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The digital layer of Green Hydrogen

GREEN AMAGONIA Key Technical Challenges to Profitable Production



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a versatile energy carrier



Electrified Haber-Bosch

The dominant technology for green ammonia production

- > Hydrogen from electrolyzers (not SMR)
- > Compressors are fully electric
- > Limited ability to ramp up and down.
- > Minimum production rate is ~60% of nominal



Electrified Haber-Bosch



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Green ammonia projects face the challenges of intermittent energy



Renewable energy sources \rightarrow Variable energy \rightarrow Variable hydrogen production

CASE STUDY: Green ammonia in Iberia

Simulated with SOUTHERN LIGHTS



Located in South of Spain Good solar power conditions

Starting assumptions: 480 MW Solar 336 MW Electrolyzer Hydrogen production: 1.6 ton/h = 14 kt/y

Ammonia target: > Min 8 ton/h (= 192 ton/d = 70kton/y)



Ammonia prices in Europe: Grey ammonia: ~0.45 EUR/kg Green ammonia: 0.8-1.5 EUR/kg 2030 green ammonia: 0.48 EUR/kg

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CASE STUDY: Green ammonia in Iberia

Simulated with SOUTHERN LIGHTS

Project assumptions

- Island-mode operations from solar power
- Solar input from a 480 MW park
- Electrolyzer of 336 MW. Capex price: 900+150 EUR/kW
- Compressor for 1 bar \rightarrow 200 bar Hydrogen

- Hydrogen storage capex: 1000 EUR/kg
- Ammonia production capex: 3000 EUR/(kg/h)



What if there were no operational restrictions in ammonia production?



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"The Naïve scenario"

- No restriction on ramp-rates in ammonia production
- Full flexibility: Production allowed to go from 0% to 100%
- Off-takers accept a fluctuating output



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Levelized Cost of Ammonia 0.96 €/kg



"The Naïve scenario"

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- Off-takers accept a fluctuating output

Ammonia production requires storage

...when operating from variable energy and hydrogen supply





Ammonia production requires storage

Goal: Achieve 24/7 hydrogen supply for ammonia production



→ Hydrogen storage needs to be huge to achieve 24/7 supply on a *seasonal basis*.

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"Seasonal storage scenario"



- Realistic restriction on ramp- \bullet rates and flexibility
- Hydrogen storage of 450 tons \bullet = 13 days of production
- Ammonia production capacity is reduced → higher load factor
- Under-utilized storage most of the year

 \rightarrow Hydrogen storage costs are too high, if no cheap underground storage is available.

Seasonally adapted Ammonia production

Goal: Achieve 24/7 hydrogen supply with less storage



→ Hydrogen storage can be reduced when adapting ammonia production with the seasons.

SOUTHERN LIGHTS "Seasonally adapted scenario"



Seasonal decrease in production reduced storage need and keeps production costs down.

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Green ammonia becomes more profitable when adapting to variable energy inputs

Scenario	Storage size	LCOA [EUR/kg]	
"Naïve"		0.96	
Seasonal storage	450t (13days)	1.36	
Seasonally adapted	35t (1 day)	0.94	

Research made by Southern Lights team: Pierfrancesco Losi & Anton Frisk



Develop your Green Ammonia projects with SOUTHERN LIGHTS

G Costs G	Componento	Project Design specs	Target plant size	36 MW →	Number of systems # 84	Use exact	÷	Plant size 336	I K	Simul
		4 Power				count			🛪 🚴 Ammor	nia
OH:	3,8 EUK/K9	Electrolyzer K Compressor	Electrolyzern	nodels				Upload custom mod	del Ammonia produc	tion: 95.50 ton / day
01.	1 50 EUR/kg	Downstream	Manufacturer	Series	Model	Technology	System size	System Type	Min	0.00 g / da
	1,59 2010 0	Cost	Nel	MC-Series	MC500	PEM	2.5 MW	Containerized	Max	240.00 ton / da
COA:		Saes	Southern Lights	Generic_ALK	ALK 150kW	ALK	0.15 MW	Containerized	Mean	95.50 ton / da
	Elec CAPEX	Pinance	Southern Lights	Generic_PEM	PEM 220kW	PEM	0.22 MW	Containerized	Sum	871.47 kto
Energy	O&M	a results	Southern Lights	Generic_PEM	PEM 4MW	PEM	4 MW	Containerized	40	
Flec In	stallation	16	Stargate	Gateway	Gateway 200	ALK	1.2 MW	Containerized	- 30 	
La salate	ar Land lease		Stargate	Gateway	Gateway 800	ALK	4.8 MW	Containerized	• <u>§</u> 20- 10-	
Stacks Equipment Ammonia plant Capex HB Installation Energy H			Southern Li	ghts	PEM 4MW	1000 El	ectrolyzer perfor	mance map	0	
			System power nomin	al	4 MW	50 100 101 80			135	7 9 11 13 15 17 19 21 23 • Year 1 •
			System power min		10% 0.40 MW	40 40			3	
			System power max		100% 4.00 MW	6 20 · · · ·		• • • • • • • • • • •	ty 2	
		Nominal specific ene consumption	gy	59 kWh/kgH2	0 20 gg 0 20	40 Electrolyzer ope	60 80 100 rational point [%]	110 1		
			Nominal hydrogen pr	oduction	67.8 kgH2/h		Total S	tack Roman Bop	1 2 3	4 5 6 7 8 9 10 11 Month
			Nominal hydrogen pr	essure	10 Bar	Electrolyzer stack de	gradation			
			Hydrogen purity		99.995% pure	Expected stack lifetim	0	70.00	00 h Energy consump	tion: 105.05 MWh / day
			System specific foot	print	332.1m2/MW	Total stack degradatio	n at end of life	3	15% Hudrogen concur	notion: 1720 top / day
			System water consul	nption	18 L/kgH2	Yearly average degrad	ation	1.8771%/y	year	induction in doy
		1	Oxygen purity		99.7%	Degradation based on		Operational point ho	ours Nitrogen consum	ption: 78.55 ton / day
	1 28M EUF									

