

The role of HY/BECC/US in industrial decarbonization: application to refining and biomethanol production in Spain

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Short CV of José Ignacio Linares



- Mechanical Engineering
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RESEARCH LINES

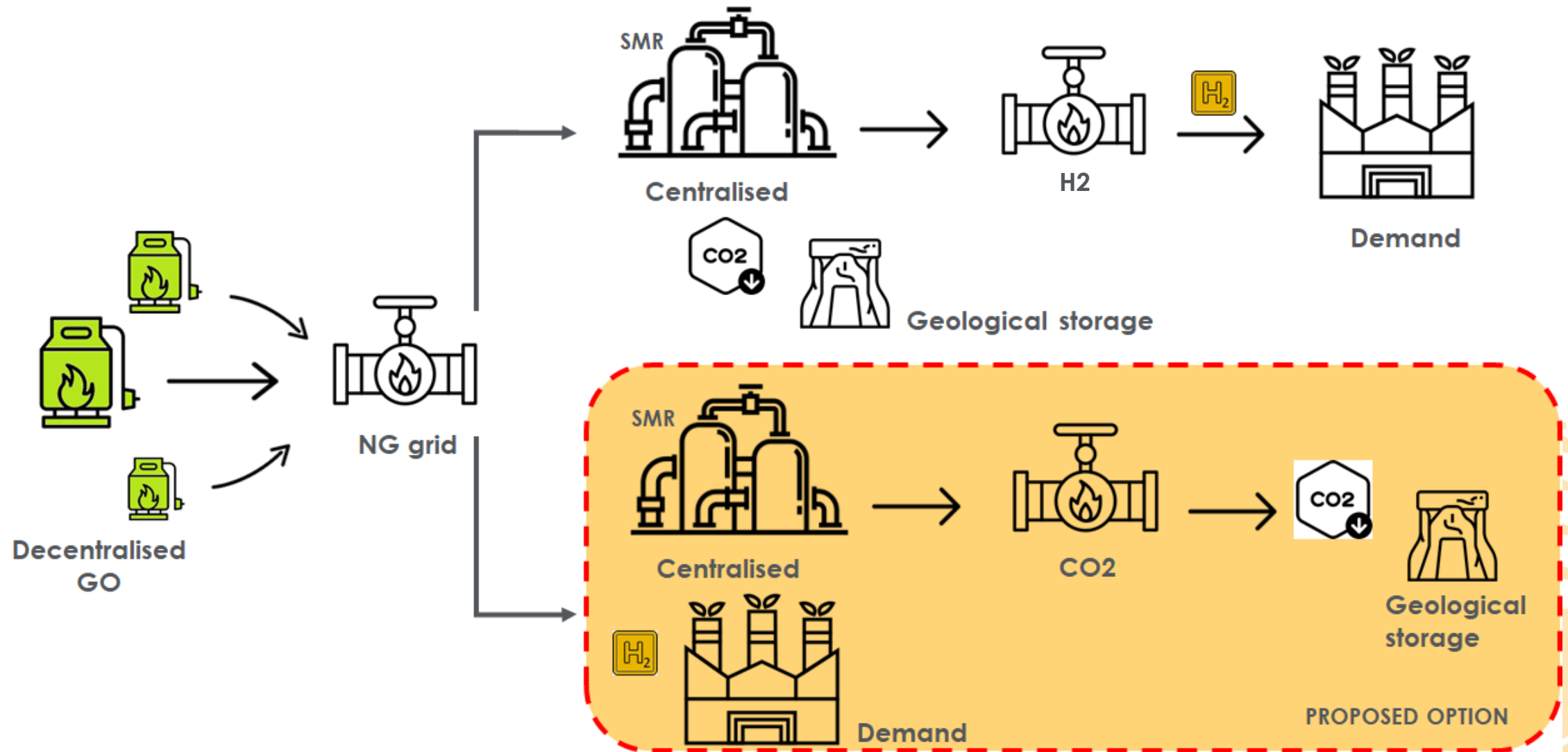
- Renewable gases, especially biohydrogen derived from biomethane
- Advanced power/reverse cycles (Brayton with supercritical CO₂, ORC, Brayton with helium)
- Energy storage in Carnot Batteries (TI-PTES)



