EARLY BUSINESS CASES FOR H2 IN ENERGY STORAGE AND MORE BROADLY POWER TO H2 APPLICATIONS

FCH-JU Programme Review Days
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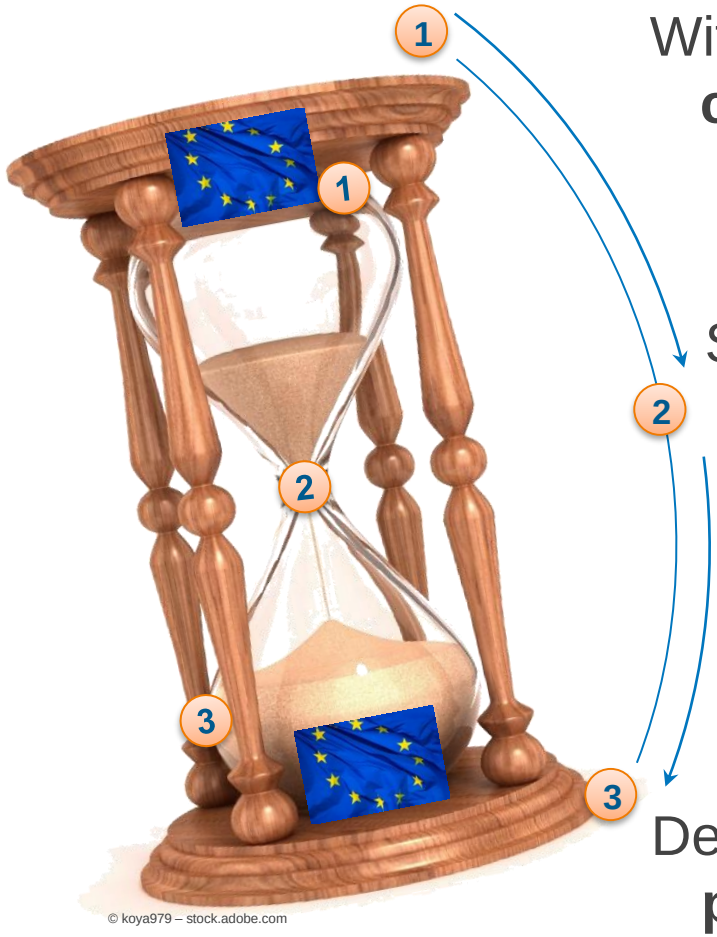
Objectives of P2H Early BizCases

Identify bankable Power-to-Hydrogen business cases for 2017-25 in the EU-28



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1. Within the EU-28, **identify locations with favorable electricity conditions** for P2H systems (at sub-national level)

2. Study **three concrete P2H business cases** for a specific location and application (industry, mobility), quantifying key performance indicators (CAPEX, revenues, margin,..)

3. Derive **boundary conditions for profitability** and assess **replicability potential** in the EU-28

Key message:

There are bankable business cases for PtoH in Europe already today

- By 2025, the European market for PtoH is estimated at a cumulative 2.8 GW, representing a market value of 4.2B€ and 400 ktons H2 per year.
- Bankability can be achieved by complementing hydrogen sales with electricity grid flexibility services
- Combining PtoH for mobility/industry applications and gas grid injection is more cost-effective than stand-alone injection
- Gas grid injection is a risk mitigation instrument until H2 demand picks up
- The Clean Energy package is a unique opportunity to create a market for PtoH in oil refineries
- PtoH is a practical and system-beneficial way to value excess of RES but requires a long-term view on grid fees, taxes and levies to enable bankability

Agenda

- Costs
- Revenues
- Business cases
- Replicability

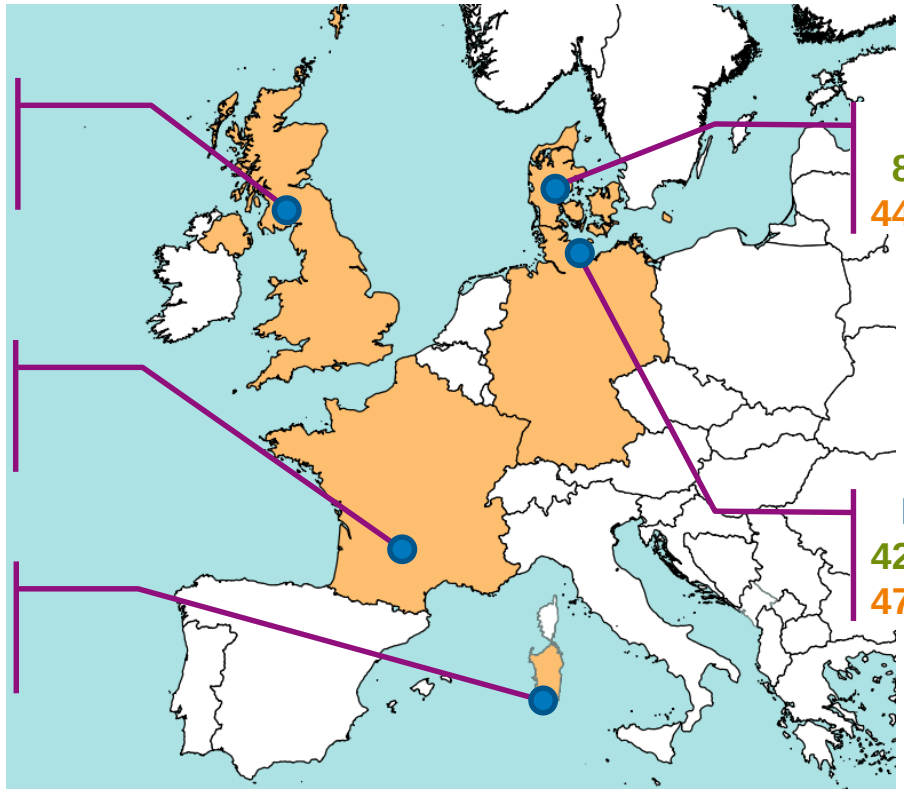
For 5 EU member states, locations with low-cost electricity were identified

