A biomethane plant and green hydrogen

Greening Energy Market and Finance

Case study presentation, track 1

612408 – EPP-1-2019-1-EPPKA2-KA

Project website: http://grenfin.eu

Bertinoro, 23/06/2022

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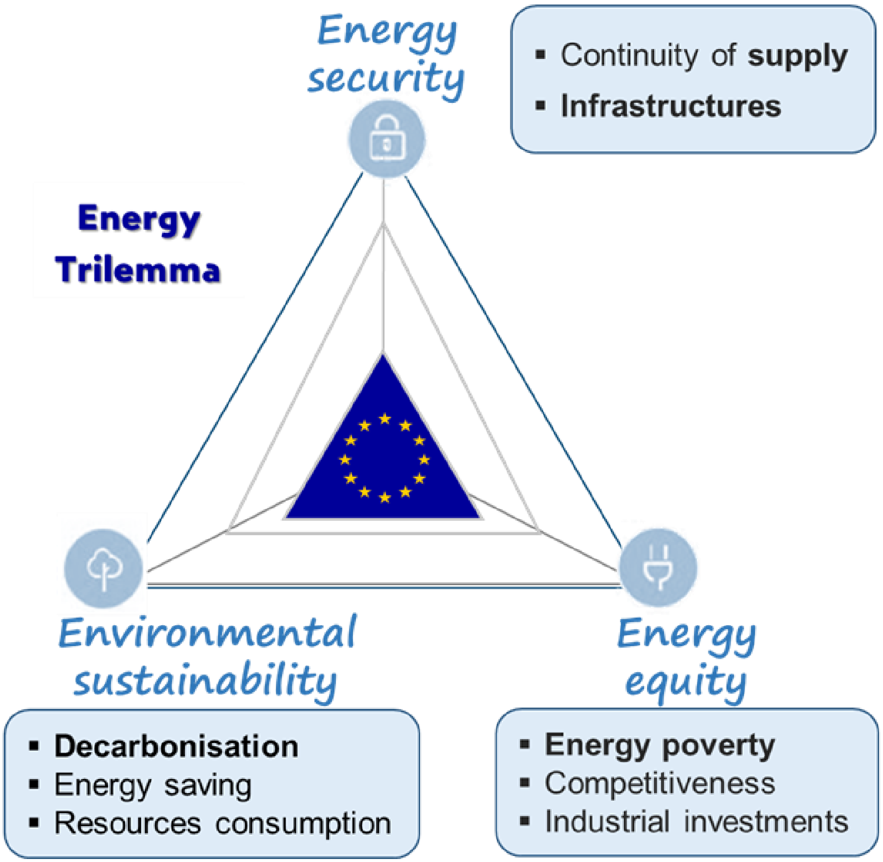
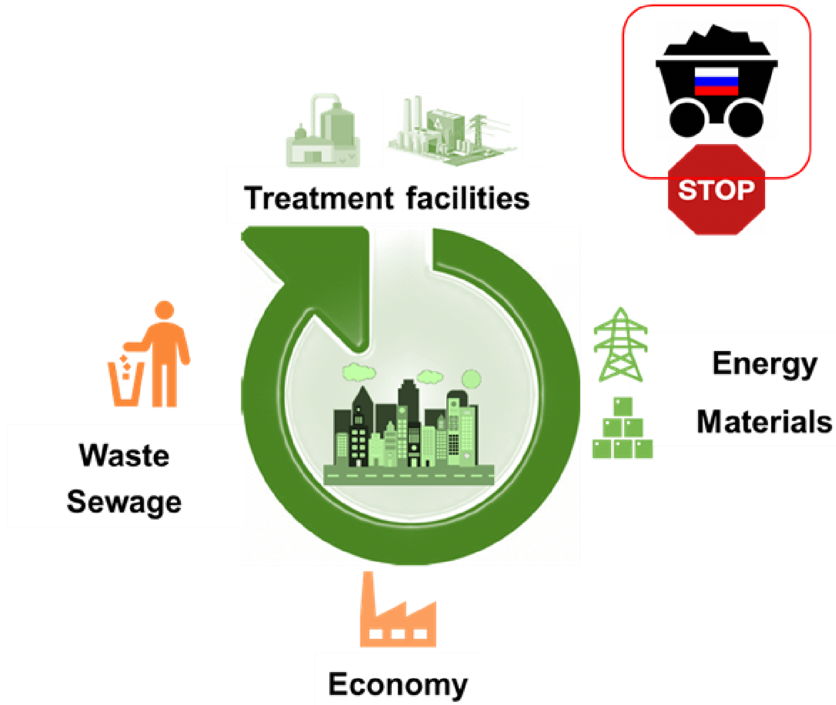
Two goals towards transition: decarbonisation and security