GENERAL CONCEPTS



BIOHYDROGEN BY STEAM METHANE REFORMING (SMR) FROM BIOMETHANE

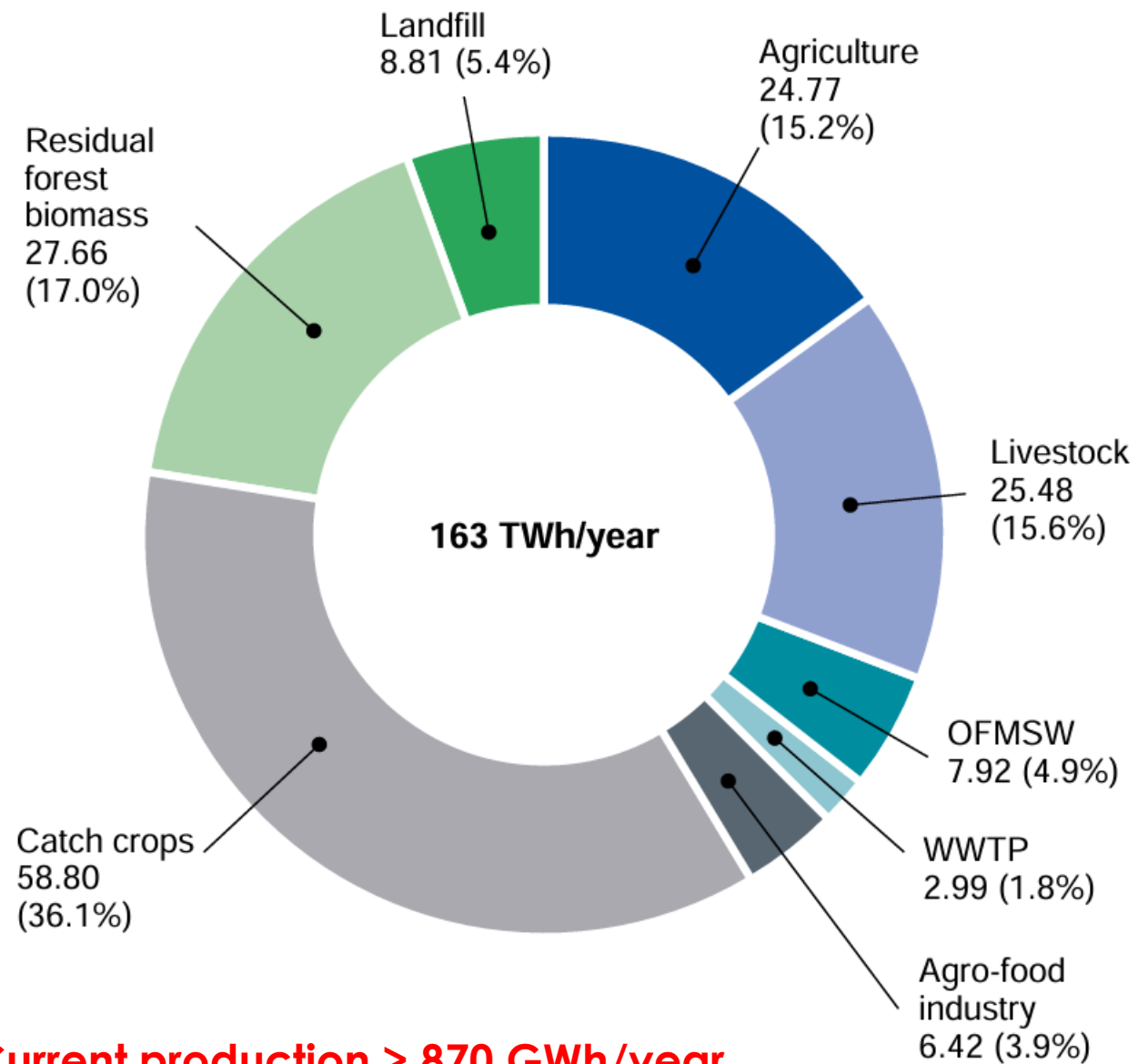


BIOMETHANE PRODUCTION

- Biogas comes from anaerobic digestion of organic waste
- Organic waste includes:
 - Organic fraction of municipal solid waste (OFMSW)
 - Landfill gas
 - Waste water treatment plant sludge
 - Intermediate crops
 - Agro/food industries
 - Forest industries
 - Manure
- Impurities are removed from biogas, producing clean biogas ($\text{CH}_4 + \text{CO}_2$)
- Upgrading removes CO_2 from biogas, producing biomethane, able to be injected in the natural gas grid and commercialized with guarantees of origin



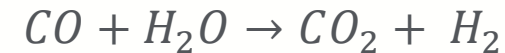
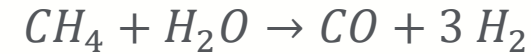
BIOMETHANE POTENTIAL IN SPAIN



Current production > 870 GWh/year

SMR EFFICIENCY

- Reforming
- Water gas shift
- Combustion (heat for reforming)

