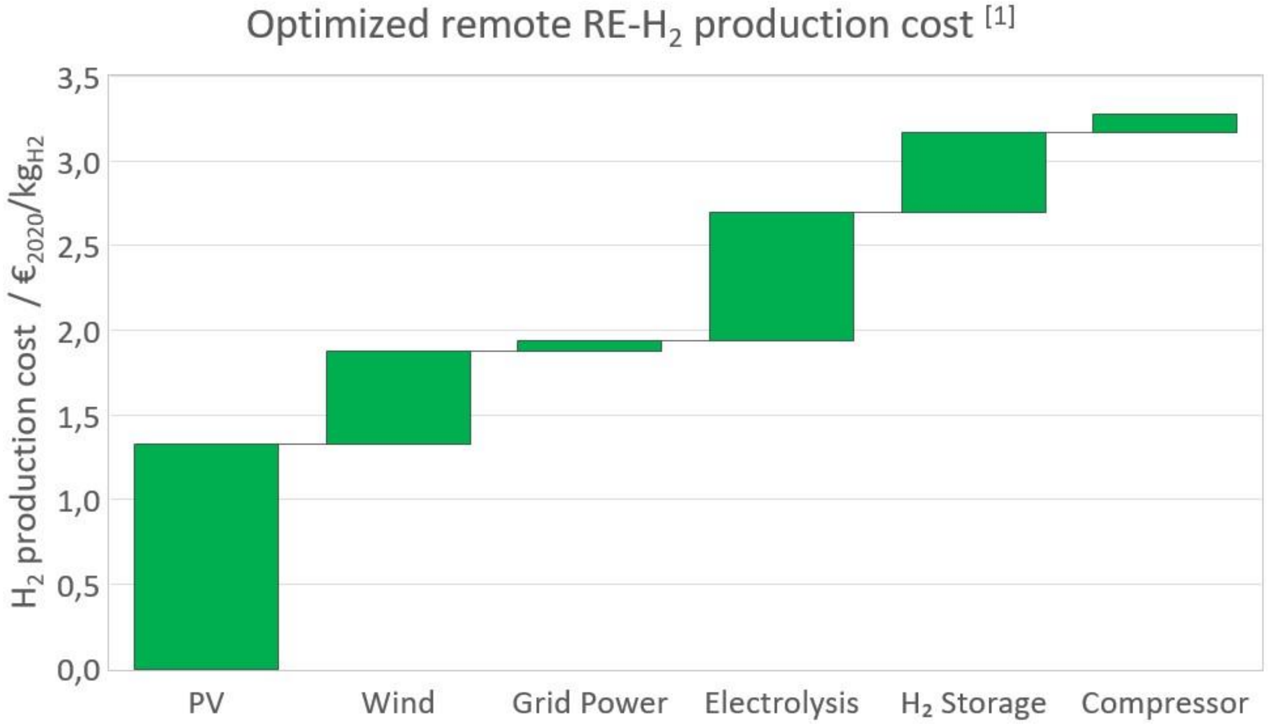




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# Local RE-$H_2$ production

## Time-frequency analysis [1]

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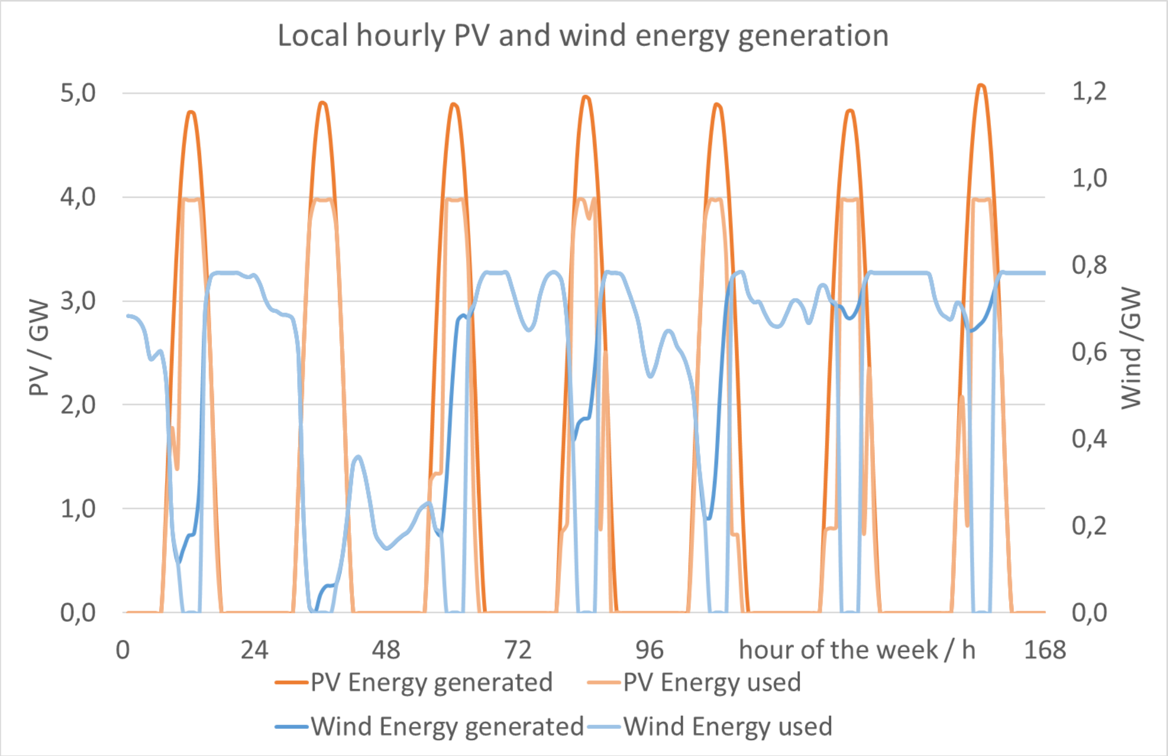
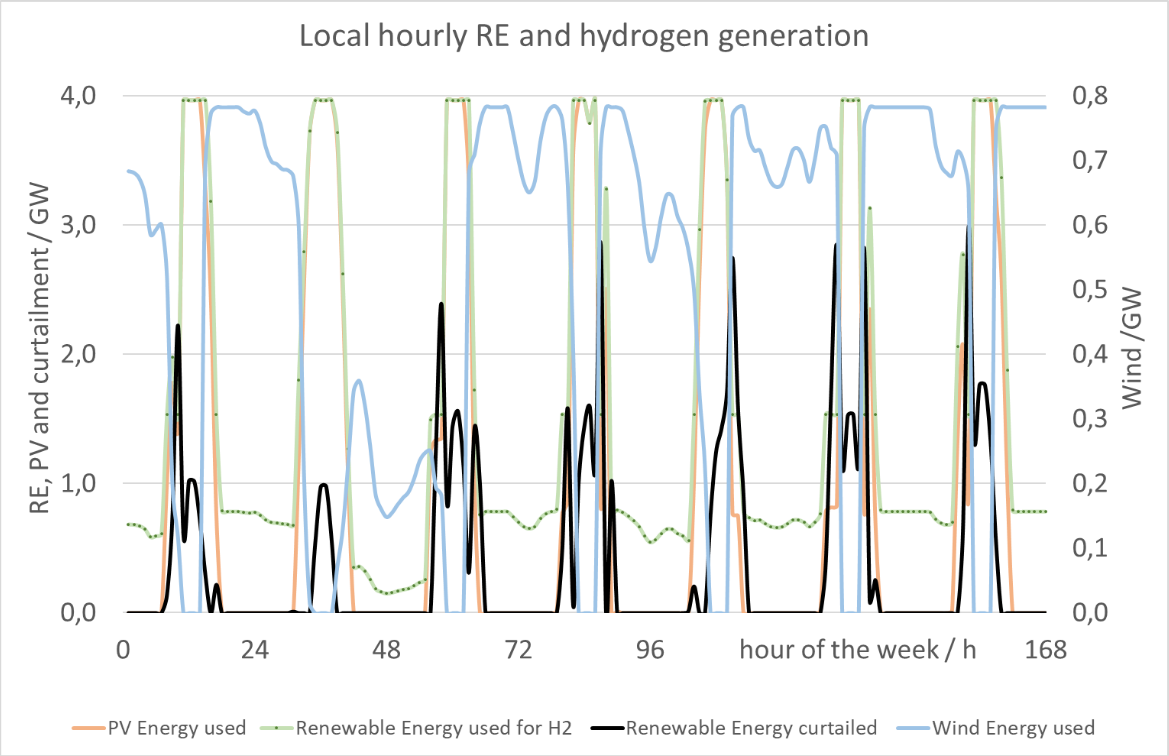
- 1 GW $H_2$: Tsau Khaeb National Park, Namibia (latitude -26.8, longitude 15.3)
  - Wind and solar energy are not complementary
  - Up to 3 GW curtailment unavoidable