- Replacing Russian fossil fuels requires to use every sort of domestic **source of energy**
- Circular economy enables efficient use of resources and **reduces need of fossil fuel** for energy sector



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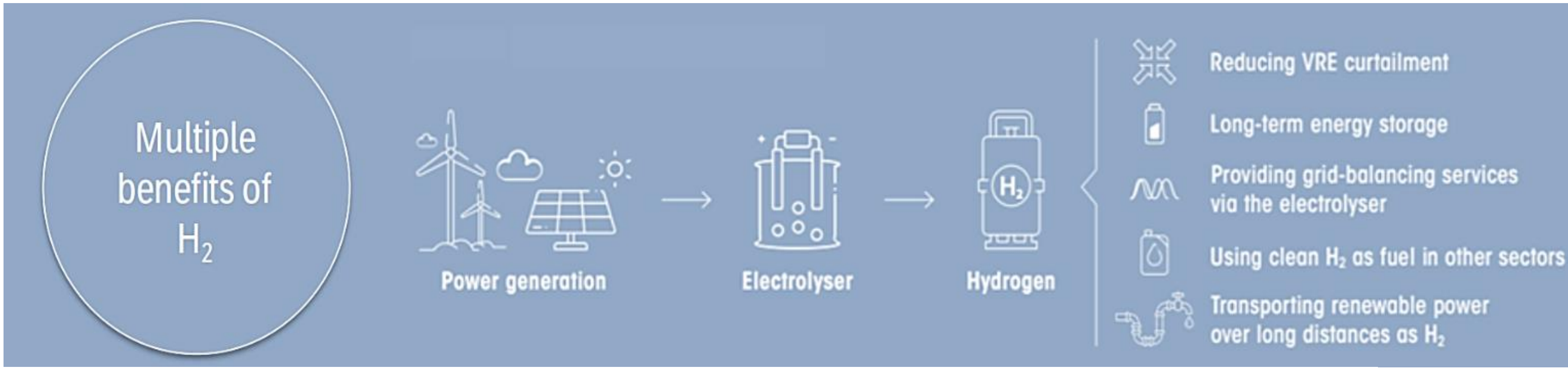
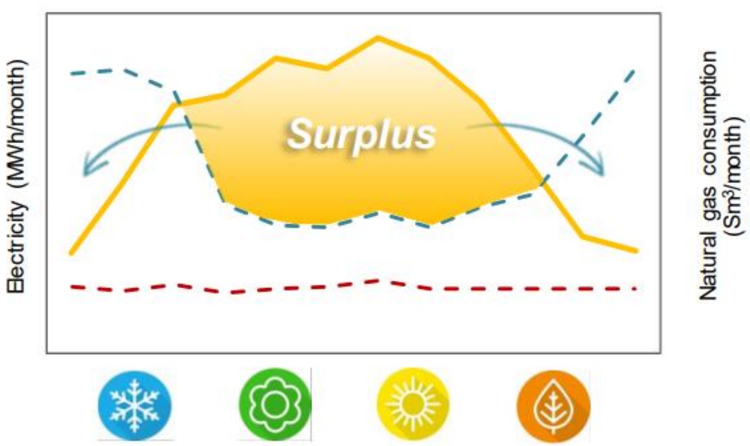
Why hydrogen?