ACTUAL DATA
w/o CCS

- $\alpha = 0.5873$
- Emissions: 8.73 kg CO₂ / kg H₂
- Efficiency (LHV) = 75.9 %
- Production = **20.36 t H₂/GWh-HHV CH₄**

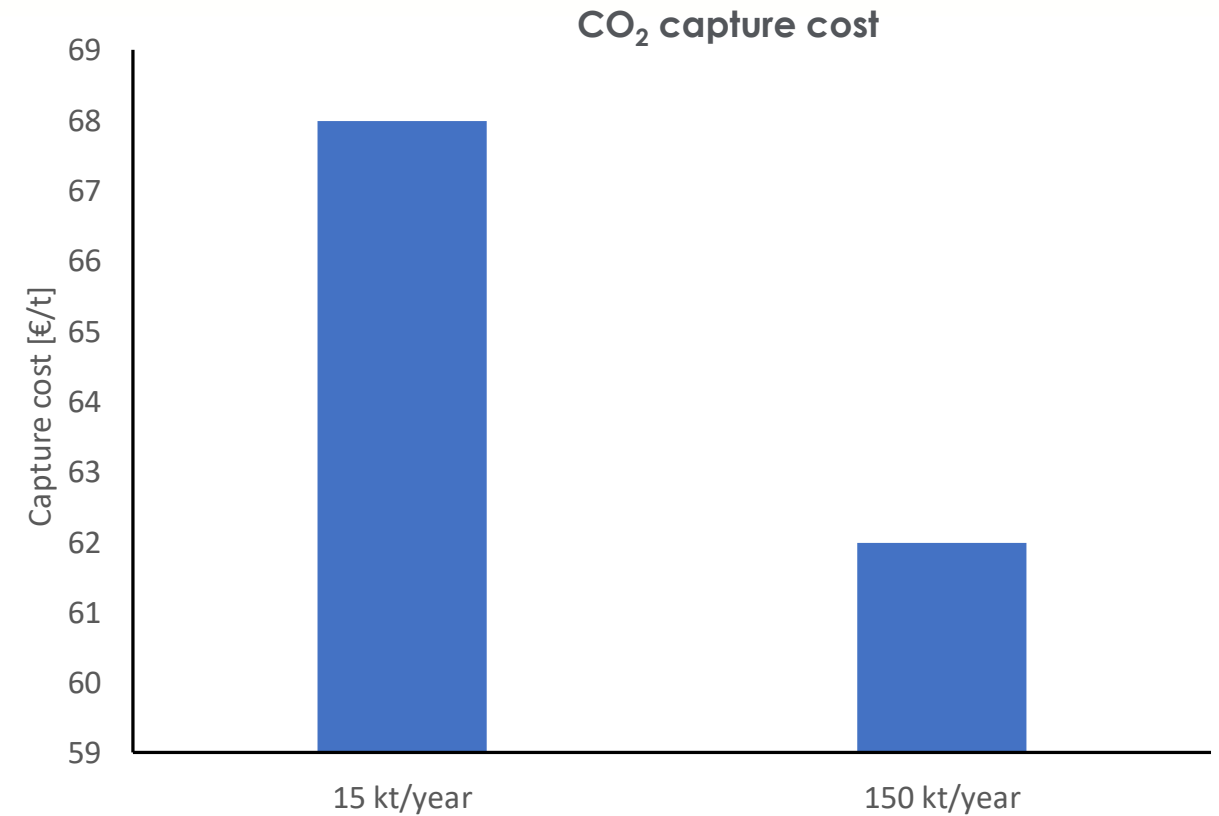
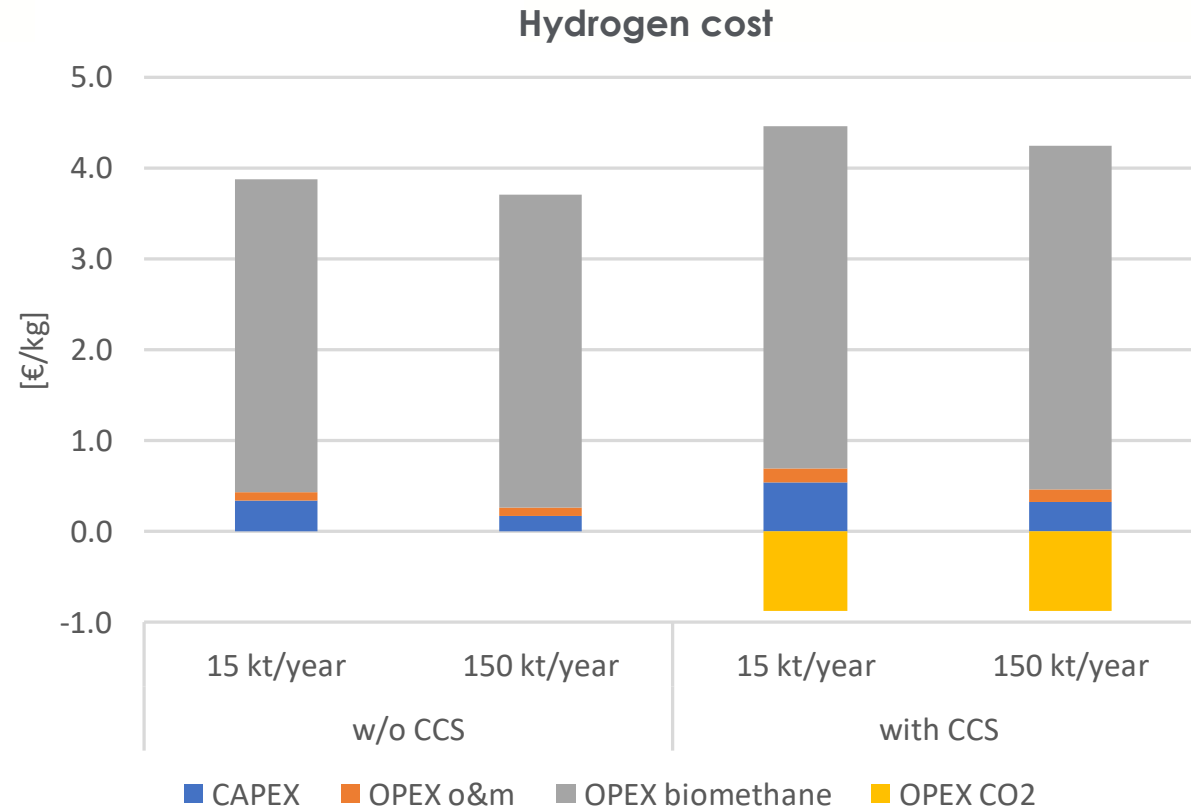
ACTUAL DATA
with CCS