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# Local RE-$H_2$ production remarks

- 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

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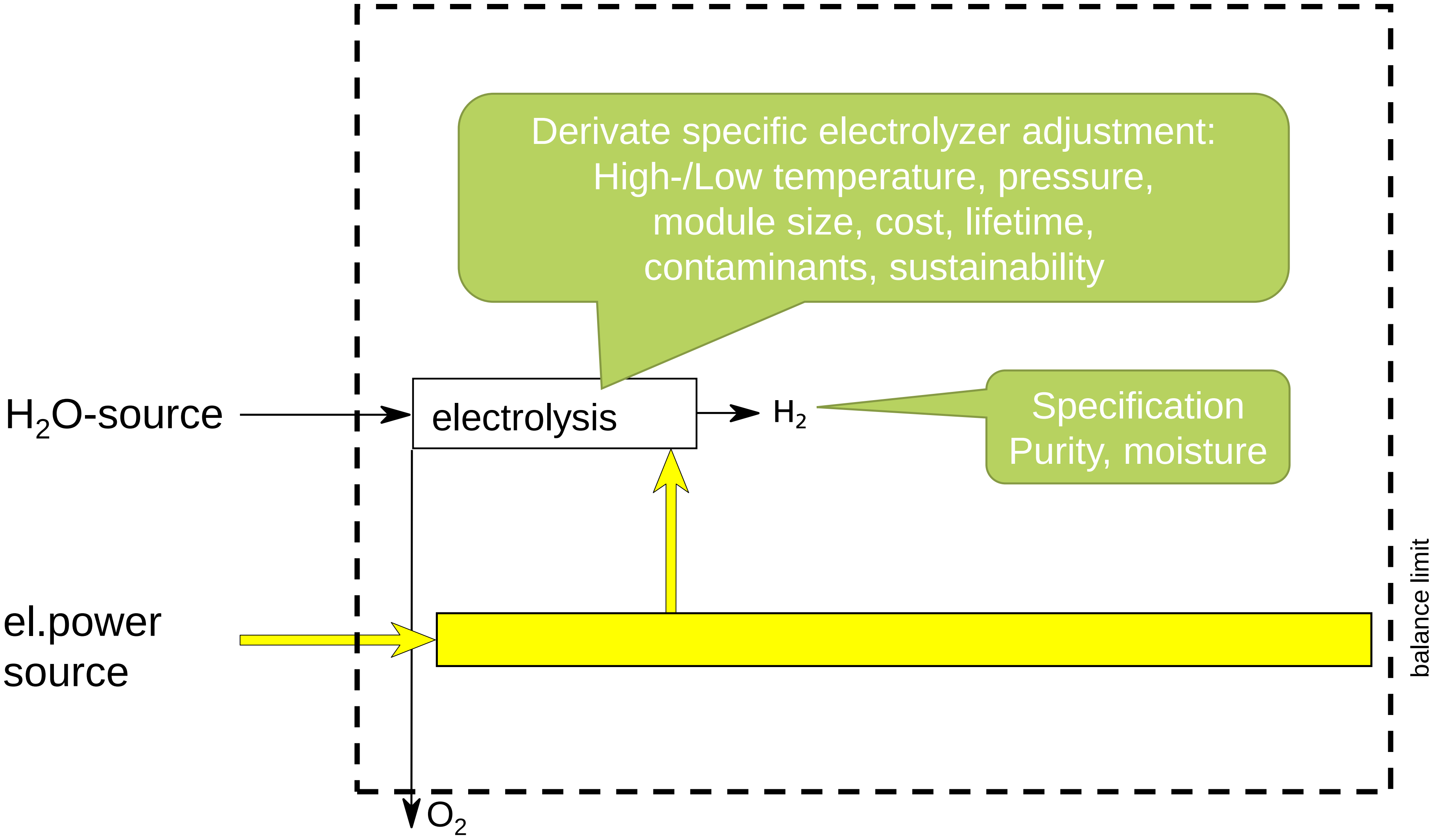
# Derivate production
## Generalized assessment [1]