Electrical energy production (photovoltaic)
Electrical energy consumption
Natural gas consumption

- **Storage:** Hydrogen can be used as a storage to correct the discontinuous behaviour of renewable energy sources like solar and wind
- **Decarbonization of hard-to-abate sectors:** Hydrogen can be used as a feedstock and fuel in hard-to-abate sectors like gas-intensive industry or heavy transports

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Overview of methods for hydrogen production – SMR

There are several ways to produce hydrogen. We are going to discuss some of them

One of them is labeled as the “**grey**” one: SMR, Steam reforming of natural (fossil) gas

- Steam is used to separate molecules of methane, under particular pressure and temperature conditions
- Outputs of the process are hydrogen (H_2) and carbon dioxide (CO_2).

When CO_2 is captured directly at the end of the process e.g., by CCS, SMR is labelled as “**blue**”

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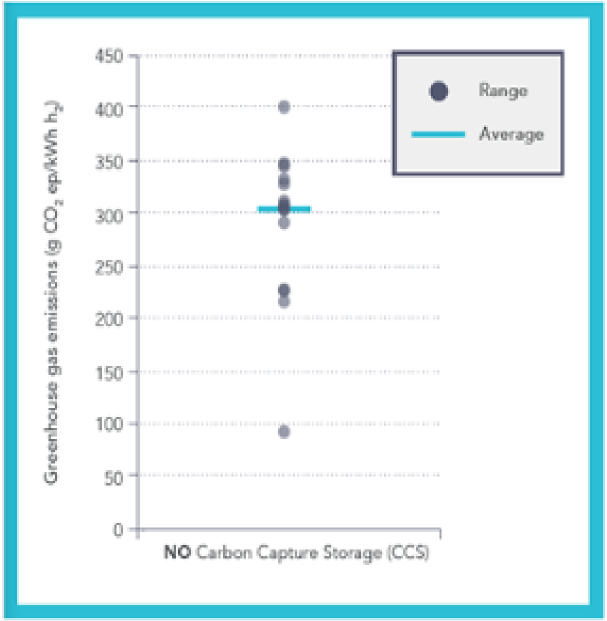
Carbon footprint – Grey hydrogen emissions

Without CCS:

- Range of 288-347 g CO_2 eq/kWh

value		source / notes
288 - 347	range of g CO2eq / kWh H2	"A greener gas grid: what are the options?" - Sustainable gas institute, Imperial college London, July 2017
288	lower g CO2eq / kWh H2	
318	**average g CO2eq / kWh H2**	
347	upper g CO2eq / kWh H2	
0,29	lower kg CO2eq / kWh H2	
0,32	**average kg CO2eq / kWh H2**	
0,35	upper kg CO2eq / kWh H2	
39,37	Higher heating value H2, kWh / kg	(assumption)
8,50	lower kg CO2eq / kg H2	
9,37	**average kg CO2eq / kg H2**	i.e. 60% of impacts (assumption)
10,25	upper kg CO2eq / kg H2	
15,62	**average kg CO2eq / kg H2**	100% of impacts
2,34	**kg CO2eq / kg H2**	A greener gas grid: what are the options?
17,97	**kg CO2eq / kg H2**	



➢ 17,97 kg CO_2 eq/kg H_2 total emissions (direct + upstream)

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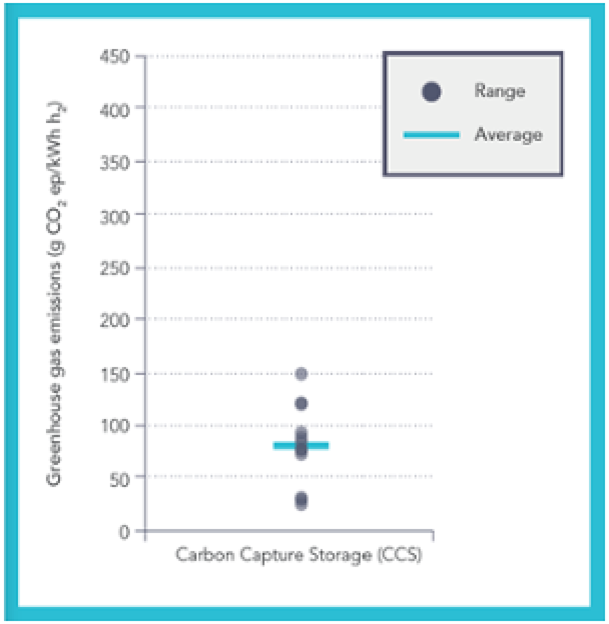
Carbon footprint – Blue hydrogen emissions