- $\alpha = 0.7467$
- Emissions: 0.96 kg CO₂/kg H₂
- Efficiency (LHV) = 69.1 %
- Production = **18.54 t H₂/GWh-HHV CH₄**

COST MODEL

	w/o CCS	with CCS
INVESTMENT	$INV[€] = 56,884 \cdot \{P[t/year]\}^{0.713}$	$INV[€] = 56,884 \cdot \left\{P \left[\frac{t}{year} \right] \right\}^{0.713} + 8,347 \cdot \{P[t/year]\}^{0.8592}$
O&M	0.096 €/kg	0.148 €/kg
BIOMETHANE	$\frac{T_{biomet hane} [€/MWh - HHV]}{20.36 kg/MWh - HHV}$	$\frac{T_{biomet hane} [€/MWh - HHV]}{18.54 kg/MWh - HHV}$
CO ₂ tax	0	$- T_{CO_2} \left[\frac{€}{t CO_2} \right] \cdot 0.00864 \left[\frac{t CO_2}{kg H_2} \right]$

COST MODEL



- Biomethane: 70 €/MWh
- CO₂ tax: 80 €/t
- Life span: 25 years
- Capacity factor: 8760 h/year

- wacc: 8%
- CO₂ nominal rate: 3,5%
- Biomethane nominal rate: 0%
- O&M nominal rate: 0%