Congested areas are found where there is local overproduction of RES

Tongland (UK)
71 GWh (20 %)
117 GWh (20 %)

Albi (FR)
24 GWh (9 %)
72 GWh (15 %)

Sarroch (IT)
0 GWh (0 %)
1.4 GWh (0 %)



Trige (DK)
89 GWh (5 %)
442 GWh (13 %)

Lübeck (DE)
428 GWh (59 %)
475 GWh (40 %)

Selected subnational locations with low-cost electricity
Numbers: local curtailment frequency (% year[1]) 2017 / 2025

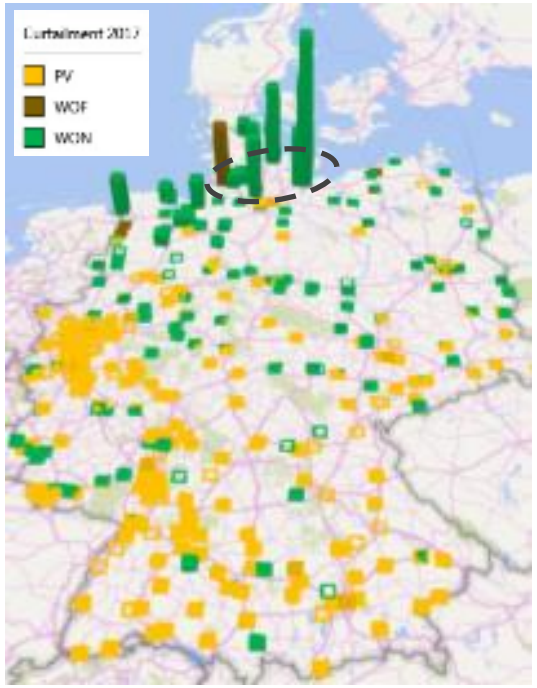
Comments

- Simulations with grid constraints show significant RES curtailment
- National level: mostly below 2% of total RES production, except for Denmark
- Node-level [HV/MV transformer]: massive curtailment shares in certain areas, up to 40%
- Curtailment occurs throughout the year in some locations

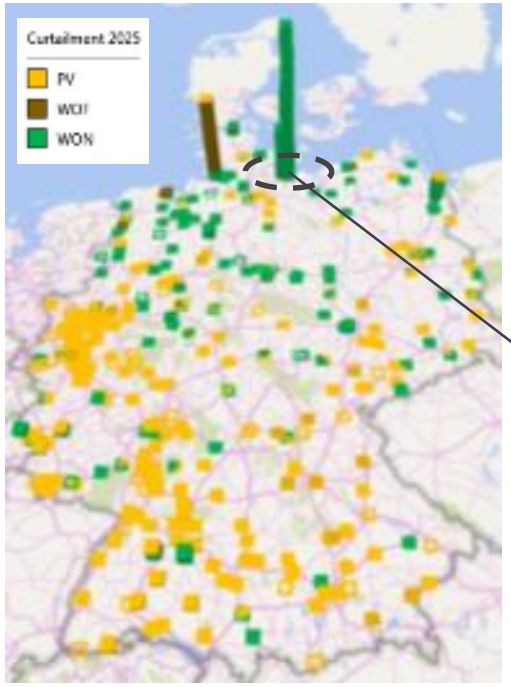
Important note: These areas are unique opportunities based on their RES curtailment potential. They are not representative of the rest of the country.

RES curtailment is a pressing issue but linked to specific areas, as the example of Germany shows

2017



2025



Curtailment at national level

2017: 2,124 GWh (1.8% of prod.)

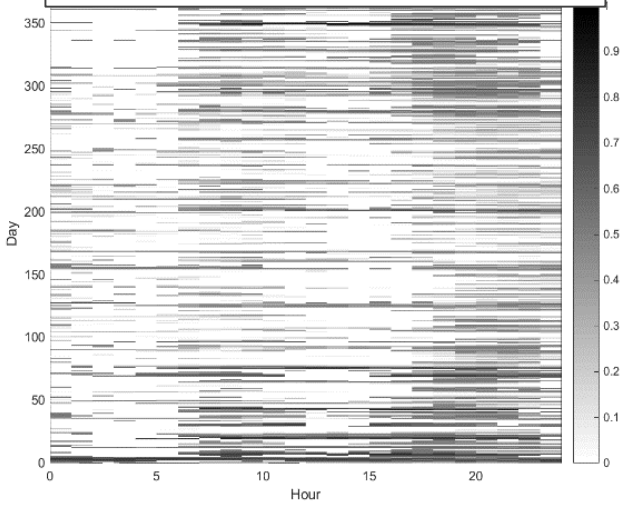
2025: 1,702 GWh (0.9% of prod.)

Interesting areas for an electrolyzer

Comments

- **Significant curtailment at national level (~2% in 2017), but no increase expected towards 2025**
- **Onshore wind** is the most **curtailed RES**:
  - Areas with high curtailment all located in Northern DE
  - Some offshore wind curtailment
  - Solar curtailment is minor
- Recommended area for electrolyser: Herrenwyk (near Lübeck)

Curtailment Profile



360 MW wind farm

Up to 40% of RES production curtailed

Curtailment in 40-60% of the hours of the year

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Power-to-Hydrogen potential revenues streams: Electrical grid services should not be considered as stand-alone applications

Large & Light Industrial applications

Mobility applications

Injection in gas grid

Electricity grid services

Island balancing

Revenues from **hydrogen sales**

PtoH application	Potential revenues* [k€/MW/year]
Refineries, without carbon penalty	237 – 512
Refineries, with carbon penalty	792 – 1068
Light industry market (delivery by trailer)	499 – 1235
Mobility (delivery to the HRS)	526 – 920
Hydrogen injection into gas grid based on national biomethane injection tariff	171 – 350**

Revenues from **grid services**

PtoH application	Potential revenues* [k€/MW/year]
Balancing services	2 -17
Frequency control services	70 - 224
Distribution grid services	< 1