With CCS:

- Range of 23-150 g CO_2 eq/kWh

value		source / notes
23 - 150	range of g CO2eq / kWh H2	"A greener gas grid: what are the options?" - Sustainable gas institute, Imperial college London, July 2017
23	lower g CO2eq / kWh H2	
87	**average g CO2eq / kWh H2**	
150	upper g CO2eq / kWh H2	
0,02	lower kg CO2eq / kWh H2	
0,09	**average kg CO2eq / kWh H2**	
0,15	upper kg CO2eq / kWh H2	
39,37	Higher heating value H2, kWh / kg	(assumption)
0,45	lower kg CO2eq / kg H2	
1,70	**average kg CO2eq / kg H2**	
2,95	upper kg CO2eq / kg H2	
7,95	**average kg CO2eq / kg H2**	Assuming all ancillary services still have the same impacts
0,68	**kg CO2eq / kg H2**	
8,63	**kg CO2eq / kg H2**	



➢ 8,63 kg CO_2 eq/kg H_2 total emissions (direct + upstream)

Overview of methods for hydrogen production – a "green" version of SMR

By steam reforming of **biomethane**, use of fossil gas thus climate-altering emissions can be avoided. In this case study, biomethane is self-produced in a waste treatment plant (HERAmbiente)

- The plant facility receives organic, agricultural, or agro-industrial waste, so-called "biomass"
- Biomass is digested by bacteria, producing biogas (anaerobic phase)
- Biogas is treated and upgraded, producing so-called biomethane
- The biomethane is then used to produce hydrogen: **the emitted CO_2 is not climate-altering** as it is part of the natural carbon cycle and is re-absorbed through the photosynthesis of biomass

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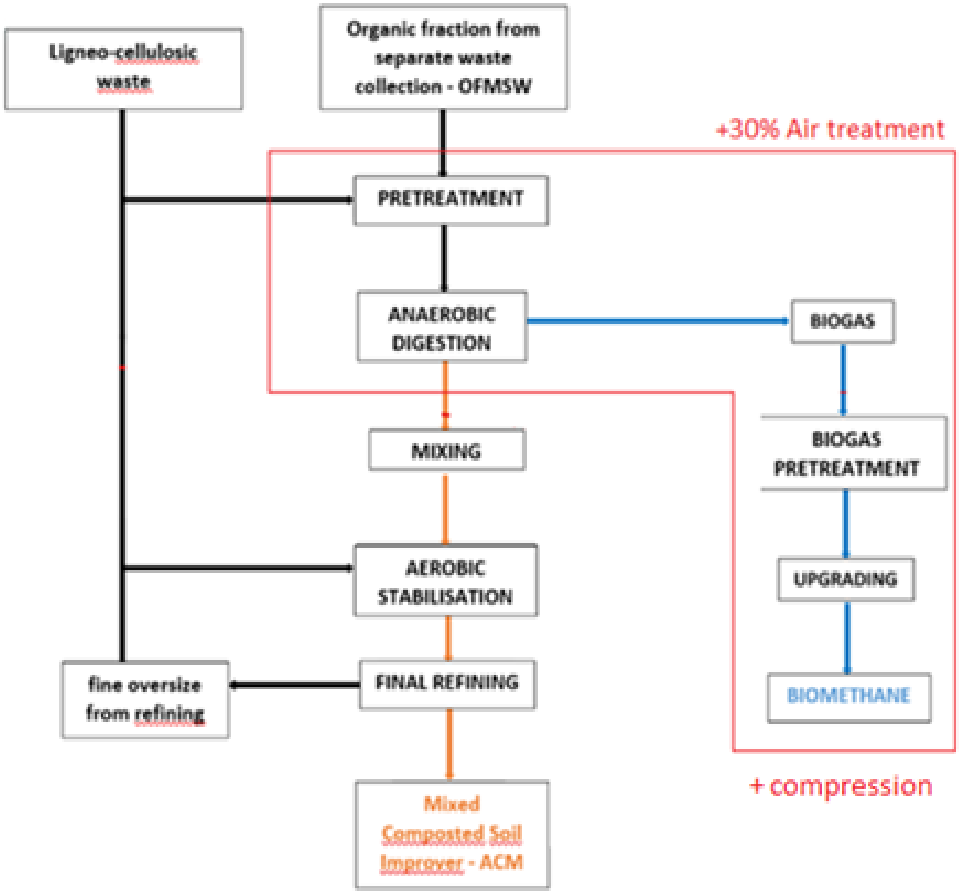
Hydrogen production: "Green" hydrogen from biomethane

