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Sustainable Hydrogen for Development in West Africa

Final Report

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Research, analysis, and presentation by Columbia SIPA graduate students with consultation of UNDP staff. Contents do not reflect current UNDP views or policy

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Research Context

1. There is global consensus that sustainable hydrogen (in the form of, and henceforth discussed as H_2) will play a key role in reaching net zero

2. H_2 ecosystems offer opportunities for developing countries to pursue sustainable development and equitable growth

3. H_2 is a long-term vision and not a short-term fix: Realising opportunities needs careful implementation

Research Objective

1. Our client, United Nations Development Programme (UNDP), is interested in "Creating an opportunity space for sustainable H_2 ecosystems in West Africa"

2. This research project evaluates the opportunity H_2 offers for the ECOWAS region, considering experiences across the continent

3. The project proposes a framework for developing country governments and donors to consider trade-offs when scaling robust H_2 ecosystems. It informs UNDP Country offices on the value of H_2 as an energy carrier

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Report Summary

1. Research question: Is H_2 energy a good solution for West Africa? If so, how can countries implement a robust H_2 ecosystem?

2. Headline finding: H_2 offers an opportunity for net-zero aligned import substitution and industrialization; however, there are significant obstacles to overcome

3. Recommendation: Pursue a 'no-regret', multistage implementation approach over the long-term

Table of Contents

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Data Collection

Extensive desk-based research

H2 ATLAS AFRICA

IRENA International Renewable Energy Agency

Hydrogeninsight Powered by RECHARGE

Key informant interviews

H2Global

IFC

USAID

IEEFA.org

Integrated Africa Power

UNDP

Weekly UNDP engagement

CGEP

SIPA faculty input

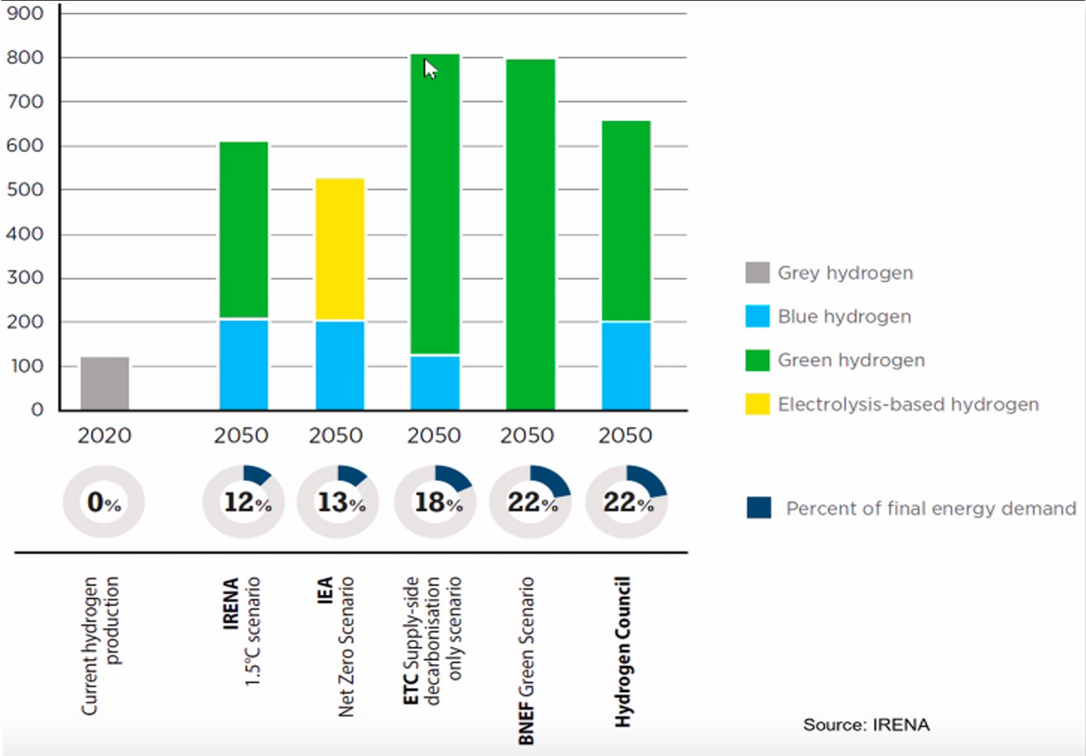
NREL Transforming ENERGY

NREL workshops

Introduction to Sustainable H_2 as an Energy Carrier

H_2 will play a key role in reaching net zero globally

H_2 production forecasts, million tonnes[1]



All net zero scenarios include substantial scaling of sustainable H_2 by 2050

How is H_2 produced?