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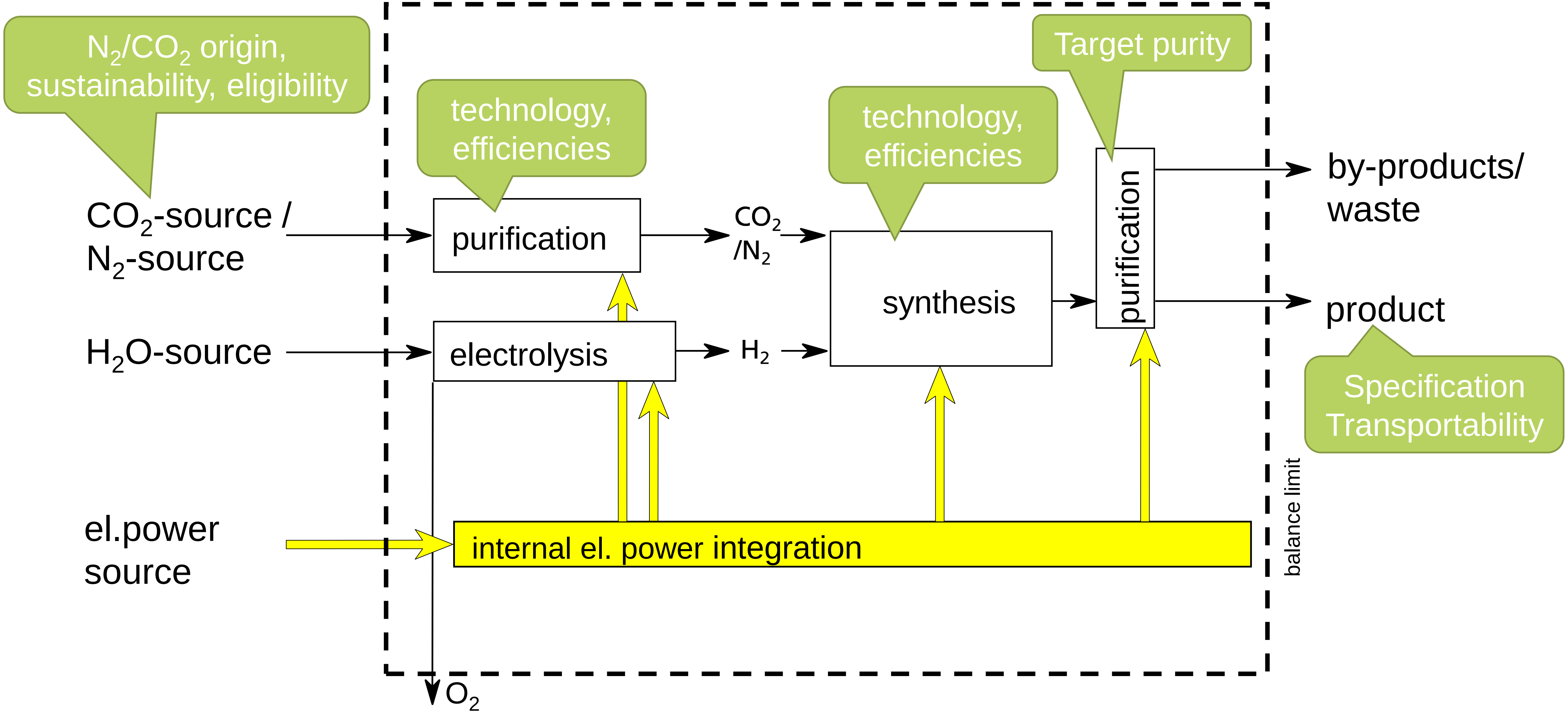


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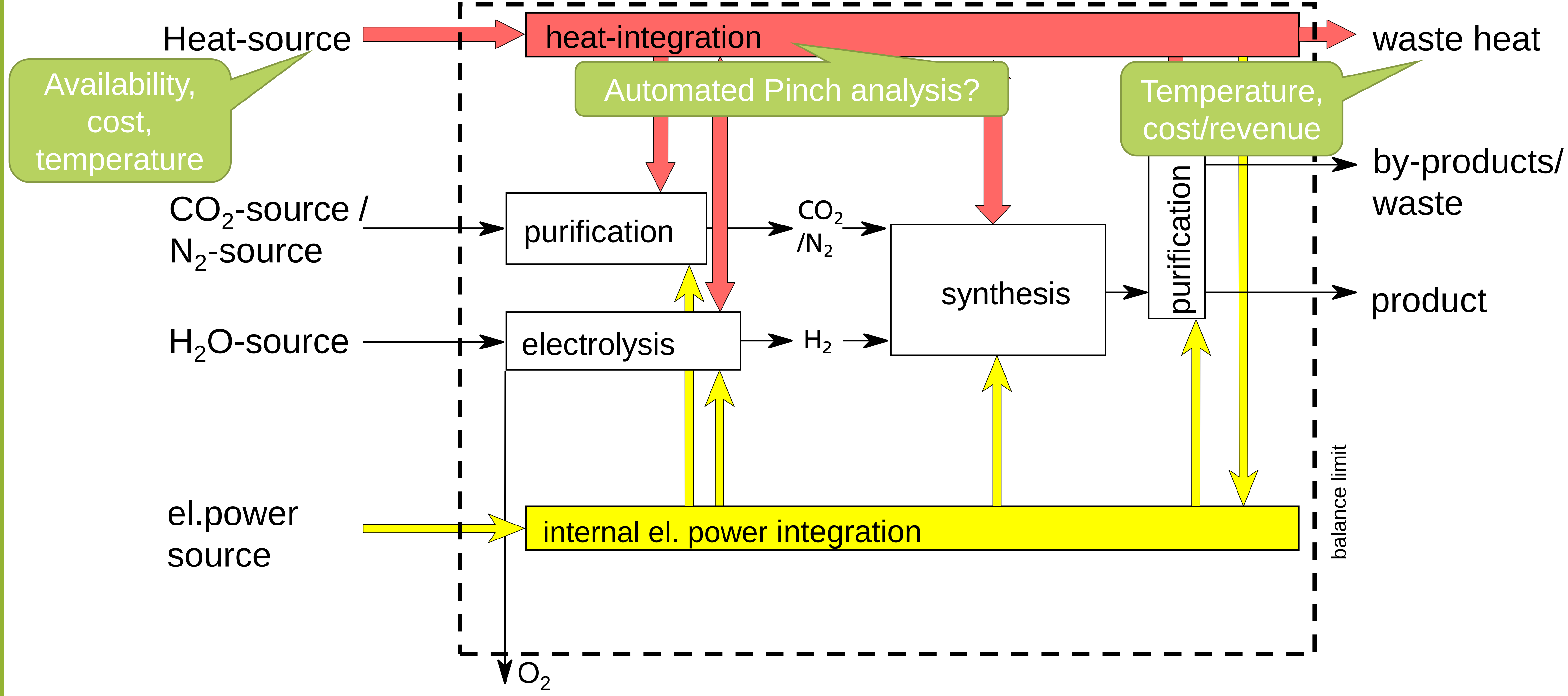