No climate-altering direct emissions thanks to use of biogenic source (organic waste → biomethane)

Assumptions for **upstream emissions**:

- activities boundary - see right
- 30% of air treatment processes linked to biomethane production
- not including:
  - I/O transport of waste
  - disposal activities of liquids deriving from pretreatment of waste
  - consumption of sodium hydroxide in biogas pre-treatment



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Hydrogen production: "Green" hydrogen from biomethane

Process	Activity	value		source / notes
Pre-treatment	Power consumption	90.000	kWh/m	
		1.080.000	kWh/a	
		268,6	g CO_2e/ kWh	ISPRA 2021 - Emissions from power consumption (national mix 2019)
		87,4	g CO_2e/ kWh	DEFRA UK 2021 - WTT electricity generation, data for Italy
		24,2	g CO_2e/ kWh	DEFRA UK 2021 - WTT electricity T&D, data for Italy
		410.622	**kg CO_2e / a**	
	Water supply	85	m^3 / m	
		1.020	m^3 / a	
		0,149	kg CO_2e / m^3	DEFRA UK 2021 - Water supply
		152	**kg CO_2e / a**	
Emissions from pre-treatment:		**410.774**	**kg CO_2e / a**	
Emissions from anaerobic digestion:		**859.112**	**kg CO_2e / a**	
Emissions from biogas pretreatment and upgrading:		**1.369.186**	**kg CO_2e / a**	
Emissions from air treatment:		**205.794**	**kg CO_2e / a**	
Emissions from air treatment:		**364.997**	**kg CO_2e / a**	
Total emissions from biomethane production:		**3.209.863**	**kg CO_2e / a**	assuming average electricity mix
Total emissions from biomethane production:		**623.439**	**kg CO_2e / a**	assuming only renewable power supply. Still accounting for T&D losses

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Carbon footprint – “Green” hydrogen from biomethane emissions

Biomethane production: 7,500,000 Sm^3 = 1,549,171 kg H_2

upstream emissions from biomethane generation	3.209.863	kg CO_2e / 7.5 mln CH_4 Sm^3
Total life-cycle emissions from SMR "green" - energy mix	**2,07**	**kg CO_2e / H_2 kg**

upstream emissions from biomethane generation	623.439	kg CO_2e / 7.5 mln CH_4 Sm^3
Total life-cycle emissions from SMR "green" - renewables	**0,40**	**kg CO_2e / H_2 kg**

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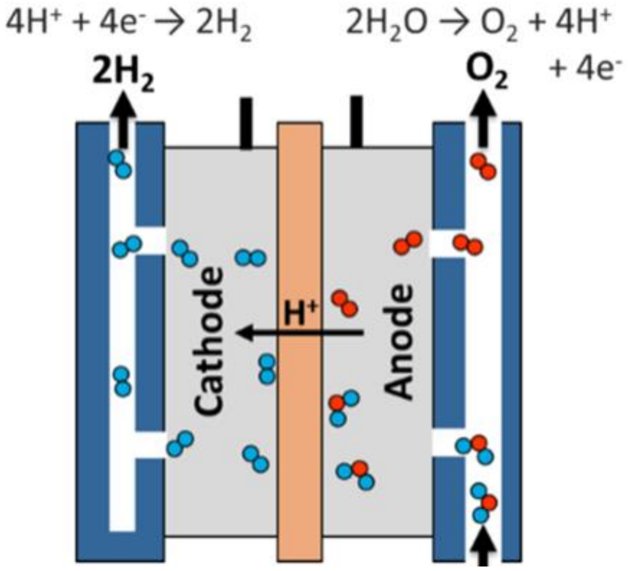
Overview of methods for hydrogen production – Electrolysis

An alternative way to produce **green** hydrogen is by using renewable-powered electrolysis. Most of the growth in low-carbon hydrogen production is expected to come from this method

- Based on water molecules separation
- Uses renewable power
- The water's hydrogen and oxygen atoms are separated, thus **without emitting CO_2**



Hydrogen production: green hydrogen from electrolysis

- Principle of additionality: a key requirement for the renewable-based electricity to be used by electrolysis to produce green hydrogen.