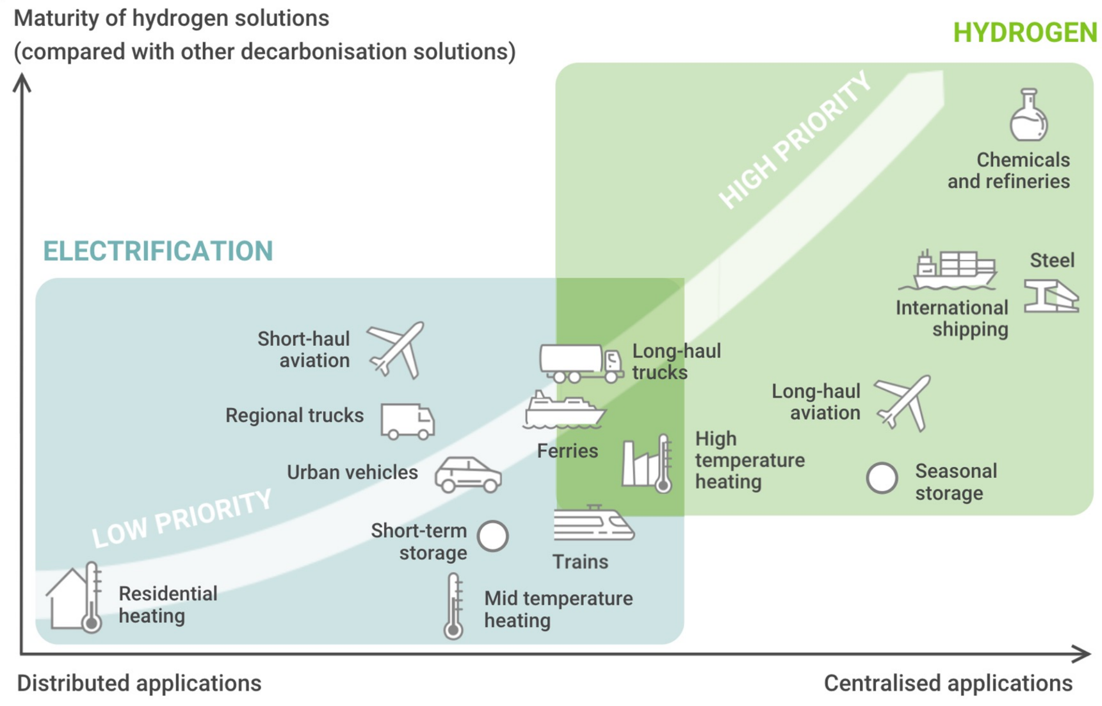
Grey	Steam methane reforming (SMR)
Blue	SMR + carbon capture and storage (CCS)
Green	Electrolysis powered by renewable electricity
Pink	Electrolysis powered by nuclear energy
Turquoise	Methane pyrolysis

The industry is moving away from "H_2 colours" towards production processes and their GHG emissions intensities

Sources: 1 IRENA (2023): 'Geopolitics of the Energy Transformation'; 2 IRENA website: 'H2'; 3 CNBC (2022): 'What is green H2 vs blue H2 and why it matters'; 4 MDPI (2023): 'Green H2 Cost and Potential'; 5 Reuters (2023): 'US unveils clean H2 plan, nuclear power role uncertain'; 6 TNO (2023): 'Methane Pyrolysis'

H_2 is a versatile energy carrier with priority applications

H_2 end-use ladder



Outline of priority H_2 applications

Chemicals and refining	Substituting fossil-fuel based H_2 in **fertilizer production** and in **oil refining**
Steel production	**Direct reduced iron** (DRI) – Using H_2 instead of coking coal in ironmaking
International shipping	Using low-carbon H_2-derived **ammonia** as an alternative marine fuel
Long-haul aviation	Using low-carbon H_2-derived **synthetic fuels** instead of jet fuel in airplanes
Seasonal storage	**Storing power over longer periods** in the form of low-carbon H_2
Industrial heating	Using H_2 for high-temperature industrial heating in **cement and metals production**

There is broad consensus on priority H_2 applications: where H_2 is already used in the production process, or where there are scarce alternative abatement options (e.g. electrification)

Given scarce time and resources, focus scaling efforts on priority applications

Source: IRENA (2023): 'Geopolitics of the Energy Transformation'

What are the obstacles to scaling clean H_2?

	Network requirements	Competitiveness	Regulatory / political	Social / environmental impacts
General barriers	**Capital intensity**[1] • ~$27m to set-up mid-sized plant[2] • >$100m cost for FEED studies for >100 MW H_2 projects[3] **Network externalities** • Chicken and egg problem: need to simultaneously scale supply and demand, and build the network to connect them • Natural monopolies	**Nascent technology** • R&D/pilots required to unlock innovations and cost efficiencies • Delays and faults in electrolyser manufacturing shipments[1] • Existing electrolysers operating on average at 10% of capacity[4] **High financing costs** / WACC • Offsets cost advantages from local renewables potential[5]	**Lack of market**[6] • No valuation of the lower GHG emissions from sustainable H_2 limits demand **Lacking / slow implementation of support policies** delays investment decisions **Country risks** increase financing costs	**Environmental integrity** concerns • Different production types • Measuring GHG emissions from grid-connected electrolysers • Need for **water resources** / desalination plants **Land use** and **access** impacts • H_2 production uses more land and water than renewables alone[2]
H_2-specific barriers	**Lacking transport infrastructure** • H_2 properties make it difficult to transport (see next slide) • Although using H_2 as an element is not new, a scaled ecosystem and market is: "The vast bulk of today's H_2 never leaves the compound on which it is made, let alone cross an international border"[8]	**Energy losses**[6] • Electrolysis: ~30-35% energy lost • Conversion to carriers: 13-25% • Transportation: requires energy = 10-12% of H_2 energy itself **High costs** • Production costs today $4.5-12/kg H_2 but need $2-3 for competitiveness[6] • Most end-uses require further costly redesign to facilities	**Divergences in definitions** around environmental integrity, safety, etc. **risks market fragmentation** and delays investment decisions	**H_2-specific safety protocols** needed • Involves specific knowledge and capabilities for safe production, storage, transport, and use[7] • Shortage of **qualified engineers** to install, monitor, operate, and maintain H_2 systems[7] Need to prioritize domestic water/energy resources for **local benefits** over pursuing export opportunities