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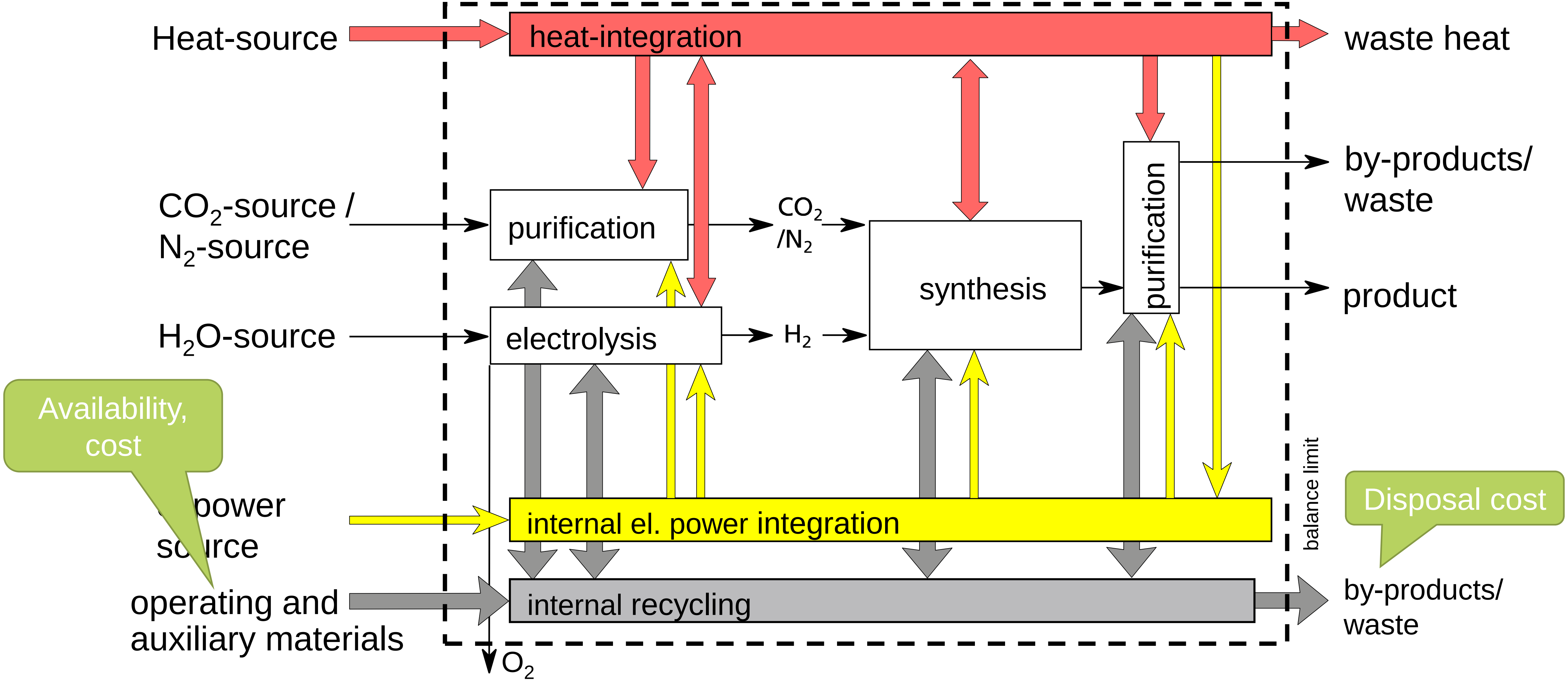


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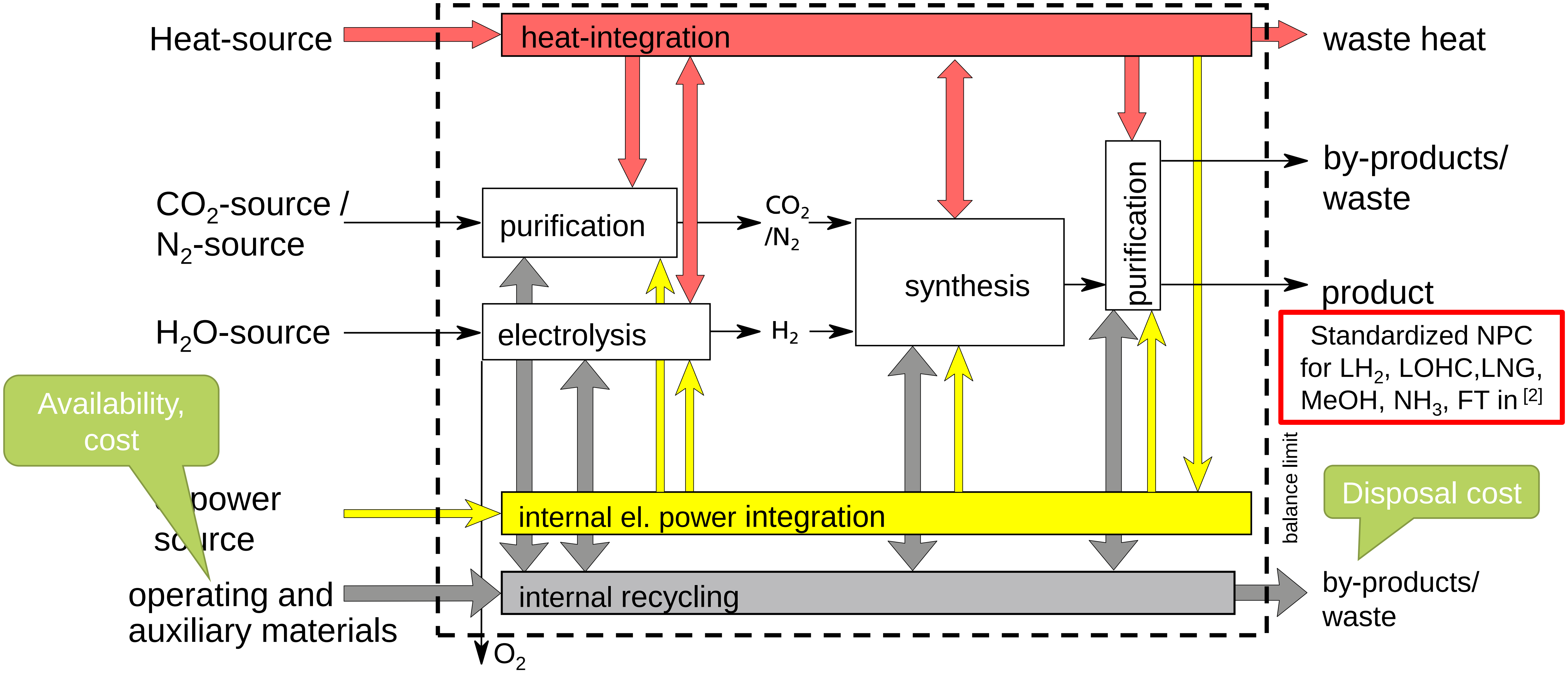


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# Derivate production
## Example: LNG production

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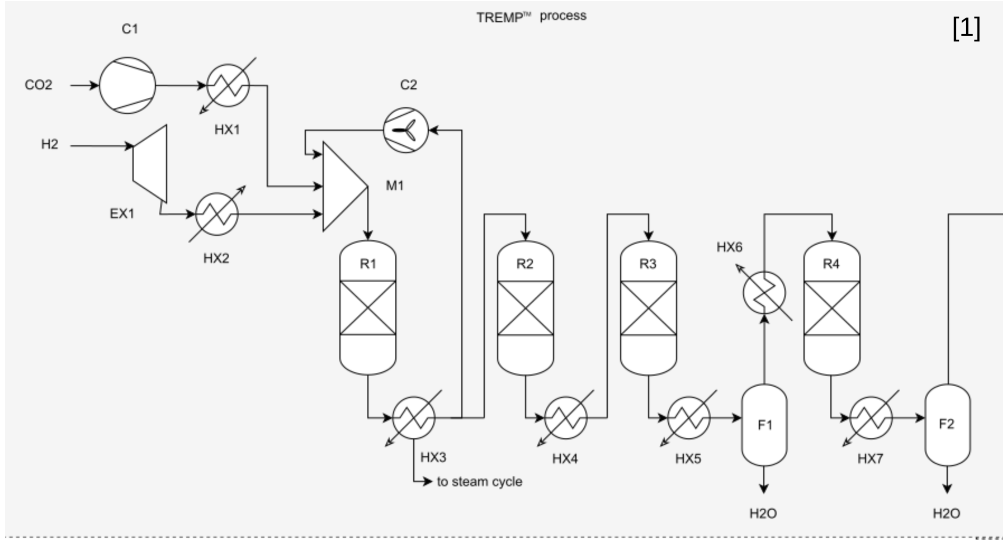
### Advanced TREMP™-process