- In our model we assume that **a new renewable PV solar plant has to be installed** to generate green power, so avoiding supply from the grid that would the reduce renewable energy amount in the mix.

- As a result, all the emissions from this process are "upstream" emission. Nearly 100% derives from the PV plant and a very low percentage attributed to water supply.

Carbon footprint – Green hydrogen emissions

Upstream emissions from water supply	
9	kg H20 / kg H2
1000	kg / m3 H20
0.01	m3 H20 / kg H2
0.149	kg CO2e / m3 H2O
0.0013	**kg CO2eq / kg H2**

DEFRA UK 2021 – Water supply

Upstream emissions from solar PV generation	
0.12	kg CO2eq / kWh H2
39.37	Higher heating value H2, kWh / kg
4.72	**kg CO2eq / kg H2**

Conversion factor (from kWh to kg)

Upstream emissions from the production of the electrolyser were excluded from the model

4.73	**Total life-cycle emissions from green electrolysis** (kg CO2e / H2 kg)

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Climate impacts comparison and analysis

Process	Direct emissions, kg CO_2e / kg H_2	Upstream emissions, kg CO_2e / kg H_2	Total life-cycle emissions, kg CO_2e / kg H_2	
SMR - Grey (No CCS)	15,6	2,3	**18,0**	*
SMR - Blue (CCS)	8,0	0,7	**8,6**	*
Electrolysis	0,0	4,7	**4,7**	**
SMR - Green - avg. IT mix	0,0	2,1	**2,1**	
SMR - Green - 100% RES	0,0	0,4	**0,4**	

Process	Compared to grey SMR (no CCS)	Compared to green electrolysis	Only using renewable power
SMR - Grey - No CCS			
SMR - Blue (CCS)	-52%		
Electrolysis	-74%		
SMR - Green - avg. IT mix	-88%	-56%	
SMR - Green - 100% RES	-98%	-91%	-81%

*Could be lowered by consuming only renewable power

**Not including upstream emissions from electrolyser construction

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From Biomethane to Hydrogen: framework

- **Realization of a plant** suitable to treat the 100% of the biomethane produced at the plant in Sant'Agata Bolognese in Emilia-Romagna, Italy

- **Two methods compared:** SMR made from biomethane and electrolysis
- **Static timeframe:** prices and production volumes do not change over time
  - ➔ Revenues & other economical data are linear
- **Assumptions** linked to the plant: 15 years of use, cost, prices, taxes

Assumptions		
biomethane cost	€/Nm3	0,8
biomethane input to steam reforming	Nm3 CH4 / Nm3 H2	0,46
hydrogen selling price - baseline value	€/kg	2,5
depreciation years	year	15
taxes	%	27,9%
USD/€ exchange rate	€/USD	0,95

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Sources : Investopedia

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Biomethane to Hydrogen: OpEx & CapEx and incentive

- **Capital expenditures**: funds used by a company to acquire, upgrade, and maintain physical assets such as property, plants, buildings, technology, or equipment
- **Operating expense**: business expense occurring through normal business operations. Include rent, equipment, inventory costs, marketing, payroll, insurance, step costs, and funds allocated for research and development.

- Definition of an **incentive** to produce green hydrogen necessary to ensure an IRR (internal rate of return) of the initiative exceeding 8%
  → Green boxes are not assumptions, but are adaptable to both methods

hydrogen selling price – baseline value	€/kg	2,5
hydrogen selling price – incentive	€/kg	?
hydrogen selling price – total	€/kg	?