Sources: 1 H2 Insight (2024): 'Green H2 production will grow more slowly than expected everywhere apart from China, says IEA'; 2 Energy Transition (2023): 'Unlocking green H2 potential to solve Nigeria's energy crisis'; 3 EnergyPost.eu (2024): 'Scaling H2 financing in Emerging Markets and Developing Countries'; 4 BNEF (2024): 'Energy Transition Investment -Trends 2024'; 5 ESMAP and World Bank (2020): 'Green H2 in Developing Countries; 6 IRENA (2021): 'Making the breakthrough: Green H2 policies and technology costs'; 7 ESMAP and World Bank (2020): 'Green H2 in Developing Countries'; 8 BNEF (2022): 'Liebreich: The Unbearable Lightness of H2'

H_2 has several molecular characteristics that impede a scaled and traded H_2 economy

Technical aspects of H_2	Why it impedes scaling
Energy losses[1] • 30-35% energy lost in electrolysis, 13-25% in conversion to carriers • Transportation: requires energy = 10-12% of H_2 energy itself	**Hinders competitiveness** as an energy carrier • Lowers overall efficiency and increases resource consumption • Makes transportation less efficient and difficult
Interactions with other materials • Safety issues: very wide flammability range, low energy required for explosion, and odourless/colourless gas with invisible flames[2] • Pipes, valves, pumps, tanks, etc. have to resist embrittlement[2]	**Requires bespoke infrastructure and safety protocols** • Involves specific knowledge and capabilities for safe production, storage, transport, and use[3] – cannot simply use existing infrastructure and operations • Shortage of **qualified engineers** to install, monitor, operate, and maintain H_2 systems[3]
Low volumetric energy density • Lightest element so low energy density per unit volume = 25% that of jet fuel, 40% that of Liquefied Natural Gas (LNG)[2] • Issue: needs more volumes to meet identical energy demand	**Constrains H_2 applications** for end-use in transport sector • H_2 fuels take up more space than traditional fuels in cars/trucks/planes, which leads to more trips as transport media are volume-constrained[2]
Low liquefaction temperature • -253°C (versus -162°C for LNG)[2] • Issue: liquefaction is highly energy-intensive, consuming 30-40% of H_2's energy content vs. <10% for LNG[2]	**Makes transporting H_2 difficult** • Unlike LNG, liquified H_2 is very nascent • Difficulty to make liquefaction economically viable, which constrains options for transporting H_2 over longer distances (more so than natural gas)

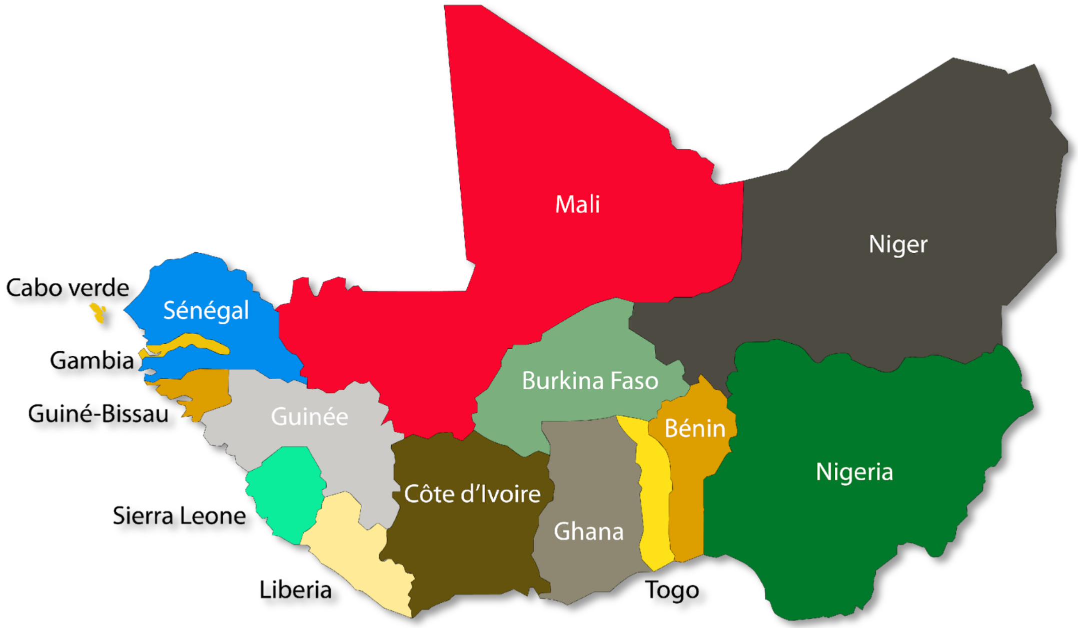
1 IRENA (2021): 'Making the breakthrough: Green H2 policies and technology costs'; 2 BNEF (2022): 'Liebreich: The Unbearable Lightness of H2'; 3 ESMAP and World Bank (2020): 'Green H2 in Developing Countries'

West African Regional Context

Potential for scaling a sustainable H_2 ecosystem in West Africa

Economic Community of West African States (ECOWAS)

ECOWAS is a "regional political and economic union of 15 member countries located in West Africa, widely varying within the region in terms of demography and socioeconomic conditions"[1]



Note: Map colours are arbitrary

Why ECOWAS?