Primary applications

Secondary applications (combinable with primary applications for little extra cost)

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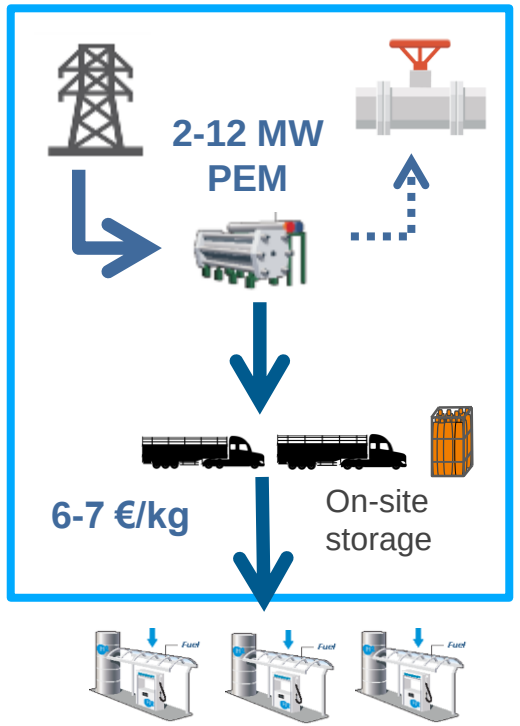
Three different business cases were analysed in three regions both 2017 and 2025

On-site production for mobility can generate profitable business cases but is excluded due the fact it has been covered intensively in previous studies.

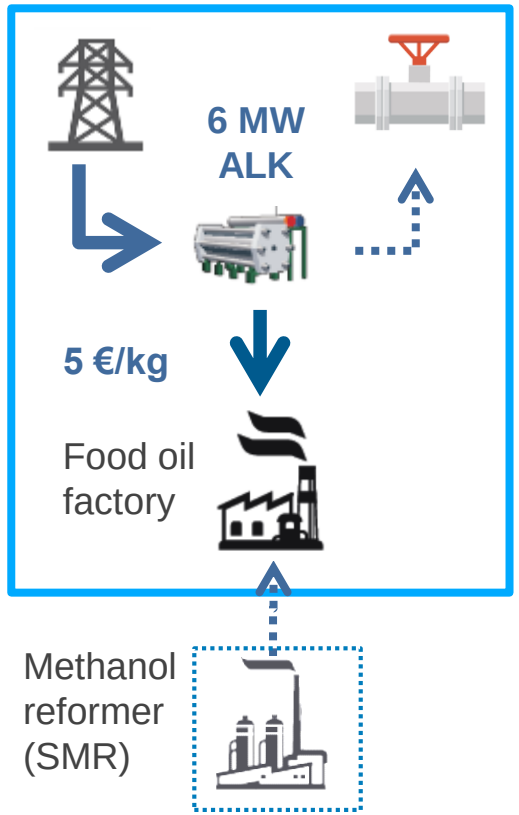
Boundary Scope

Semi-Centralised production for mobility
(Albi-FR)

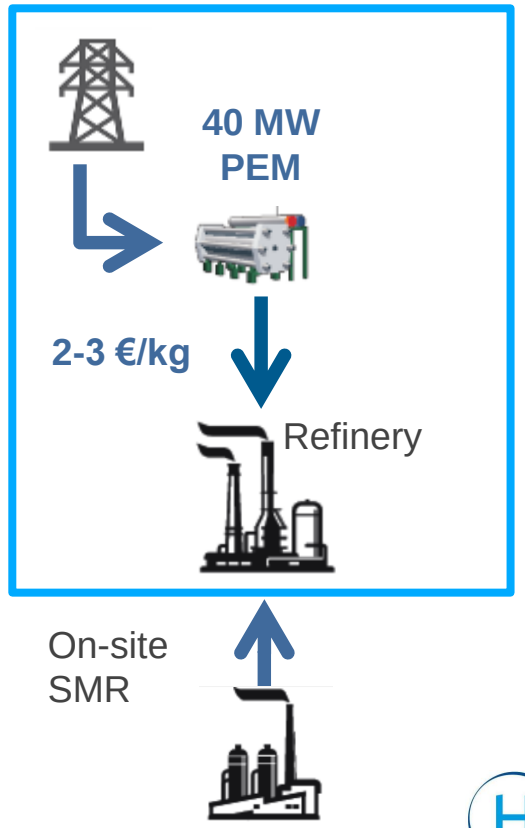


Regional network of hydrogen stations

Light industry
Food oil factory
(Trige-DK)



Large industry
Refinery
(Lübeck-DE)



Bankable business cases were found in the best locations



WACC on CAPEX: 5% Project lifetime: 20 years	SC mobility (Albi, France)		Food industry (Trige, Denmark)		Large industry (Lubeck, Germany)	
	2017	2025	2017	2025	2017	2025
Primary market H2 volume (t/year)	270	950	900	900	3 230	3 230
Average total electricity price for prim. market (€/MWh)	44	45	38	47	17	26
Net margin without grid services (k€/MW/year)	**39**	**71**	**228**	**248**	**-146**	**30**
Net margin with grid services (k€/MW/year)	**159**	**256**	**373**	**393**	**-13**	**195**
Share of grid services in net margin (%)	**75%**	**72%**	**39%**	**37%**	**-**	**85%**
Payback time without grid services (years)	**11.0**	**9.0**	**4.6**	**3.7**	**-**	**8.4**
Payback time with grid services (years)	**8.0**	**4.5**	**3.4**	**2.7**	**-**	**3.5**
Key risk factors	• Taxes & Grid fees • H2 price • Size of fleets • Injection tariff • FCR value		• H2 price • Taxes & Grid fees • FCR value		• Taxes & Grid fees • FCR value • Carbon price	

Profitable stand-alone primary applications have a payback time ranging between 4 and 11 years.
Providing grid services can reduce payback time by 30-50%.