[1] Rönsch, S., et al., 2016

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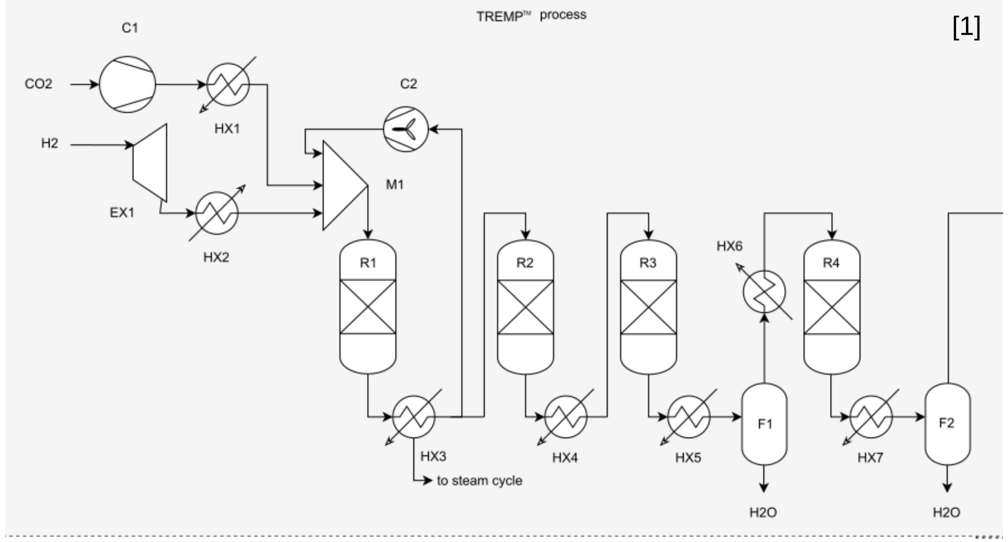
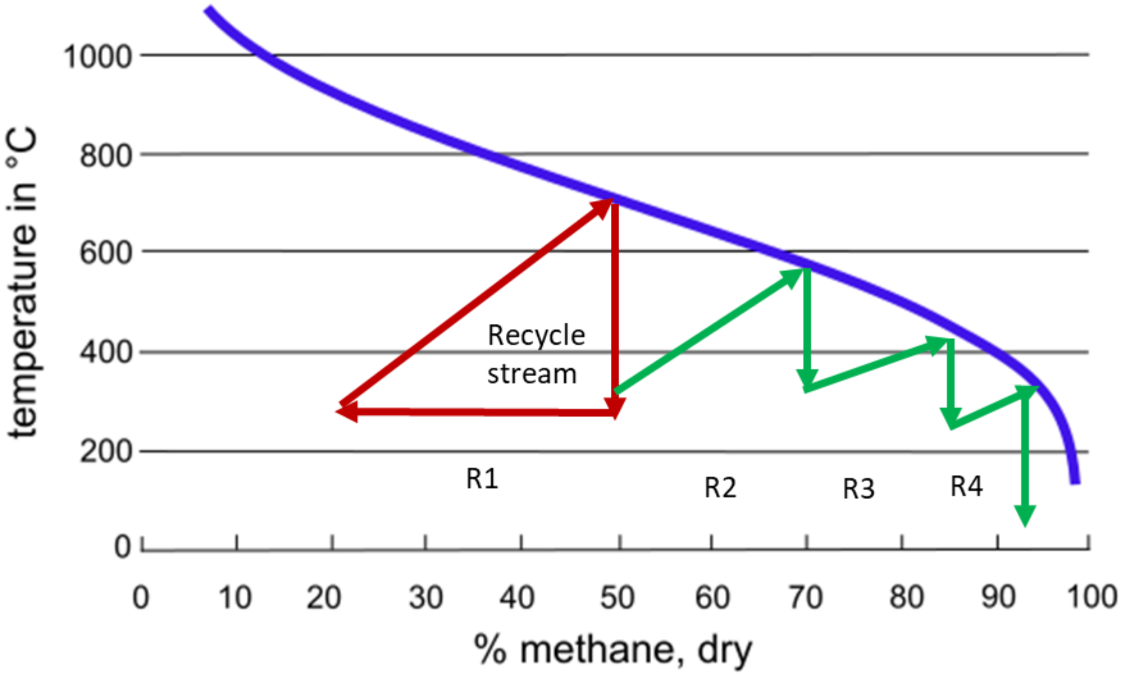



- High temperature in R1
  - ➢ Steam cycle option
  - ➢ Superior efficiency




[1] Rönsch, S., et al., 2016

# Derivate production
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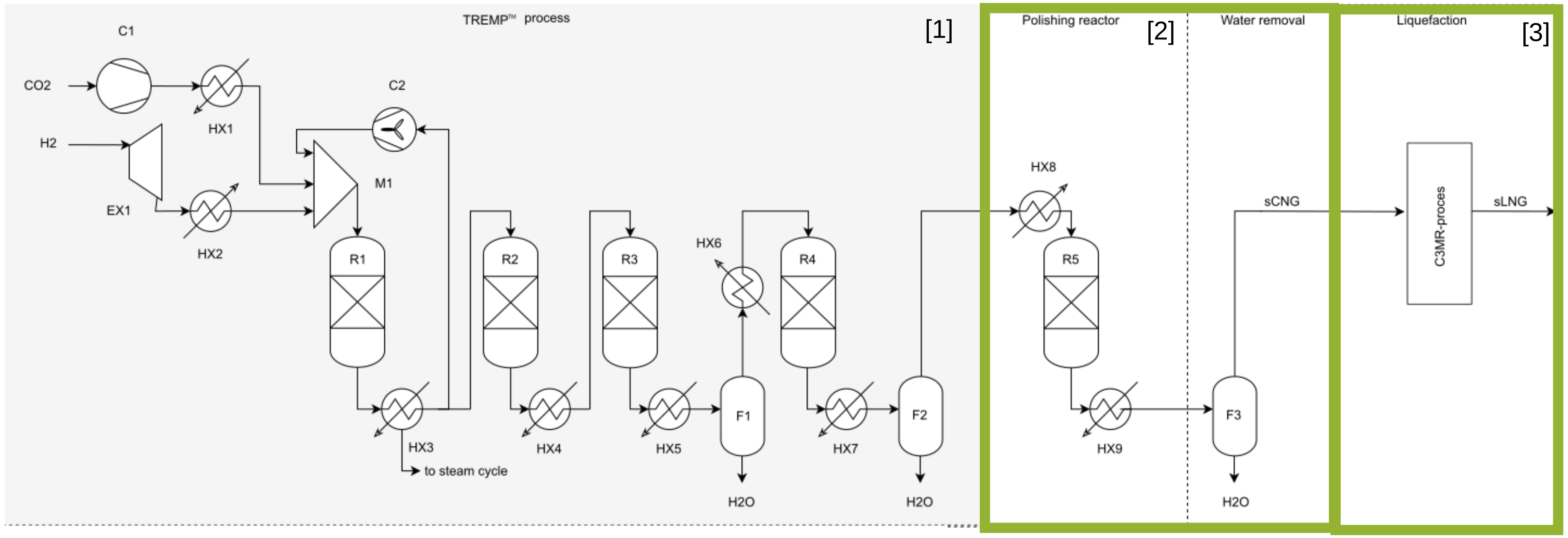
**Advanced TREMP™-process**