ECOWAS has a structured regional H_2 policy: the **ECOWAS Green Hydrogen Policy and Strategy Framework** with specific objectives:[1]

- Produce 0.5 Mt/yr by 2030 and 10 Mt/yr by 2050
- 3 green H_2 clusters by 2025
- 5 scalable production projects by 2026

ECOWAS presents a **valuable case study:**

1. **Implementation gap:** Despite the ambitious regional strategy, there is a lack of national frameworks and on-the-ground implementation. ECOWAS therefore presents a valuable case study to assess how national implementation may look like in practice. This is also the entry point for the UNDP: to support developing country governments in taking ownership of successful national implementation

1. **Development opportunity:** The report focuses not solely on decarbonization – where the opportunity is smaller given the region is responsible for only 1.8% of global GHG emissions[3] – but on development – there is a significant development opportunity given ECOWAS is home to 11 of the world's 45 least developed countries[4]

Source: Image from Dunmade (2019); 1 ECOWAS (2023): 'ECOWAS Green H2 Policy and Strategy Framework'; 2 IRENA and UNIDO (2024): 'Green H2 for sustainable industrial development: A policy toolkit for developing countries'; 3 ECOWAS (2022): 'Regional Climate Strategy'; 4 UN 'List LDCs'

The energy context in West Africa

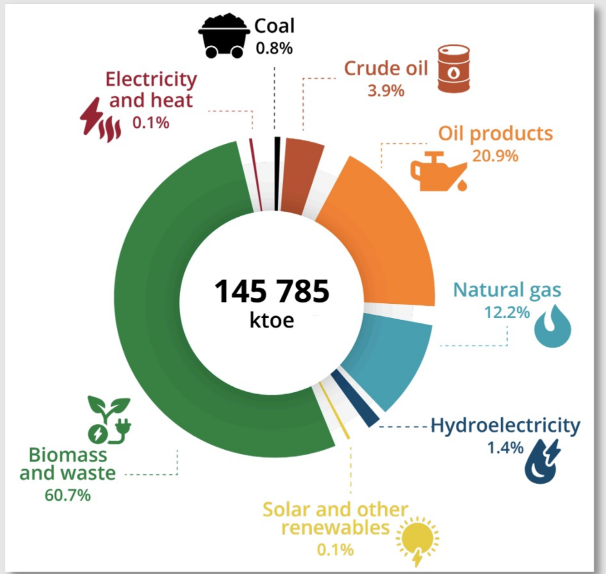
46% of ECOWAS population lacks access to electricity, among lowest rate globally[1]

Only **19%** of have access to clean cooking, second lowest in continent[2]

Where there is energy access, it is often **unreliable and expensive**

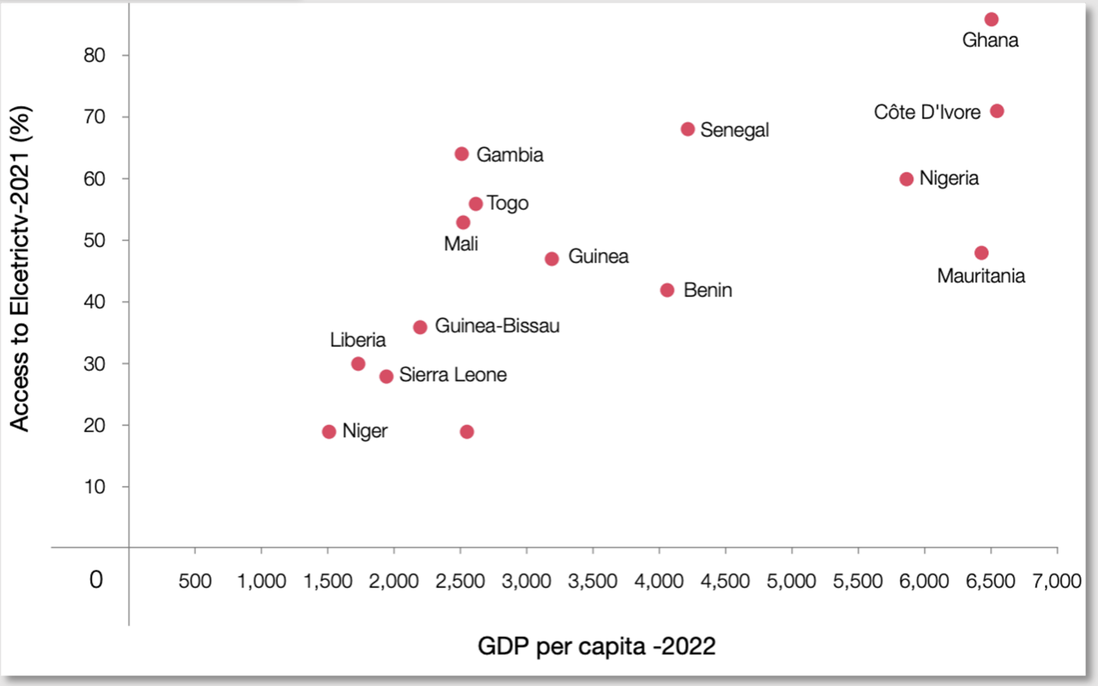
- Unreliable: shortages of 80 hours/month with blackouts, causing firms to lose 5-10% revenues[4]
- Many use expensive back-up diesel generators to ensure reliable power, increasing refined oil imports exposed to volatile oil prices. Power costs at 25 cents/kWh, twice global average[4]