Agenda

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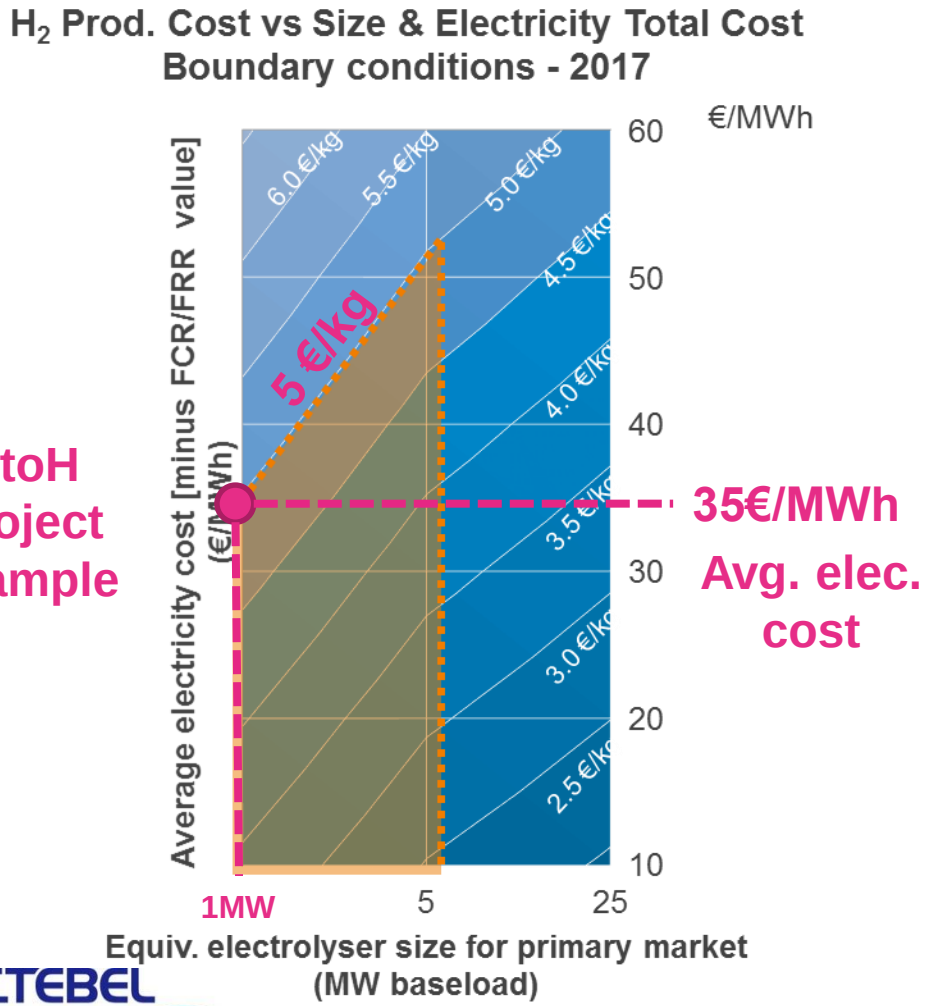
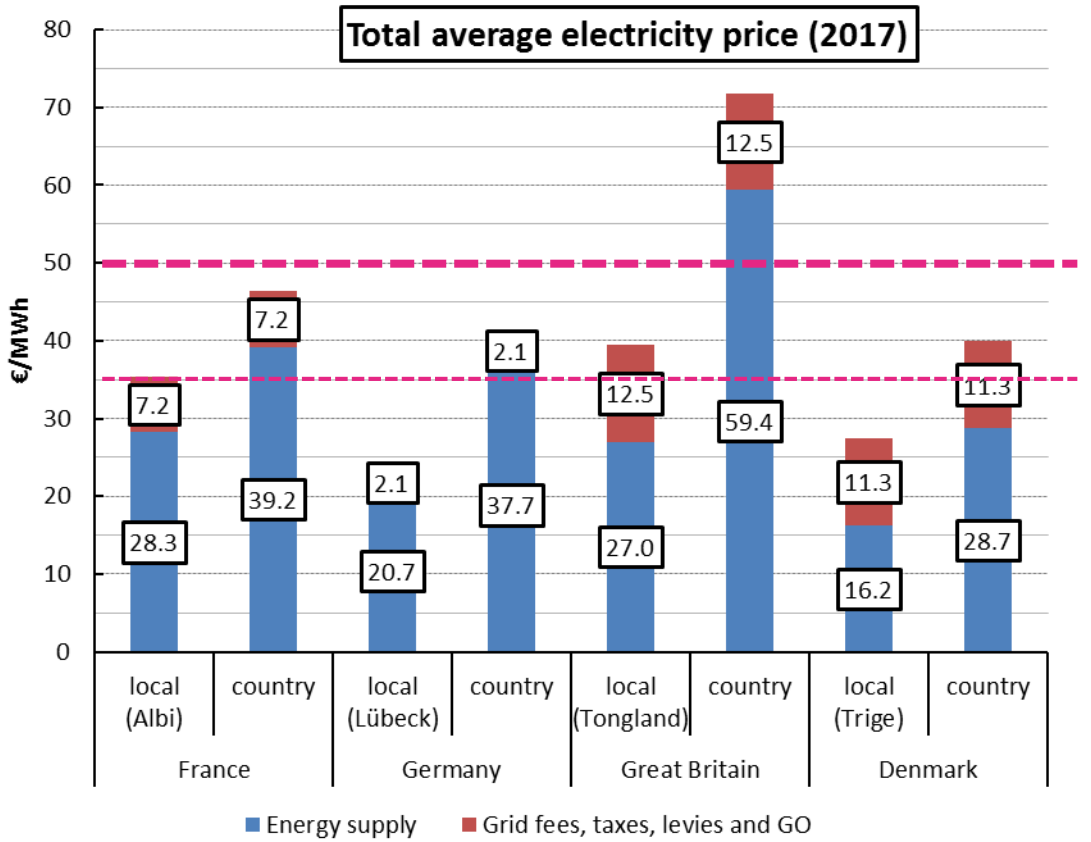
- Replicability

Rule of thumb: PtoH business cases profitability depends on:
(1) primary market size, (2) hydrogen selling price and (3) average electricity cost