APPLICATION TO REFINING AND CHEMICAL INDUSTRY IN SPAIN

GREY HYDROGEN PRODUCTION IN SPAIN



HYDROGEN PRODUCED BY SMR OF NATURAL GAS

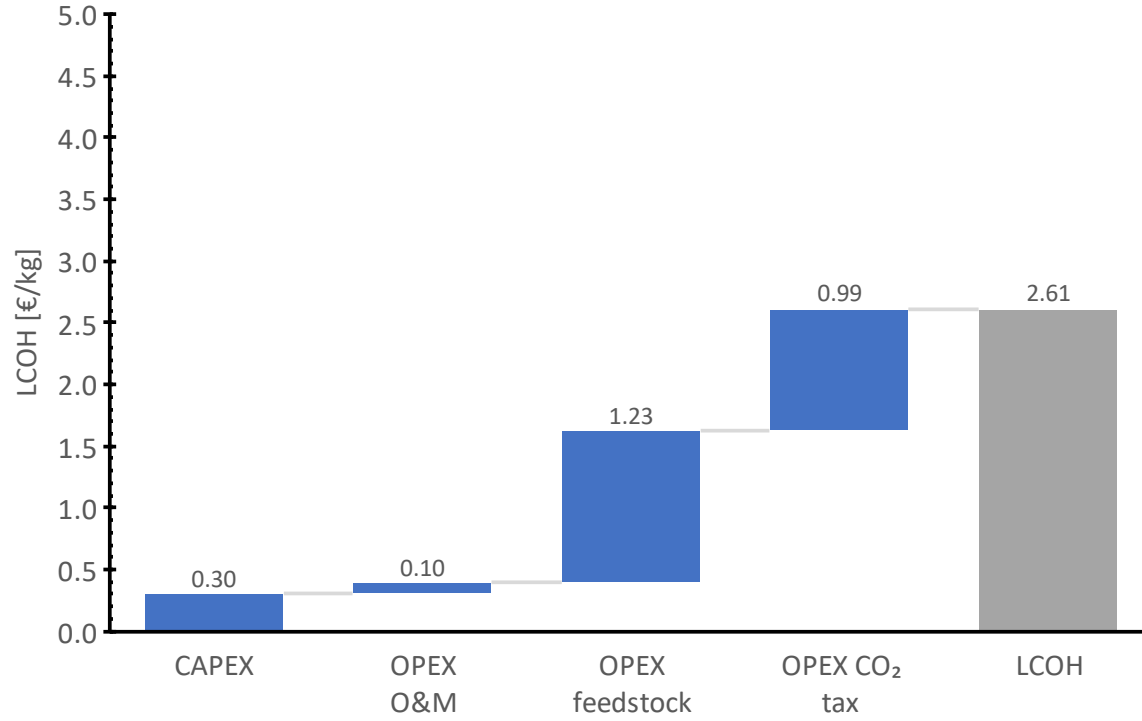
- 531,497 t/year in 2023
- 15 SMR facilities (15 kt to 150 kt)



ESTIMATED GEOLOGICAL STORAGE CAPACITY

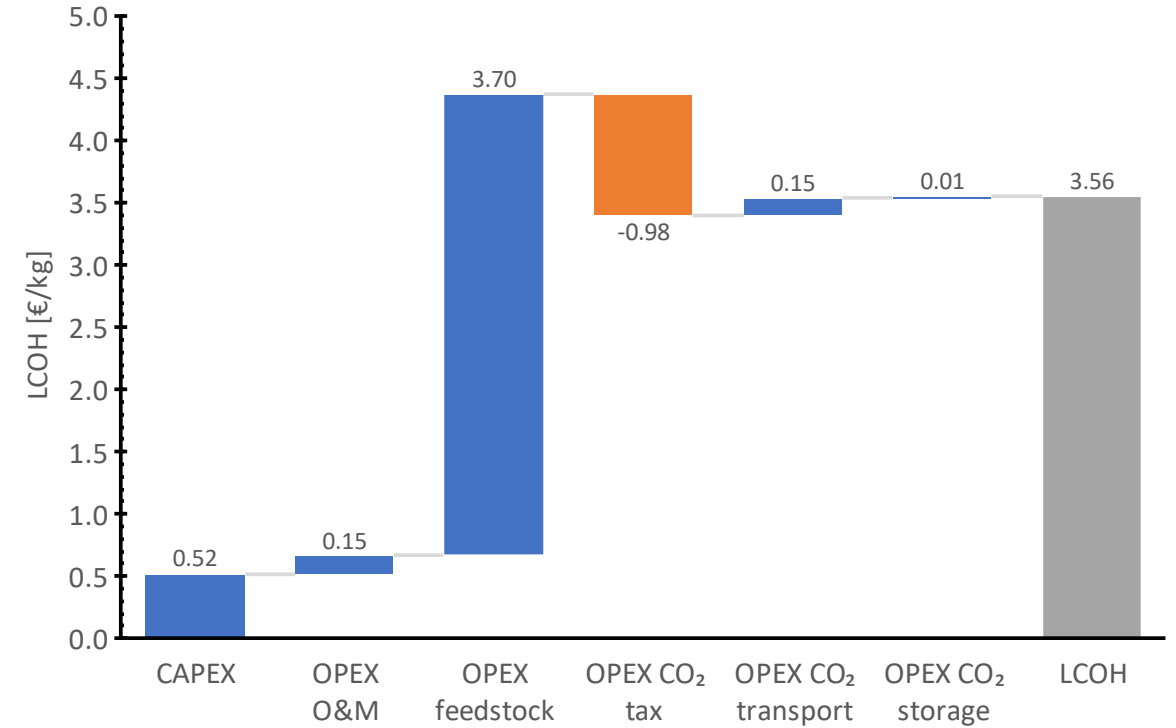
- Overall estimated capacity: 21 Gt
- 103 sites
- Deep saline aquifers