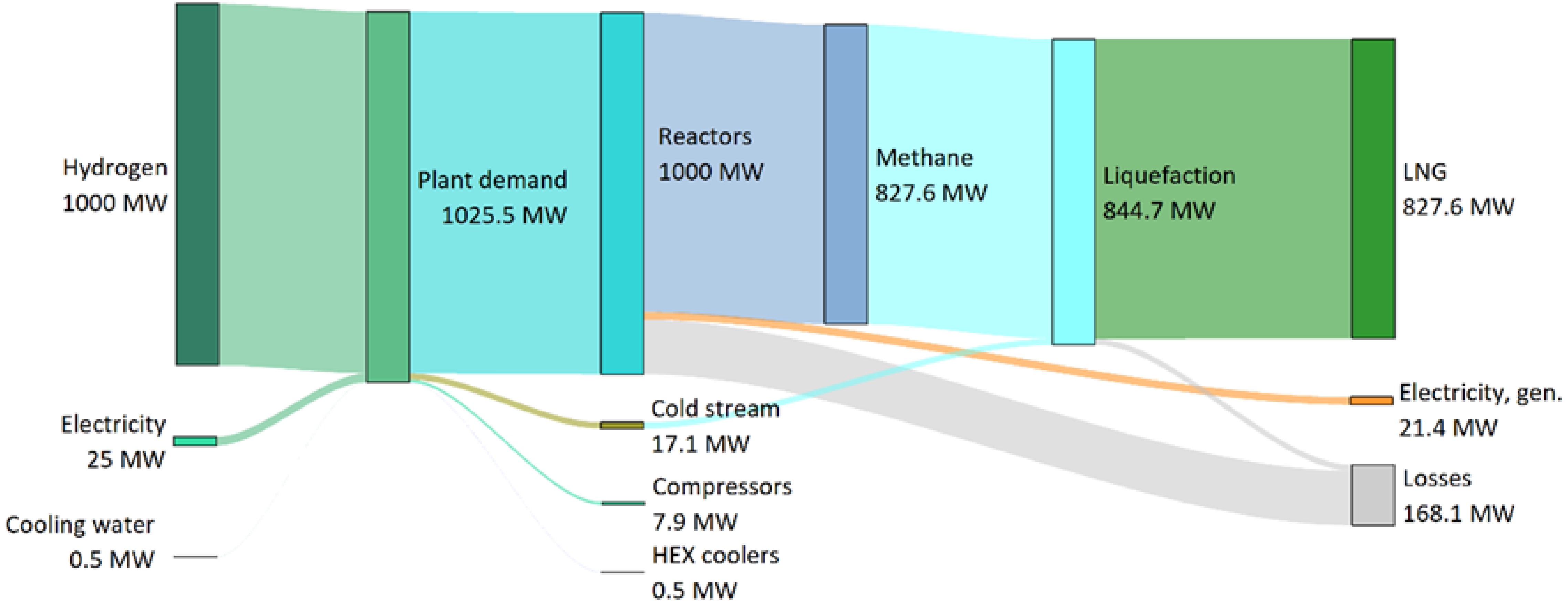

Simulation assumptions:
- No impurities
- No side reactions

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

[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 [1]
## Example: LNG production

- Energy flow diagram of the optimized LNG production process



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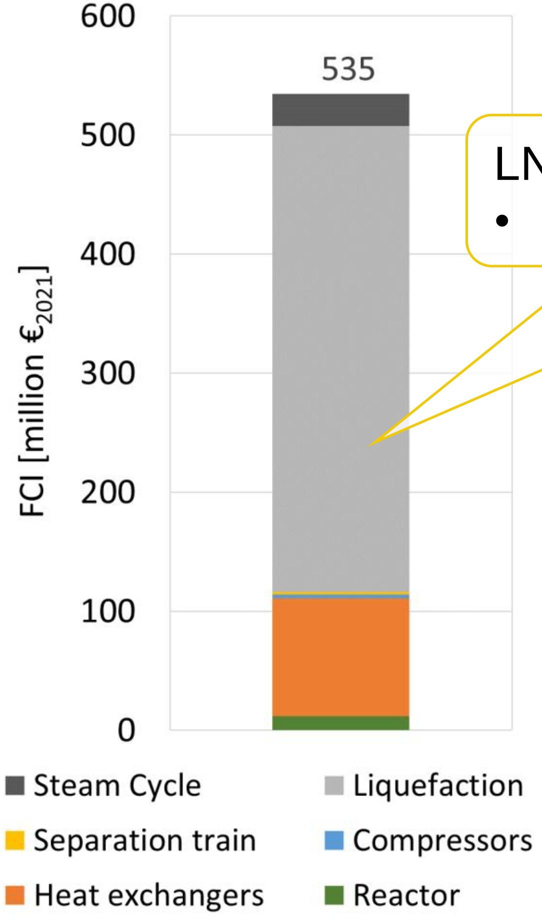
# Derivate production [1]
## Example: LNG production

- FCI breakdown of LNG plant in Namibia [1]




LNG liquefication (single train) [2]
- 391.25 M€$_{2021}$



[1] Dietrich et. al (2021). Hydrogen Non-Conventional Storage Options. In: Encyclopedia of Electrochemical Power Sources, doi: 10.1016/B978-0-323-96022-9.00183-3
[2] Zhang, Jinrui et al. (2020) Comprehensive review of current natural gas liquefaction processes on technical and economic performance. Doi: 10.1016/j.applthermaleng.2019.114736