PtoH project example

35€/MWh Avg. elec. cost



Grid services revenue
15 € / (MW.h)

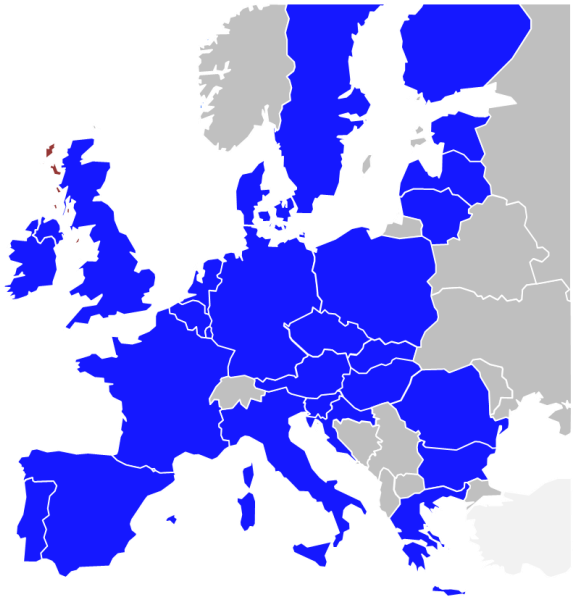
50€/MWh

35€/MWh

These graphs can be used by project developers to pre-evaluate business cases for suitable location and bankability.

By 2025, the European market for PtoH is estimated at a cumulative 2.8GW, representing a market value of 4.2B€.

EU-28 market potential	Cumulative market size	Market value	H2 Volume
2017	1500 MW	2.6 B€	200 ktons/year
2025	2800 MW	4.2 B€	400 ktons/year



Bankability boundary conditions:

Average electricity cost of 40-50 €/MWh or lower (baseload and incl. grid fees, taxes & levies)

Enhancing conditions for replication:

- *Access to curtailed RES at a price discount of 60% compared to the system price;*
- *Partial exemption from grid fees, taxes & levies.*
- *Recognition of green H_2 as compliance option in Fuel Quality Directive*

Policy options to realize this market potential

Business cases replicability relies on:

1 Low-cost electricity

→ **Exemption from grid fees, taxes or levies**
A (partial) exemption can be justified by the grid-beneficial mode of operation of electrolysers

→ **Avoid inflating electricity prices with costs unrelated to electricity supply**

→ **Access to curtailed electricity**
Bilateral contracts between RES operators and consumers can lead to lower electricity price

→ **Provide a clear regulatory framework on how to access curtailed RES electricity**

2 Access to grid service revenues

→ Electrolysers can provide grid frequency control when allowed for loads, with more benefits in asymmetric procurement

→ **Develop EU framework guidelines to provide a level playing field for access to grid frequency control services**

3 Recognition as green hydrogen

→ Power-to-hydrogen electrolysers can provide gas with low carbon intensity

→ **Provide a level playing field for the injection of carbon lean gas into gas grid**, be bio-methane or green hydrogen

→ **Recognize green hydrogen as compliance option to reduce carbon intensity of conventional fuels** in the forthcoming revisions of the FQD and RED II

Annex

Early business cases are found in low-cost electricity areas (≤ 40-50 €/MWh), driven by: (1) low burden of grid fees, taxes & levies (2) local price discounts

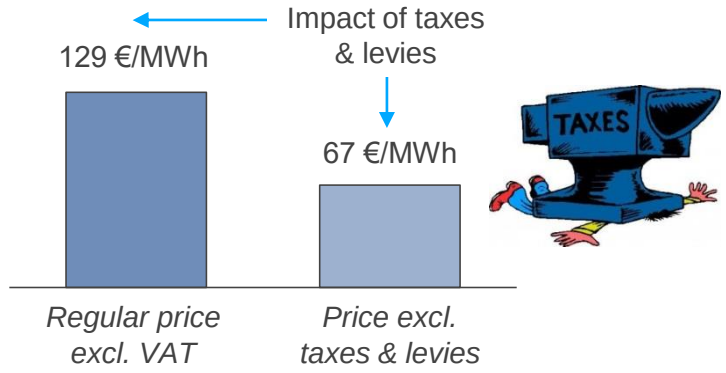
Total (baseload) electricity price ≡ Total cost of supplying electricity to the electrolyser (≠ wholesale electricity price); includes grid fees, taxes, levies and green certificates for electricity purchased from the grid

Uncontestable part of electricity bill:

- (i) grid fees
- (ii) taxes
- (iii) levies

- Driven by regulation
- (Partial) exemptions already in place in some EU member states:
  - Taxes & levies: electro-intensive consumers
  - Grid fees: storage (incl. H2) if operated in system-beneficial mode

Electricity price of industrial consumer in Germany (2016)[1]