Access to sustainable energy is a key priority for the region



ECOWAS energy supply in 2021[1]

There is a **positive relationship** between energy access and GDP per capita across ECOWAS[3]



Sources: 1 ECOWAS (2024): 'ECOWAS Key Energy Facts and Figures'; 2 ECOWAS (2023): 'ECOWAS Green H2 Policy and Strategy Framework'; 3 PwC (2023): 'Accelerating renewable energy investment in West Africa'; 4 World Bank (2019): 'West Africa: Power Across Borders'; 5 IRENA (2023): 'Scaling up renewable energy investments in West Africa'

Findings: Opportunity for net-zero-aligned industrialization and import substitution over the long-term through careful implementation

The report follows the following framework to answer the research questions: Is H_2 energy a good solution for West Africa? If so, how can countries implement robust H_2 ecosystems?

A End-Use Goals (*Why*)

1. Suitability of End-Use for H_2
2. Opportunity Selection
3. End users' Willingness to Pay

B Target Value Chains (*What*)

1. Production Decisions
2. Storage & Transport
3. Identify H_2 Hub Opportunities

C Participatory Planning (*Who*)

1. Stakeholder Communications and Engagement
2. H_2 Pursuits & Underserved Communities
3. Training and Local Content Provisions

D Enabling Environment (*How*)

1. Identify Risks & De-risking Strategies & Tools
2. Financing Instruments & Capital Structure
3. Develop Policy, Regulatory, & Legal Framework

Developing country governments can apply this framework to answer whether H_2 energy is a good solution for their jurisdiction, and if so how to implement a robust H_2 ecosystem

A. Choose target opportunities where development goals align with fit for H_2

Should developing country governments produce H_2 to export or for domestic consumption?

The export paradigm

"The current global discourse on [sustainable H_2] **mostly reflects the perspective of the Global North**".[1]

- Many point to the potential for abundant untapped renewable resources in developing countries to produce H_2 for exports. Developed countries with H_2 supply gaps like Germany, South Korea and Japan will import H_2

There are certain **benefits to exporting sustainable H_2**:

- Export revenues may **improve trade balances** and facilitate **access to foreign currencies**[1]
- Access to a **wider range of offtakers**, e.g. exports to EU could leverage the region's higher willingness to pay[2] and the EU CBAM*
- Access to **external financing** like from Export Credit Agencies (ECAs), e.g. H2Global €900 million fund for green ammonia imports to EU[3]

However, a strategy focussing only on exporting pure H_2 has **neo-colonial undertones** and **overlooks development opportunities domestically:**

- Neo-colonial undertones: focuses less on benefits to host country and more on using low-carbon H_2 produced to satisfy decarbonization needs in the developed world[1]
- It can drive local opposition to H_2 projects, e.g. local civil society groups sent a letter to the Namibian president to reconsider the Hyphen project due to environmental concerns and opaque tendering[4]

Reframing the narrative

This report builds on recent efforts to reframe the question from "What can developing countries do for sustainable H_2?" to **"What can sustainable H_2 do for developing countries?"**[1]

Examining the full range of domestic applications **maximises local sustainable development and equitable growth benefits**[1]

- It creates the whole H_2 value chain, especially downstream to support industrialization
- It increases local skills and provides permanent employment

A domestic focus can support several development and wider policy aims, e.g.

- Build out domestic **energy and water resources** to support expanding energy and water access
- Scale domestic fertilizer production to displace volatile fertilizer imports to **improve food security**
- Scale H_2 use in heavy industry to displace fossil fuel imports to **improve energy security** and support **industrialization**
- Avoid **stranded assets** by supporting the decarbonization/net-zero aligned industrialization of local economy and avoiding building conventional, fossil-based projects with long-term carbon lock-in[1]

Sources: 1 IRENA and UNIDO (2024): 'Green H2 for sustainable industrial development: A policy toolkit for developing countries'; 2 Expert interviews; 3 H2Global (2022): '900 million euros for the market ramp-up of green H2'; 4 Energy Transition (2023): 'The hype around Hyphen – path towards Namibia's energy revolution or Global North dependency?'
* Carbon Border Adjustment Mechanism

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A general framework for governments to prioritize H_2 applications

Only consider priority applications

There is widespread **consensus on priority H_2 applications** (i.e. sectors not suited for electrification):[1]

- Chemicals and refining
- Iron and steelmaking
- High-temperature heating
- Long-haul transport

A project's use case influences its ability to find **offtakers** and **access external support**