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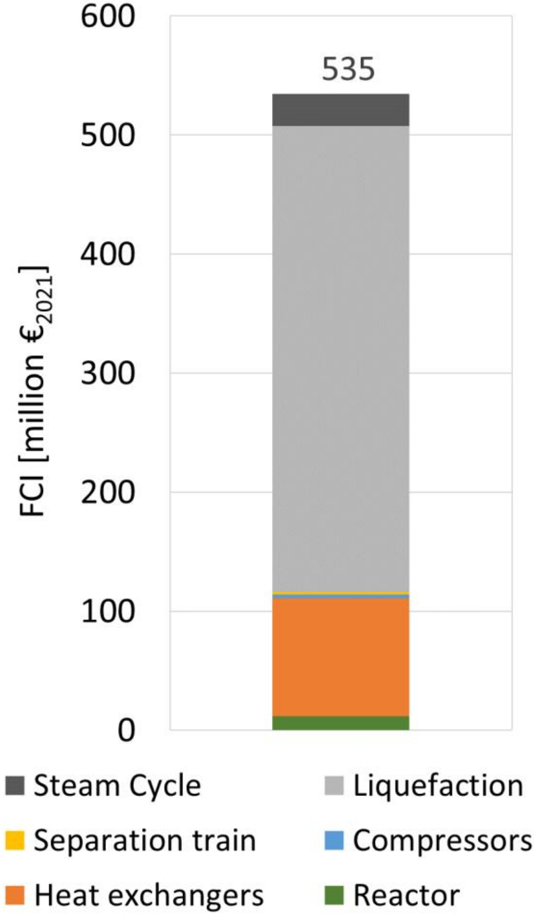


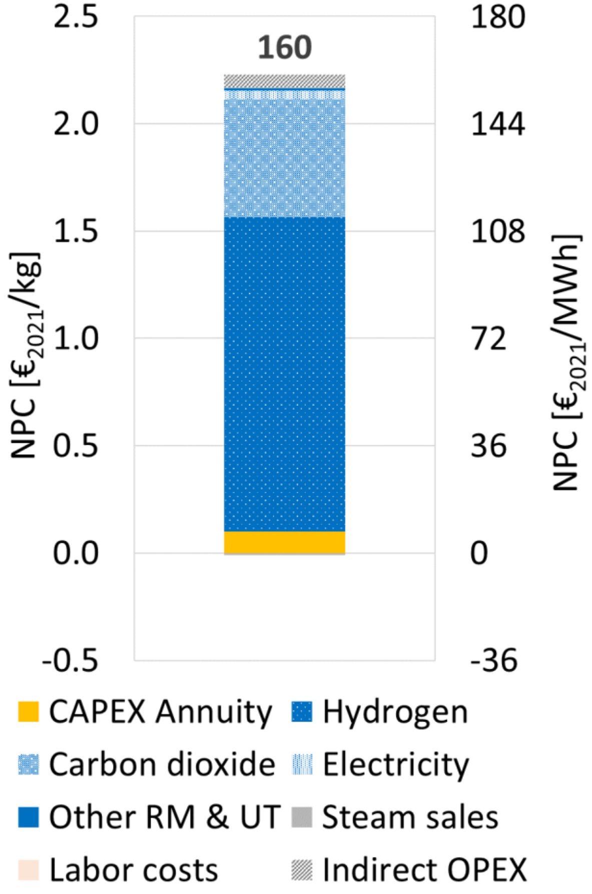




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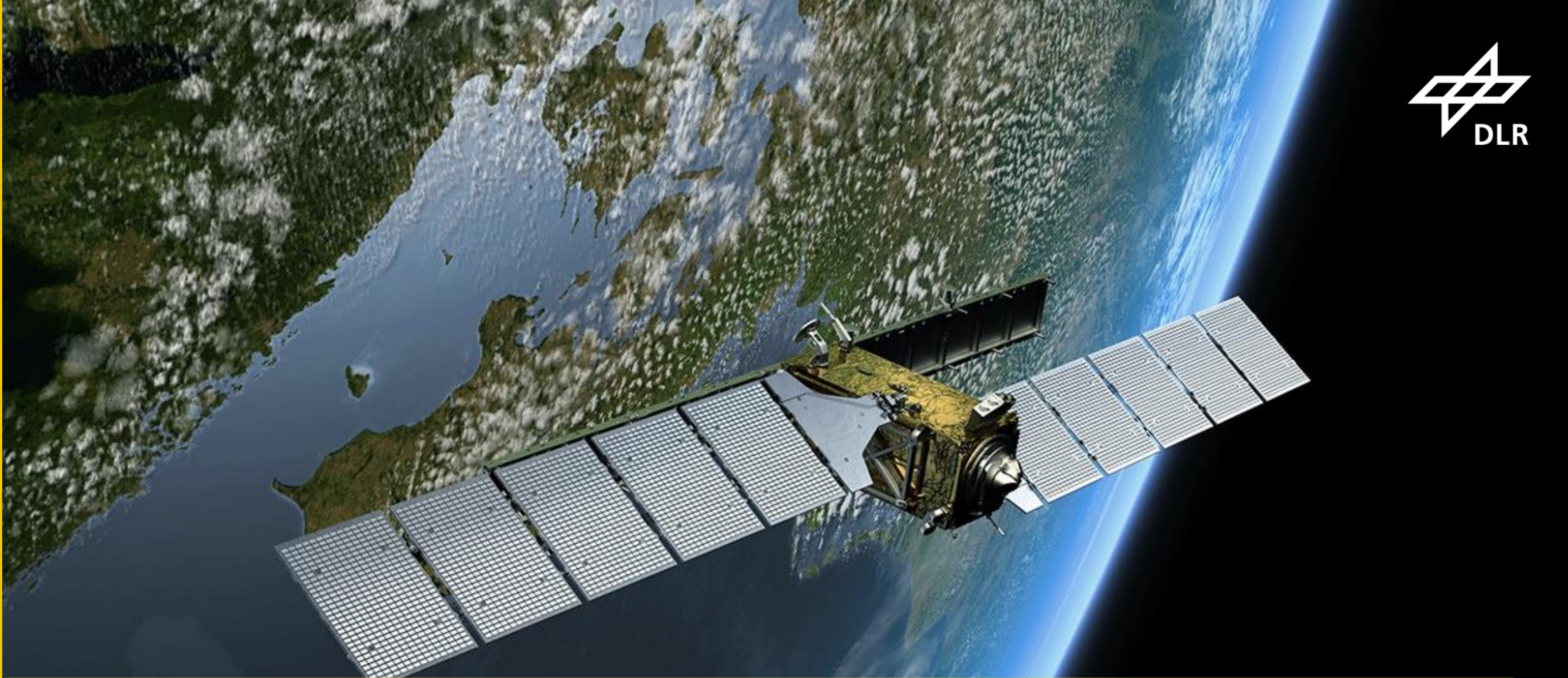