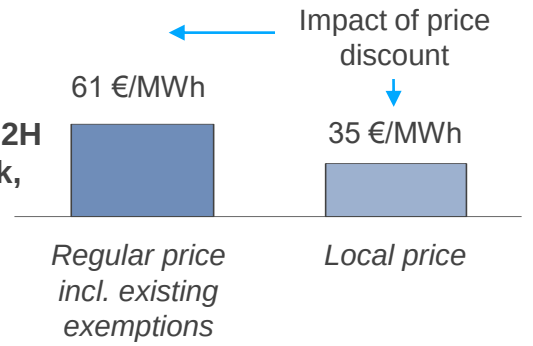


Costs related to electricity supply

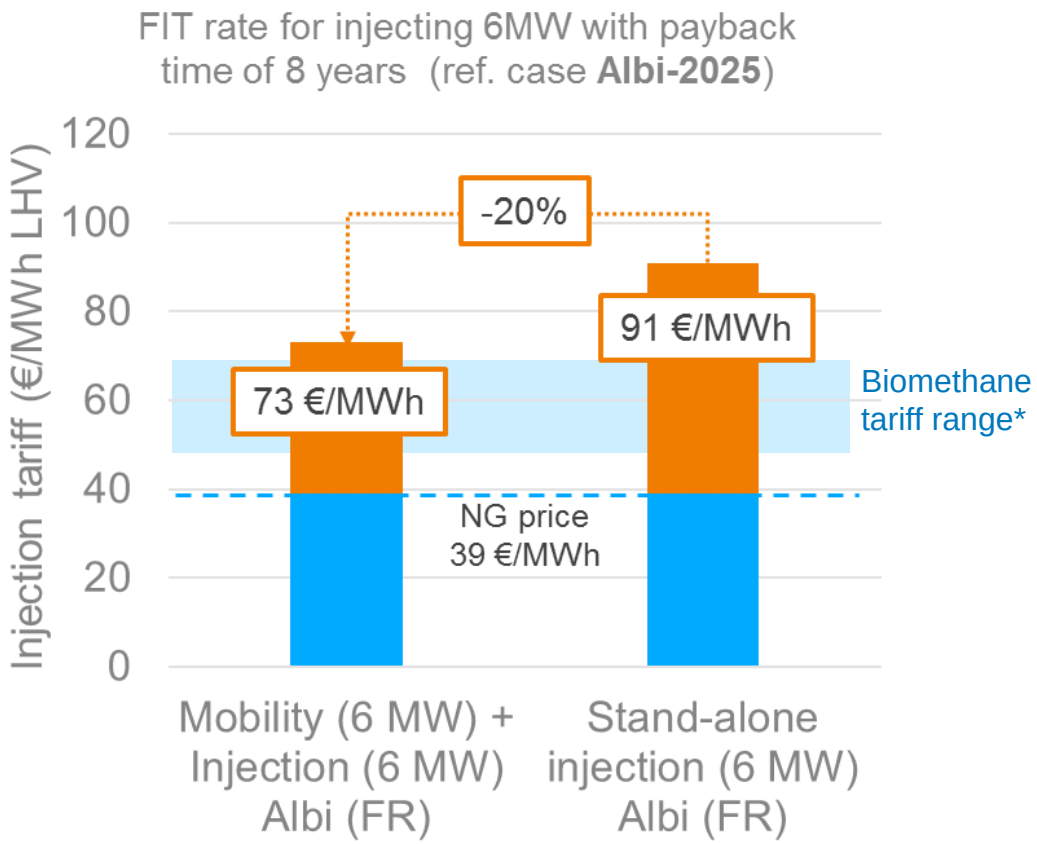
"wholesale price component"

- Driven by (national/regional) wholesale price
  → fundamental drivers such as electricity demand and gas / coal / carbon price
- Can also be driven by grid congestion triggering local price discounts
  → example: reward flexibility to avoid congestion or reduce RES curtailment

Simulated price of P2H system in Herrenwyk, Germany (2025)



Combining PtoH for mobility/industry applications and injection is more cost-effective than stand-alone injection for greening of natural gas



1

Green H_2 gas grid injection lowers the carbon footprint of natural gas and should thus be **eligible for feed-in tariffs** in line with existing supporting regimes for bio-methane.

2

Combining injection with mobility or industry reduces the level of feed-in tariff needed.
The bulk of the electrolyser CAPEX is paid by mobility or industry clients. The injection tariff only needs to cover marginal injection costs (and very limited injection-specific CAPEX).

For this reason, H_2 injection into gas grid is considered as a secondary application

Should the stand-alone injection business case have a tariff of 73 €/MWh, the payback time will more than double to > 16 years.

Deep dive on Refinery in Germany (Lübeck / Hemmingstedt)

Context, Local refinery and Scenario

Local context

- **Four local refineries** near Lübeck
  - 3 in Hamburg @ 70 km from Lübeck
  - 1 in Hemmingstedt / Heide @ 110 km from Lübeck

Local refinery

- **Heide refinery** is the one with the highest H_2 demand with 3.4 t/h (**30 000 t/year**)
- On-site SMR is considered to supply the current H_2 demand

Scenario

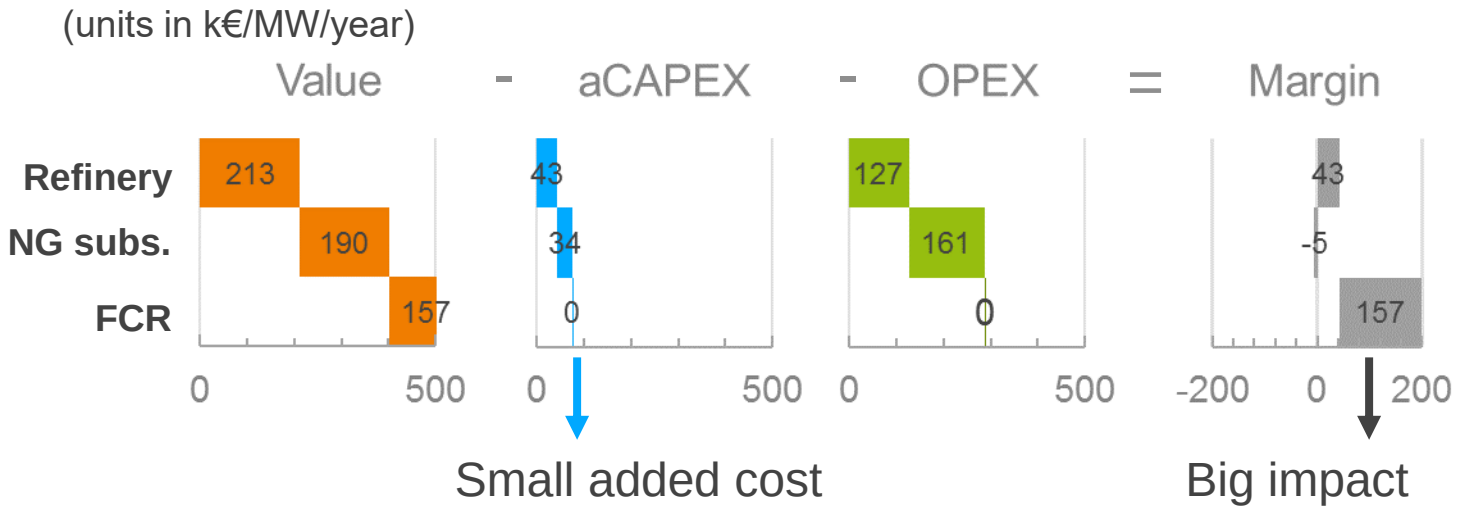
Focus in 2025 on a multi-MW electrolyser project **to supply part of increasing H_2 demand** and **to reduce carbon footprint of fuel production**. The electrolyser complements local SMR.