Come talk to us at booth **B08**

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Develop your Green Ammonia projects with SOUTHERN LIGHTS



Get the full presentation and case study here!

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Sources and supporting material



Ammonia production costs

Platts Ammonia Price Chart

Monthly average price, April 2024 (\$/mt)

Platts' new Ammonia Price Chart shows monthly averages of daily assessments for gray, blue and green ammonia across a range of geographies and delivery options. Click on a price for more info

Filter by geography N	orthwest Europe - Filter by pathway All -						
475.71 ▲ CFR Northv	vest Europe						
520.23 CFR North	west Europe						
939.43 ▼ Dlvd Northwest Europe from US Gulf Coast							
1010.38 ▼ Dlvd Northwest Europe from Middle East							
1037.68 – Dlvd Northwest Europe from EC Canada							
S&P Global Commodity Insights	Source: S&P Global Commodity Insights Concept by Henry Edwardes-Evans, James Burgess and Mario Perez						



Ammonia production costs

Cost of green ammonia

EXHIBIT 5: Future cost for green ammonia

Though the current cost of green ammonia is very high compared to traditional ammonia. However, this cost is expected to decrease as the renewable energy cost decreases. The current Price of green ammonia is in the range of \$700 – 1400 per tonne at sites with renewable resources like sun and wind. By 2030, it is expected to drop to \$480 per tonne, and by 2050, to \$310 per tonne. To make green ammonia competitive with traditional ammonia, a carbon price reduction of around \$150 per tonne of CO₂ is needed. It is also estimated that, if the renewable electricity price is below \$20 per megawatt-hour, green ammonia will be competitive with traditional ammonia.

Year	2020	2030	2040	2050	
Low end (\$/tonne)	720	475	380	310	
High end (\$/tonne)	1400	950	750	610	

Note: Rounded to \$ 5 per tonne. Source: IRENA

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Ammonia production costs

https://iea.blob.core.windo ws.net/assets/6ee41bb9-8e81-4b64-8701-2acc064ff6e4/AmmoniaTec hnologyRoadmap.pdf

Figure 1.6 Simplified levelised cost of ammonia production for commercial and near-zero-emission production routes in 2020



IEA, 2021.

Notes: SMR = steam methane reforming; ATR = auto-thermal reforming; CCS = carbon capture and storage; VRE = variable renewable energy. The simplified levelised cost is calculated using a discount rate of 8% and a design life of 25 years for all equipment, with the exception of the electrolyser stack (11 years) and system (28 years). CAPEX includes core equipment costs, corresponding to the plant battery limit (including CO_2 capture equipment in the case of CCS-equipped routes, electrolysers in the case of electrolysis-based routes, and hydrogen storage in the case of the dedicated VRE electrolysis route), and includes engineering, procurement and construction costs, equating to 70% of core equipment costs. A 95% capacity factor is used for all equipment apart from the dedicated VRE electrolysis route, where a 50% capacity factor is used for all equipment apart from the total levelised cost of varying the regional coefficient for CAPEX and fixed OPEX (a factor of 73-127% of the CAPEX cost estimated for the United States), energy cost variation for natural gas (USD 3-8.2/GJ), coal (USD 1.3-2.9/GJ), electricity (USD 4.5-30.2/GJ) and bioenergy (USD 2.2-4.4/GJ). The dedicated VRE electrolysis route uses a narrower electricity cost range (USD 2.8-11.1/GJ). Where relevant, the central values for the column series are calculated based on an output weighted average of the fuel prices faced across regions today. For the electrolysis routes, electrolyser cost = USD 1477/kW_e, electrolyser efficiency = 64% and feedstock refers to the electricity used for electrolysis. For CCS-equipped routes, the CO₂ capture rate is 90%, the CO₂ transport and storage costs vary by used for electrolysis.

Ammonia production requires storage

...when operating from variable energy and hydrogen supply

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Green Hydrogen as a Clean Energy Resource and Its Applications as an Engine Fuel - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Salt-cavern-basedhydrogen-storage-8_fig1_377431718 [accessed 19 Jun, 2024]