- Willingness to pay (WTP) varies by sector and location[2]
- Use-cases are often included in external entities' selection criteria to decide whether to support and/or finance projects, e.g., IFC and H2Global[2]

Prioritize existing users for feasibility and flexibility

End-users already **using H_2 as a molecule in their production** are ideal anchor buyers

- Substitute fossil-fuel based H_2 as an input to ammonia production and in oil refining
- Leverage existing H_2 infra

Ammonia production is both most feasible and flexible:

- Easier H_2 end-use, as simple replacement of H_2 input
- Transportable today, with existing shipping and port infrastructure for ammonia, and an existing global market
- Wider, flexible offtaker range: domestic market (for fertilizers, power storage) + for exports (leading long-distance transport option; potential as maritime fuel)

Strategically expand into new uses based on local context

Develop **downstream industries** with more value add

- Support green industrialization

Choice of end-use target **depends on local context**[4]

- Produce green industrial products in countries with significant relevant raw materials (e.g., green steel where high-grade iron ore resources or green aluminum where bauxite resources)
- Produce jet and maritime fuels in countries with major airport hubs or large container ports

See **Technical appendix** (slides 60-64) for an assessment of H_2 use-cases across fertilizer, steel, aluminum and cement production

Countries often prioritize **ammonia production** due to feasibility and flexibility

- E.g., Morocco[5], South Africa[6], Egypt[7]

Other end-uses require more preparation to assess feasibility and redesign production facilities to be able to use H_2

Country governments should assess the feasibility and domestic market potential of different use-cases and target end-uses with the highest potential and comparative advantage

1 IRENA (2023): 'Geopolitics of the Energy Transformation'; 2 Expert interviews; 3 ; 4 IRENA and UNIDO (2024): 'Green H2 for sustainable industrial development: A policy toolkit for developing countries'; 5 Reuters (2023): 'Morocco's OCP plans $7 billion green ammonia plant to avert supply problems'; 6 CNN (2023): '$4.6 billion plant in South Africa will make 'the fuel of the future'; 7 H2 Insight (2022): 'Egypt grants final approval to $5.5bn green H2 and ammonia project near Suez Canal';

Sustainable H_2 has potential to add net-zero aligned development and industrialization in West Africa

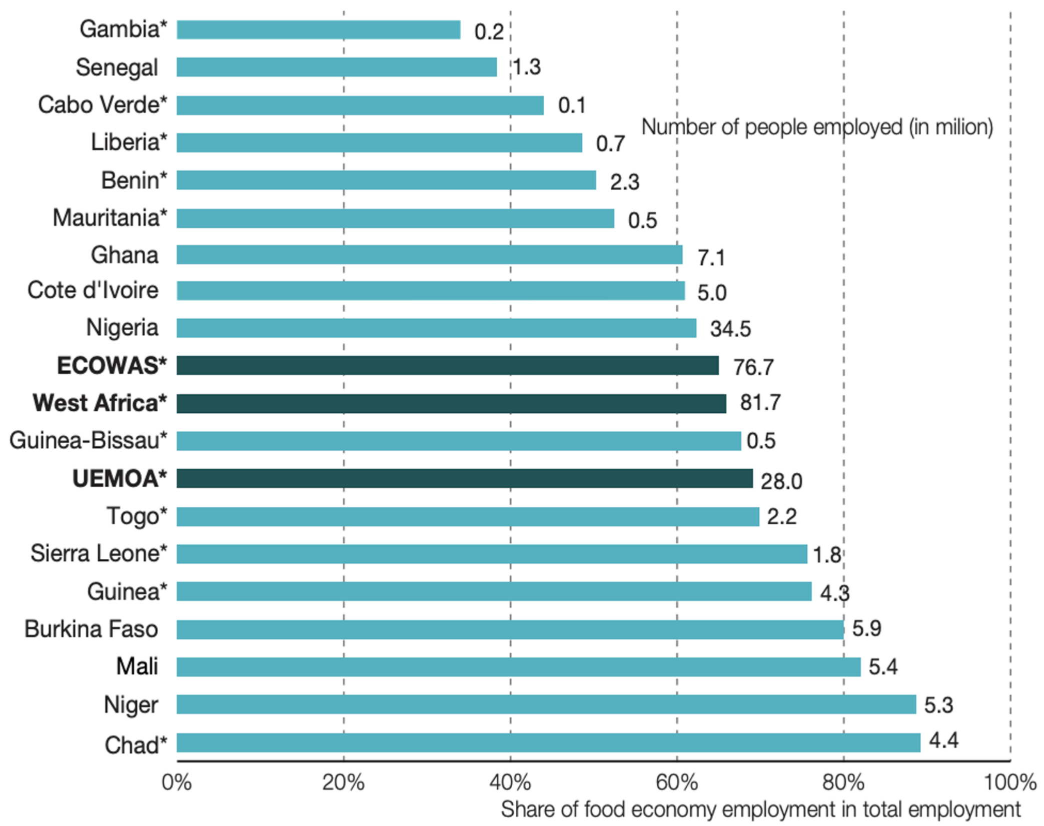
SDGs	Regional development gaps	Regional policy goals	National policy examples	Sustainable H_2 opportunity
7 AFFORDABLE AND CLEAN ENERGY	**55%** lack access to electricity[1]	ECOWAS Renewable Energy Policy (EREP): **Universal access to electricity** by 2030[3]	**Liberia's Rural Energy Strategy and Master Plan** to expand rural electricity access to 20% in 2025 and 35% in 2030[8]	**Energy access**: build renewable power capacity for electrolysis-based H_2 production with deliberate plans for **excess power output to feed expanding energy access**
6 CLEAN WATER AND SANITATION	**30%** lack access to safe drinking water[1]	The West Africa Water Resources Policy (WAWRP): promote integrated **water resources management**[4]	**Togo Urban Water Security** (TUWS) project is part of national push to expand water access to >86% of Lomé population and then 100% nationwide[9]	**Water access**: build desalination plants for electrolysis-based H_2 production with deliberate plans for **excess water output to feed expanding clean water access**
2 ZERO HUNGER	**36 million** people undernourished[1]	Economic Community of West Africa Agricultural Policy (ECOWAP): roadmap for **improved access to fertilizers**[5]	**Nigeria's Presidential Fertilizer Initiative** to ensure domestic capacity for fertilizer production[10]	**Food security**: developing regional ammonia-based fertilizer production can **reduce dependence on fertilizer imports** for agriculture and contribute to food security
7 AFFORDABLE AND CLEAN ENERGY	**80%** of fuel needs are imported as refined[2]	West African Common Industrial Policy (WACIP): Raise intra-ECOWAS trade, notably in **petroleum products**[7]	**Niger** aims to scale domestic oil refining capacity[11]	**Energy security**: developing regional oil refining capacity can **reduce dependence on refined petroleum imports**
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	**Reliance on exporting raw materials** and importing value added intermediate goods	WACIP: Raising **local raw material processing rate** from 15-20% to 30% by 2030[7]	**Ghana's 1D1F initiative** to shift from dependence on raw material exports to manufacturing, value addition and processed good exports[12]	**Industrialization:** developing low-carbon H_2 can contribute to **building out downstream value chains** in iron & steel, aluminum and cement sectors