COST COMPARISON



LCOH with natural gas w/o CCS

- Current cost weighted by production facility
- Natural gas: 25 €/MWh-HHV
- CO₂ tax: 80 €/t
- 26 TWh-HHV of natural gas

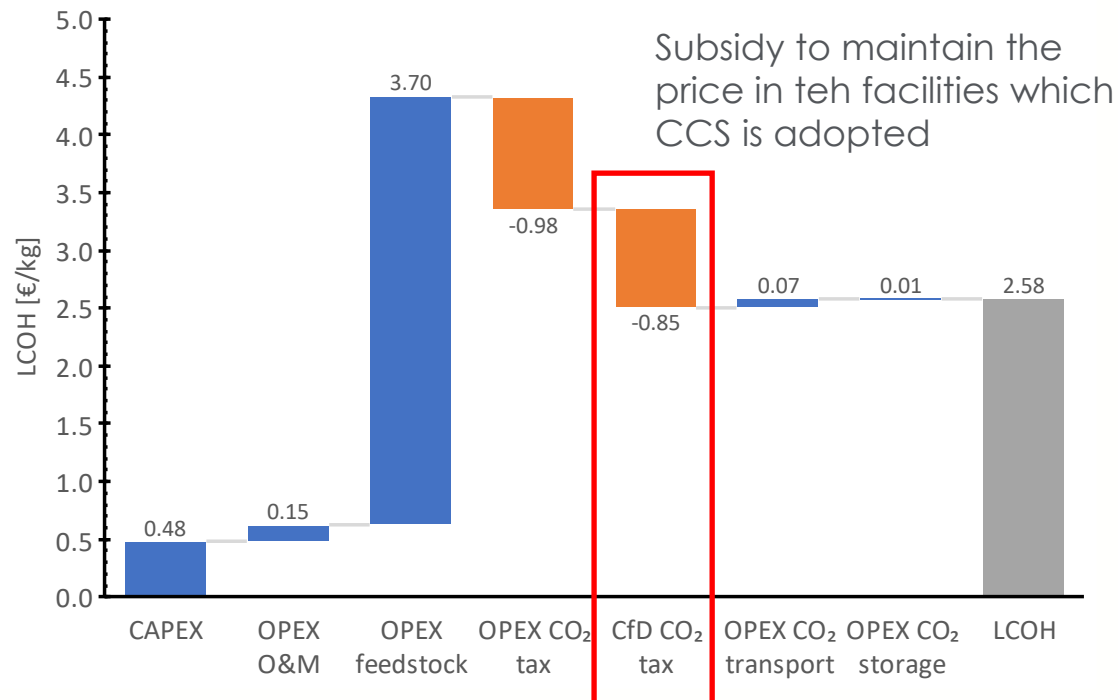


LCOH with biomethane with CCS

- Cost weighted by production facility
- Biomethane: 70 €/MWh-HHV
- 29 TWh-HHV of biomethane