2017 & 2025: 3230 t/year (50% of increasing demand) → 20 MW electrolyser

The PtoH system is oversized by 200% to compete against the SMR production

PtoH can compete with H_2 production from SMR at big volume

Main parameters	2025
Grid fees, taxes, levies and Guarantee of origin (DE)	1.7 €/MWh (EnWG §118)
Grid service value	19 €/(MW.h) (FCR)
Carbon penalty	80 €/tCO_2 [1]
Value H_2 from SMR incl. carbon penalty	2.6 €/kg (prim.) 2.4 €/kg (NG subs.)
Primary market size	3 230 t/year → 20 MW
Unit sizing	200% w/ NG sub.
Technology	PEM
Op. time and total elec. price (prim.)	48% @ 26 €/MWh
Op. time and total elec. price (NG Sub.)	47% @ 34 €/MWh
H2 production cost	2.3 €/kg
Payback time	3.5 years



NG substitution allows valorisation of remaining electrolyser capacity by bringing additional revenues from electrical grid services.

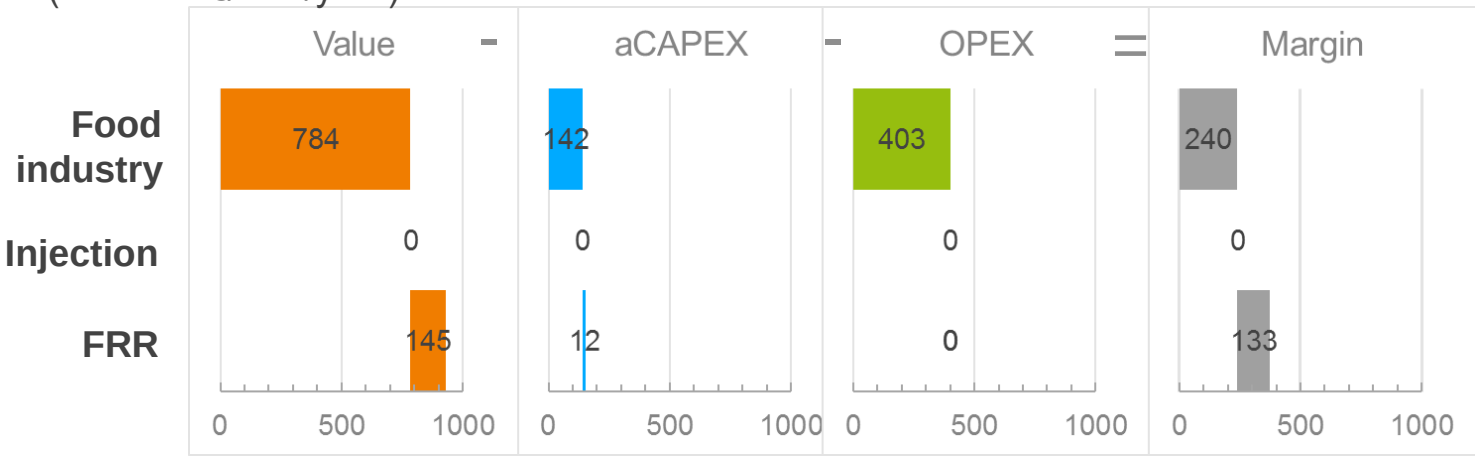
PtoH production cost can be competitive against SMR. **Payback time with grid services is 3.5 years**.

Food industry business case profitability

Main parameters	2017
Grid fees, taxes, levies and Guarantee of origin (DK)	11 €/MWh
Grid service value	17 €/(MW.h) (FRR)
H_2 market price	5 €/kg

Primary market size	900 t/year → 6 MW
Unit sizing	100% w/o Injection
Technology	ALK
Op. time and total elec. price (prim.)	95% @ 38 €/MWh
H2 production cost	3.5 €/kg
Payback time	3.4 years

(units in k€/MW/year)



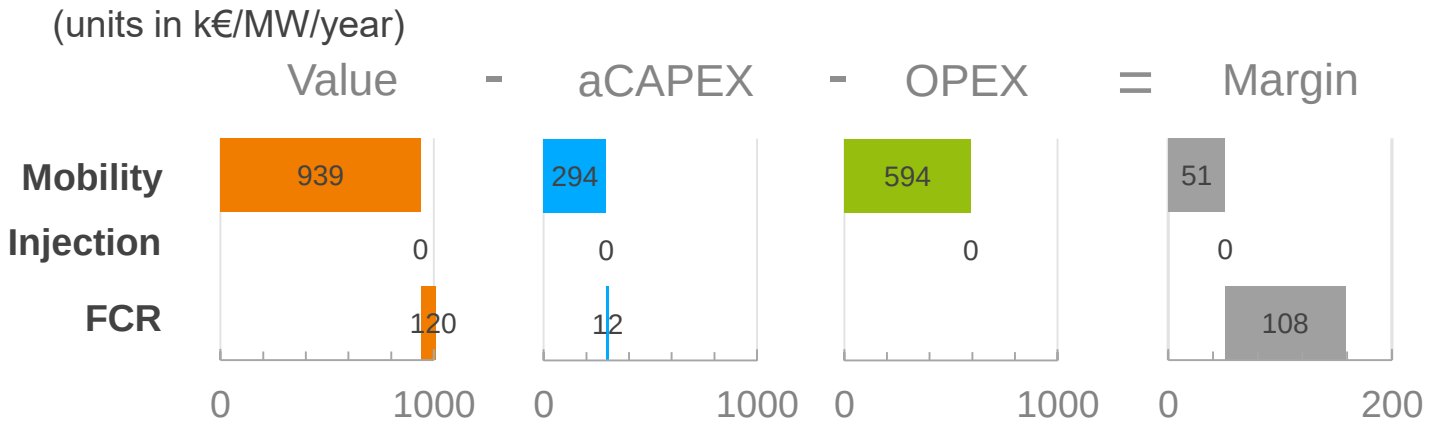
Light/food industry as a primary application for PtoH is **already a profitable and existing market**.
However, PtoH can benefit from providing grid services to generate additional revenues which can **boost the net margin by 39% at little additional investment.**

Asymetric grid services benefit to ALK electrolyser by taking advantage of their cheaper cost.