1 ECREE (2018): 'Managing Water, Food, and Energy (WEF) Resources for Sustainable Development in the ECOWAS Region'; 2 UNEP (2018): 'ECOWAS countries to develop harmonized fuel and vehicle emission standards Abidjan, Cote d'Ivoire'; 3 ECREE website: 'ECOWAS Renewable Energy Policy (EREP)'; 4 ECOWAS (2022): 'WAWRP'; 5 ECOWAP (2023): 'Leaders from West Africa and the Sahel Reaffirm Commitments to Invest in Fertilizers for Agricultural Transformation; 7 ECOTIS website: 'West African Common Industrial Policy (WACIP)'; 8 Rural and Renewable Energy Agency Libera website accessed 14/02/23; 9 World Bank (2023): 'Togo: A New Operation to Boost Access to Water in Greater Lomé'; 10 NSIA (2021): 'NSIA Implements Restructuring of the Presidential Fertilizer Initiative (PFI)'; 11 Reuters (2023): 'Niger aims to start oil exports from Benin pipeline in January'; 12 1D1F website accessed 14/02/23

Deep dive: Food security

See **Technical appendix** (slides 60 and 61) for an assessment of H_2 use-cases in fertilizer production

Share and number of people employed in food economy



Source: OECD (2018): 'Agriculture, food and jobs in West Africa'

Importance of food economy

Food economy represents **30-50% of GDP** and **>50% employment** in most ECOWAS countries

Supply chain vulnerabilities

90% of fertilizers imported[2], driving vulnerabilities to **supply disruptions**, e.g., prices **tripled** prices 2020 to 2022 due to COVID-19 and the Russia-Ukraine War

Regional policies for fertilizer investment

Fertilizer investment is a goal across the region, e.g.:

- Nigeria Fertilizer Presidential Initiative
- Mali fertilizer subsidy programme

Unique H_2 opportunity

Ammonia production – the process preceding fertilizer production – is an existing H_2 user and therefore a **low-hanging fruit H_2 application**

Unique development opportunity

Scaling regional fertilizer supplies can enhance **food security** and **support rural livelihoods**

Sources: 1 IIED (2013): 'Transformation in West African agriculture and the role of family farm'; 2 IFDC (2021): 'Fertilizer Logistics in West Africa'

+ Deep dive: Energy security

Country	Crude oil rent (% of GDP in 2021)[1,2]	Refining capacity
Senegal		1.5 Mtpy in Dakar[3]
Gambia		
Guinea-Bissau		
Cabo Verde		
Guinea		
Sierra Leone		
Liberia		
Cote d'Ivoire	0.7%	In Abidjan[5]
Ghana	4%	In Tema, but shut since 2017[4]
Togo		
Benin		
Nigeria	6%	486k bpd, multiple[6]
Niger	0.6%	20k bpd by Zinder[7]
Mali		
Burkina Faso		

Société Africaine de Raffinage (SAR) is region's oldest refinery recently upgraded to boost output to 1.5 Mtpy (from 1.2 Mtpy) and adapts units to domestic oil quality.[3] In talks with Afreximbank to raise $500m to expand to 4-5 Mtpy[3]