REACHING NET-ZERO

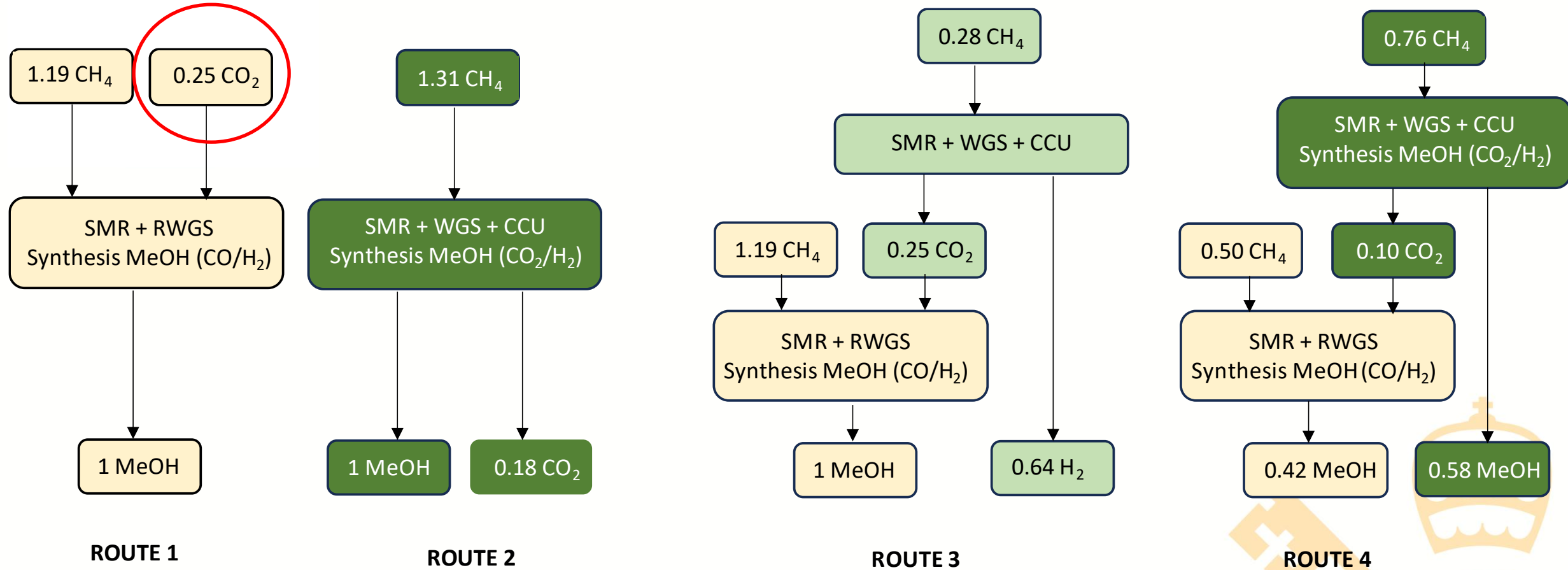
- Negative emissions are used to obtain an overall net-zero production
- Only 5 facilities are retrofitted to include CCS (14 TWh-HHV of biomethane)
- 10 facilities are maintained as is (13 TWh-HHV of natural gas)



Facility	H ₂ production [t]	Natural gas [GWh-HHV]	Biomethane [GWh-HHV]	CO ₂ emissions [kt]	Cost [M€]
San Roque/Algeciras CEP SA	13,688	672		119.63	37.27
Huelva Fertiberia	47,584		2,565	-411.13	166.03
Huelva/La Rábida CEP SA	67,393		3,633	-582.28	227.89
Cartagena Repsol	122,506		6,604	-1,058.45	403.21
Puertollano Fertiberia	21,343		1,151	-184.40	83.40
Puertollano Air Liquide	29,976	1,471		261.99	79.79
Puertollano Repsol	11,450		617	-98.93	47.76
Castellón de la Plana BP	63,989	3,141		559.27	164.80
Tarragona Air Products	41,231	2,024		360.36	107.65
Tarragona Repsol	18,479	907		161.50	50.18
Sabiñánigo	1,071	53		9.36	3.50
Muskiz Repsol	50,645	2,486		442.64	132.17
La Coruña Air Liquide	19,163	941		167.48	51.45
La Coruña Repsol	17,110	840		149.54	46.60
Aviles Nippon Gases Europe	5,870	288		51.30	16.76
TOTAL	531,497	12821	13953	-52.1	1,606