Semi-centralised production for mobility business case profitability

Main parameters	2017
Grid fees, taxes, levies and Guarantee of origin (FR)	13 €/MWh (incl. partial exemption because of electro-intensive status)
Grid service value	18 €/(MW.h) (FCR)
HRS distance	20 km one-way
H_2 market price	7 €/kg

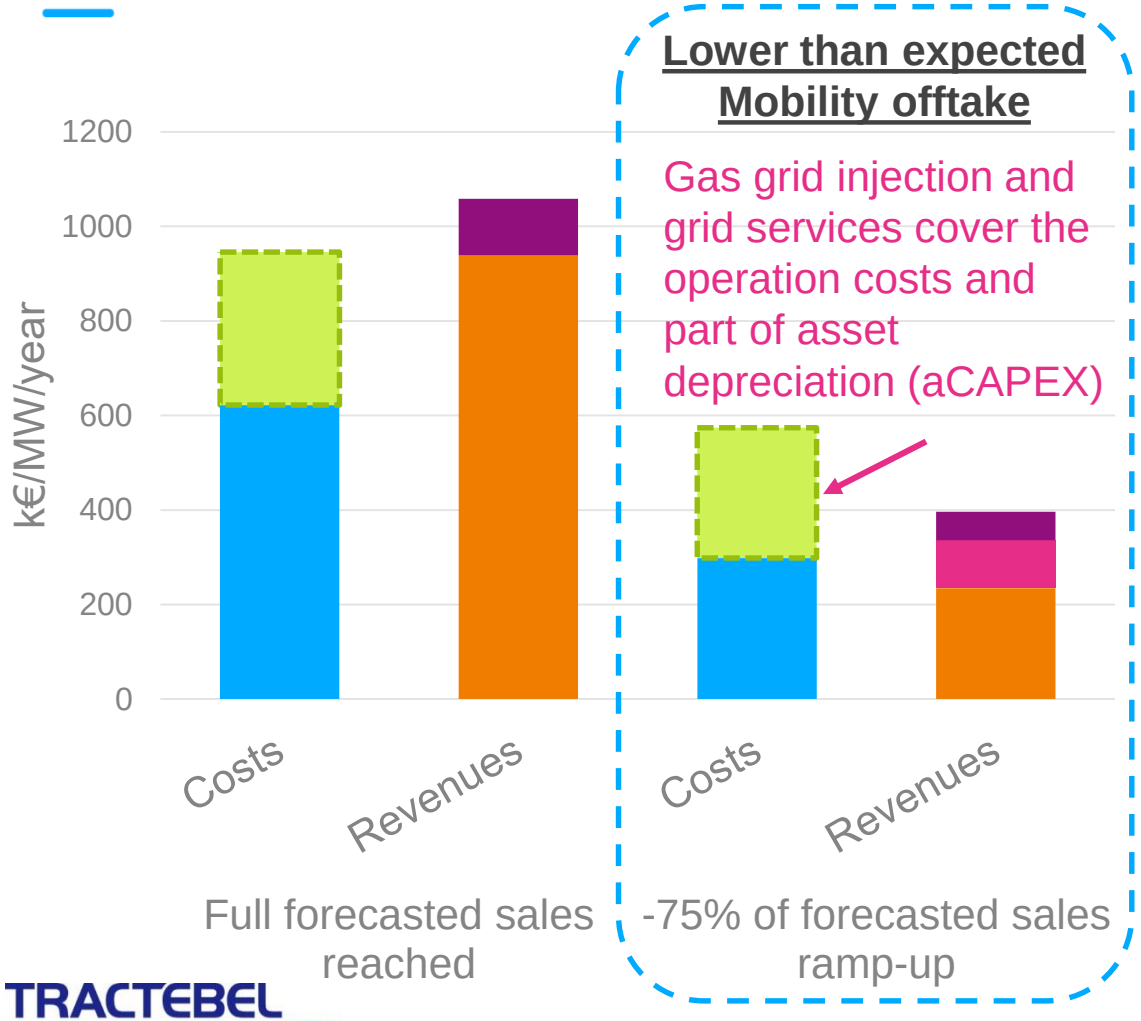
Primary market size	270 t/year → 2 MW
Unit sizing	100% w/o injection
Technology	PEM
Op. time and total elec. price (prim.)	95% @ 44 €/MWh
H2 production cost	6.7 €/kg
Payback time	8 years



Mobility as a primary application for PtoH can be **profitable today at large volume**.

Provision of grid services can **boost significantly the net margin by 75% at little additional investment.** This will accelerate the **payback time from 11 to 8 years.**

Gas grid injection is a short-to-mid-term risk mitigation instrument through the valley of death for mobility market



Gas grid injection is an enabler of Power-to-Hydrogen for mobility applications

- Gas grid injection is a **complementary application** that can **increase the revenues** of an electrolyser used for mobility or industry.
- Gas grid injection **helps mitigate the risk of lower-than-expected mobility demand** ("valley of death") **covering the operation costs and part of asset depreciation towards break-even.**

aCAPEX
OPEX
Grid services
Injection
Primary

Mobility business case
Forecasted demand: 270 t H_2/year
2 MW PEM in FR (Albi) 2017
Injection tariff @ 90€/MWh LHV