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Biomethane to Hydrogen: Incentive Price

- Computation of incentive price such that operating company makes a profit
- Internal Rate of Return (IRR) used in financial analysis to estimate the profitability of potential investments
- It corresponds to the discount rate that sets the net present value to zero
- Task: IRR should be 8%
- IRR can be understood as the rate of growth that an investment is expected to generate annually

$$0 = \text{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0$$

where:

C_t = Net cash inflow during the period t

C_0 = Total initial investment costs

- Total investment cost = CapEx
- Net cash inflows: Ebitda – Taxes = Free Cash Flow

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Biomethane to Hydrogen: Incentive Price

Goal: find the hydrogen selling price of the plant which makes us generate enough revenue such that our Free Cash Flow indicates an internal rate of return of 8% for a timeframe of 15 years.

Capital and Operating Expenditures:

- CapEx: $910/kW (with plant size of 6,205 kW): € 5,364k
- OpEx: € 6,581k
  - variable costs for biomethane: € 6,329k
  - fixed and variable costs for the plant: € 252k

Revenues:

- hydrogen produced times final selling price (unknown)

biomethane input to steam reforming	0,46
biomethane produced (Nm3/year)	7 912k
hydrogen produced (Nm3/year)	17 199k
Hydrogen produced (kg/year)	1 549k

Biomethane to Hydrogen: Incentive Price

Solution: We have only one unknown variable in our model: the selling price.

- We can use a solver in order to calculate it
- The final selling price is € 4.72
- The incentive part of the price is € 2.22

Years of operation	0	1	2	...
Hydrogen produced (kg/year)		1 549k	1 549k	...
TOTAL Opex + Capex (€/year)	5 364k €	6 581k €	6 581k €	...
TOTAL Revenues (€/year)		7 312k €	7 312k €	...
Ebitda		731k €	731k €	...
Depreciation		358k €	358k €	...
Ebit		373k €	373k €	...
Taxes		104k €	104k €	...
FCF	-5 364k €	627k €	627k €	...

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Hydrogen production through electrolysis

Electricity cost	€/MWh	75
Hydrogen selling price – baseline value	€/kg	2,5
Hydrogen selling price – incentive	€/kg	**3.35**
Total hydrogen selling price	€/kg	**5.85**
Depreciation years	year	15
Taxes	%	27.9%
USD/€ exchange rate	€/USD	0.95

Efficiency	0,64
Load h/y	3,500

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Economic costs of electrolysis

*Starting from year 0

- **Capital expenditures** = $872 x size of the plant (23,051 kW) x exchange rate
- **Capital expenditures** = 19,095,310 €

*Starting from year 1

- **Operating expenses (electricity)** = Size of plant x cost of electricity x Annual number of operating hours / 1000
- **Operating expenses (electricity)** = 6,050,844 €

- **Operating expenses (other)** = 420,097 €

Years of operation	0	1	2 …	… 14	15
TOTAL Opex+Capex (k€/year)	**19,095 k€**	**6,471 k€**	**6,471 k€**	**6,471 k€**	**6,471 k€**

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Revenues

Years of operation	1	2 …	… 14	15
Hydrogen Sales	1,549 t * 5.85 **9,067 k€**	**9,067 k€**	**9,067 k€**	**9,067 k€**

Years of operation	0	1	2 …	… 15
Ebitda		2,596 k€	2,596 k€	2,596 k€
Depreciation		1,273 k€	1,273 k€	1,273 k€
Ebit		1,323 k€	1,323 k€	1,323 k€
Taxes		369 k€	369 k€	369 k€
FCF	– 19,095 k€	2,227 k€	2,227 k€	2,227 k€

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Incentive comparison in IRR value

Method of production \ Incentive	2,22 € / kg	3,35 € / kg	Total life-cycle emissions, kg CO2e / kg H2
SMR with Biomethane	8%	34,9%	2,07
Electrolysis	-4,8%	8%	4,73

In our framework, SMR made from **biomethane needs an incentive of 2,22€/kg** in order to reach a IRR of 8%. It is **3,35% for electrolysis**

➔ **Use of SMR made from biomethane in the plant** would be more profitable; less costly, requiring a smaller incentive and less life-cycle emissions

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