APPLICATION TO BIOMETHANOL PRODUCTION IN SPAIN

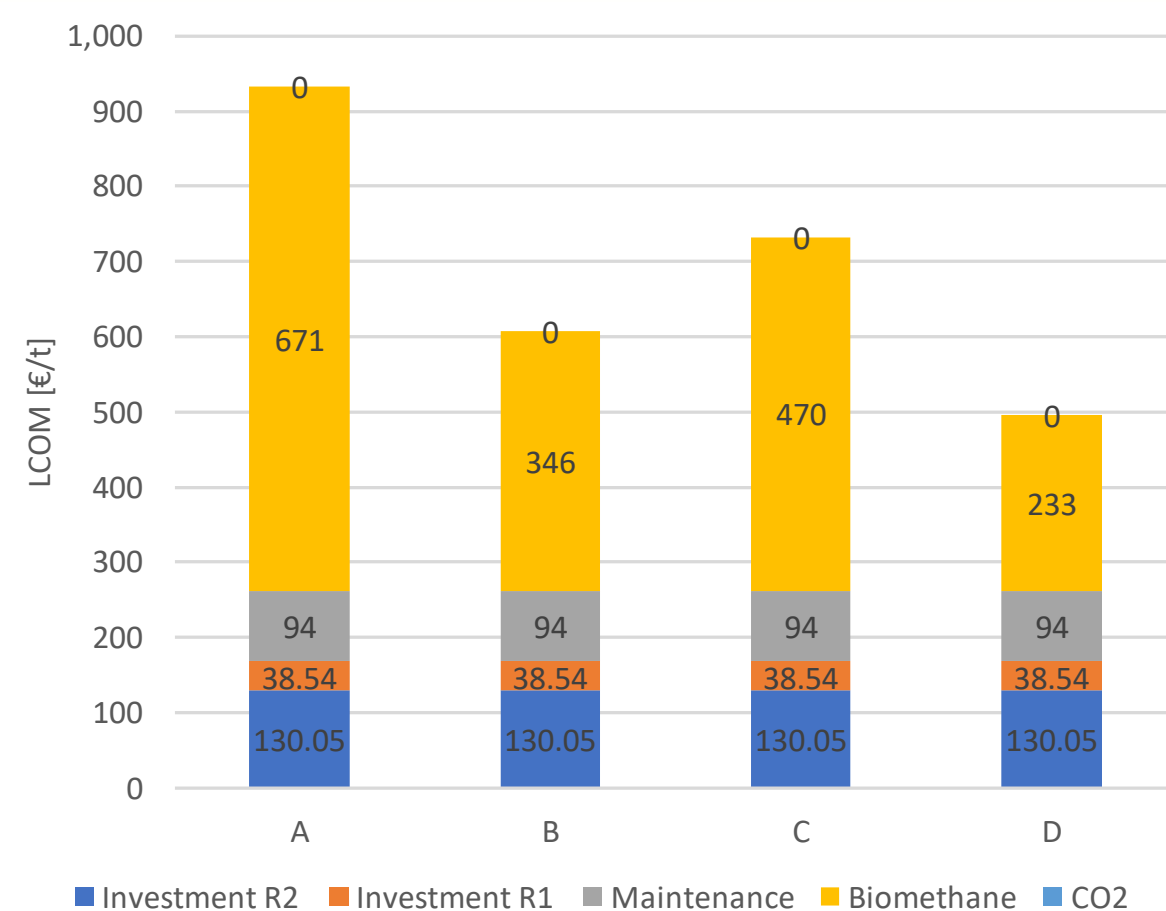
PROPOSAL



- **ROUTE 1** is the classical pathway, demanding CO₂
- **ROUTE 2** and **ROUTE 3** are self-sufficient in CO₂, by-producing CO₂ and H₂
- **ROUTE 4** is self-sufficient in CO₂, produing only biomethanol

COSTS AND POTENTIAL OF ROUTE 4

- Number of facilities of 200 kt MeOH/year:
 - Substrate A: 69
 - Substrate B: 8
 - Substrate C: 4
 - Substrate D: 4

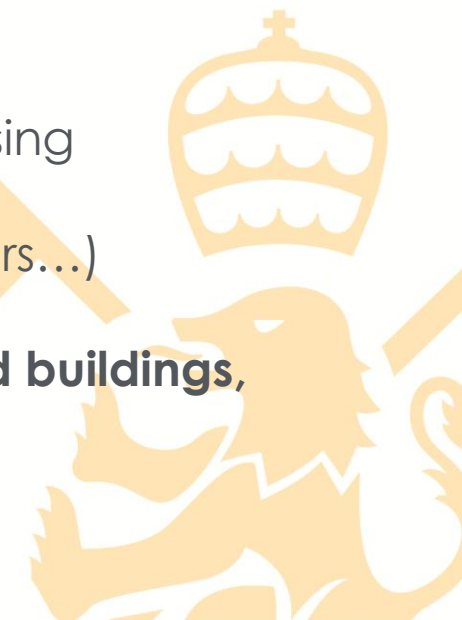


Substrates	A	B	C	D
Landfill gas [%]	7	53		100
OFMSW [%]	6	47	100	
WWTP & Agri-Food Industry [%]	7			
Agriculture waste [%]	18			
Intermediate Crops [%]	43			
Manure [%]	19			
Potential [TWh/year]	135.19	16.73	7.92	8.81
Feedstock cost [€/MWh-HHV]	69.33	35.95	48.77	24.43
T_{CH_4} [€/t]	1,071.6	555.64	753.79	377.59

CONCLUSIONS



- Biomethane has a great potential in Spain (163 TWh-HHV), but it is scaling up slowly. Currently, there are more than 870 GWh-HHV. It is the current bottle-neck
- Carbon capture cost in SMR facilities is reduced
- Negative emissions enable a net-zero hydrogen production reducing natural gas, with moderate biomethane consumption and maintaining the current infrastructure
- CCU enables biomethanol self-sufficient plants
- Some voices are rising claiming for choice the sectors where use biomethane, using electrification in the ones easy to decarbonize (i.e., buildings with HP, electric cars...)
- **TIMES opportunity: establish competition between industrial sectors, transport and buildings, looking for the optimal allocation of biomethane**



THANKS FOR YOUR ATTENTION

QUESTIONS?

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