# TRANSPORT OF RENEWABLE ENERGY VIA HYDROGEN AND DERIVATES

# Large Scale RE transport [1]

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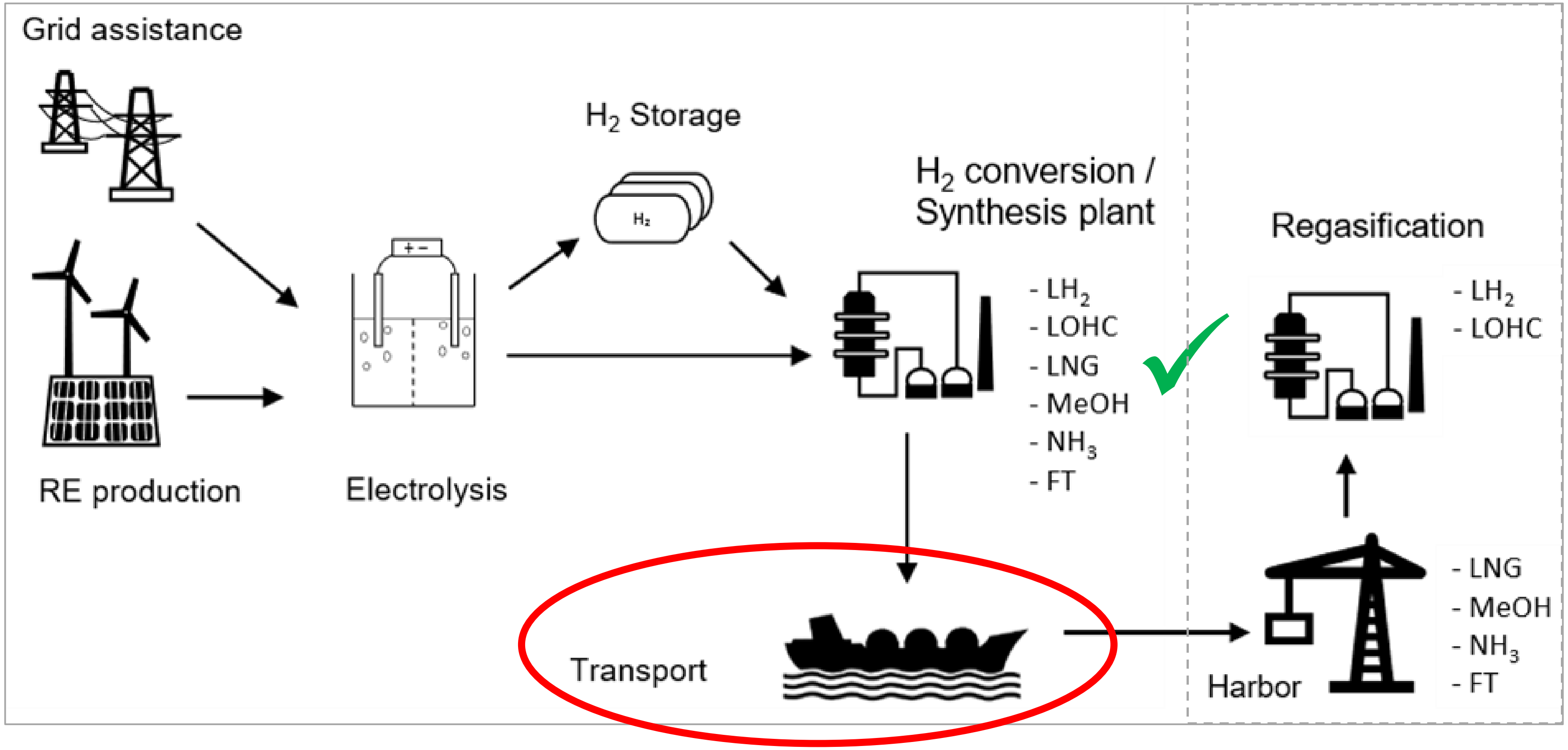
- Example: Tsau Khaeb National Park, Namibia
- Destination: WHV, Germany



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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 $Tm^3$ LH2 by mid-2020, commercial in early ´30s [1]
- 160 $Tm^3$ LH2 = 0.4 $TWh_{LHV}$ = 2.9 ktoe

- 265 $Tm^3$ commercial Q-Max LNG carrier fleet [2]
- 265 $Tm^3$ LNG = 1.6 $TWh_{LHV}$ = 80.7 ktoe

- Up to 500 $Tm^3$ commercial Ultra Large Crude Carrier fleet [3]
- 500 $Tm^3$ 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

## At the gate cost comparison [1]


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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 |
| $\eta_{HtF}$ | % $(GW_{LHV,F}\ GW_{LHV,H}{}^{-1})$ | 98.4 | 97.3* | 82.8 | 80.1 | 81.8 | 63.9 |
| $\eta_{PtF}$ | % $(GW_{LHV,F}\ GW_{el}{}^{-1})$ | 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 |
| $\eta_C$ | % | - | - | 98.5 | 95.2 | - | 95.5 |

Technical performance given in efficiencies

- Hydrogen efficiency
- Energetic efficiency
- Carbon efficiency

* Including LOHC regasification



[1] Dietrich et. al (2024). Hydrogen Non-Conventional Storage Options. In: Encyclopedia of Electrochemical Power Sources, doi: 10.1016/B978-0-323-96022-9.00183-3

# Large Scale PtX import options
## At the gate cost comparison [1]

| | 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 |
| $\eta_{HtF}$ | % $(GW_{LHV,F}\ GW_{LHV,H}^{-1})$ | 98.4 | 97.3* | 82.8 | 80.1 | 81.8 | 63.9 |
| $\eta_{PtF}$ | % $(GW_{LHV,F}\ GW_{el}^{-1})$ | 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 |
| $\eta_C$ | % | - | - | 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

* Including LOHC regasification |** Based on H2 content only

[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)



[1] Dietrich et. al (2024). Hydrogen Non-Conventional Storage Options. In: Encyclopedia of Electrochemical Power Sources, doi: 10.1016/B978-0-323-96022-9.00183-3

# Large Scale PtX import options

## At the gate cost comparison [1]

FÖRDERPROZESS-FOREN
Wasserstoff-Forum 19. - 20. November 2024
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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 |
| ηHtF | % ($GW_{LHV,F}$ $GW_{LHV,H2}^{-1}$) | [illegible] | [illegible] | [illegible]2.8 | 80.1 | 81.8 | 68.9 |
| ηPtF | % ($GW_{LHV,F}$ $GW_{el}^{-1}$) | 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 |
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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 |*** 30 €/MWh assumed for regasification heat

Transport and regasification efforts are not neglectable
- Transport safety and reliability
- Harbor capacity
- Regulation
- …

[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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# SUMMARY & OUTLOOK

# Techno Economic Assessment of P-t-X Import


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## Summary

- Large-scale transport of renewable 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 abroad has to be balanced against transformation and transport cost to become valuable for domestic energy transition ➔ Minimize $CO_2$ abatement cost <u>at home</u>!

**Transparent, standardized DLR assessment methodology can support**

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

Thursday, November 19, 2024

Hydrogen

Thema: C - Aufbau der Wasserstoffwirtschaft


# THANK YOU FOR YOUR KIND ATTENTION! QUESTIONS?

**Techno-ökonomische Bewertung von Technologien und Importoptionen für erneuerbar erzeugte Wasserstoffderivate**

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