Public-private partnership with Chinese **Sentuo Oil Refinery Ltd** (SORL) under Ghana's industrialization agenda to build a two-phase refinery:[7]
- 1st phase operational since Jan 2024: 2 Mtpy
- 2nd phase: under construction in the Heavy Industrial Area of Tema to expand to 5 Mtpy

Africa's largest oil refinery ($19 billion Dangote facility) began producing diesel and jet fuel in January 2024[8]
- planned to supply 650k bpd, meeting domestic needs
- First privately-owned to address rising gas prices and state-owned refineries running below capacity

- PetroChina-backed **export pipeline** to link Niger's Agadem oilfield to Benin port of Cotonou to export crude[9]
- Government aim to **develop more refining** of local crude[9]

Source: 1 World Bank data; 2 Statista (2024; 3 Reuters (2023): 'Afreximbank in talks to help raise $500 mln for Senegal refinery upgrade'; 4 Reuters (2022): 'Shortage of oil refineries haunts Africa as fuel prices rocket'; 5 Oil and Gas Journal (2021): 'Ivory Coast lets technology contract for Abidjan refinery'; 6 Statista (2024): 'Oil refinery capacity in selected African countries in 2022; 7 Oil and Gas Journal (2024): 'Chinese investor starts operations at new refinery in Ghana'; 8 AP News (2024): 'Africa's biggest oil refinery begins production in Nigeria with the aim of reducing need for imports'; 9 Reuters (2023): 'Niger aims to start oil exports from Benin pipeline in January'; 10 FP (2022): 'Africa Needs More, Not Less, Fertilizer'

West Africa has **limited refining capacity** despite 1,555 million bpd oil produced in 2022[2]: countries export crude oil and import refined oil products
- Even major producers like Nigeria and Angola import 80% of domestic needs[3], Ghana 97%[7]

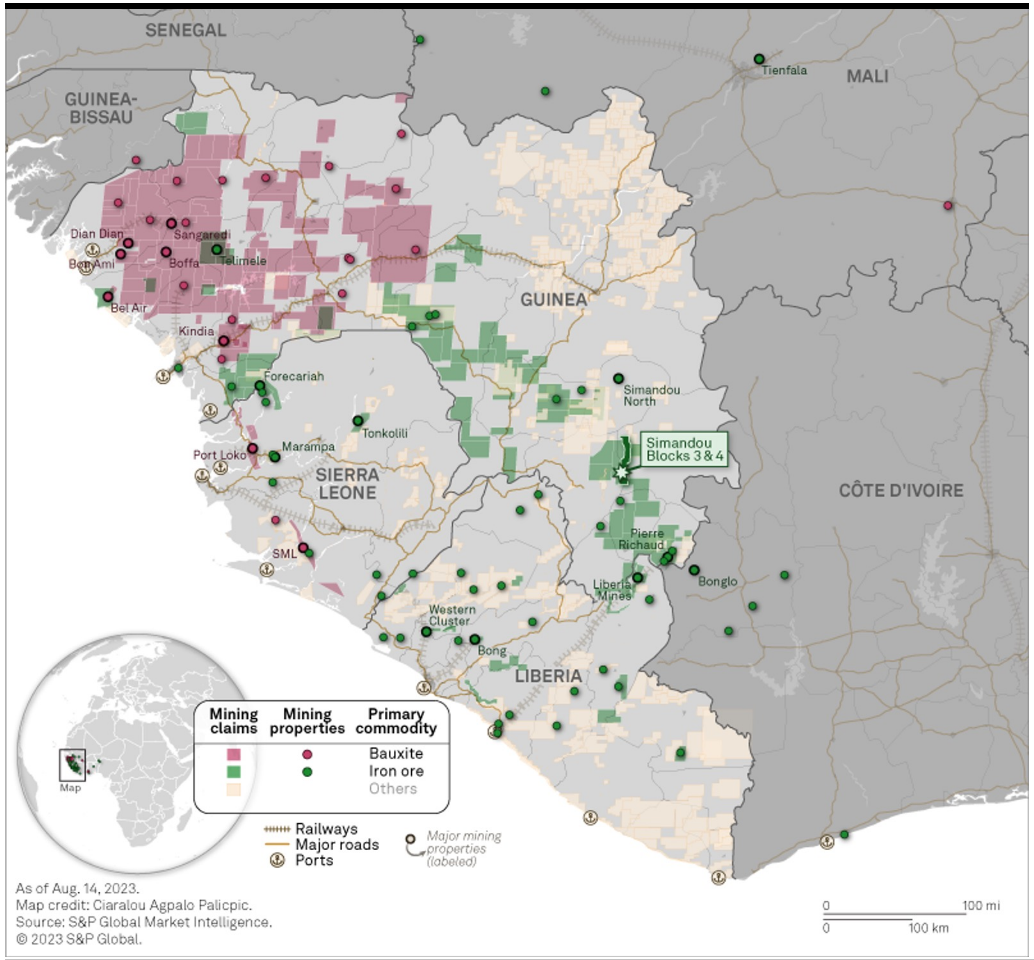
Import dependence drives **vulnerability to global supply shocks and volatile prices**
- E.g. Russia-Ukraine war "left countries dangerously short of fuel supplies, **disrupting airlines and causing queues at filling stations**"[4]

Several countries are pushing to **develop oil refining capacity** to supply domestic/SSA markets

Oil refining is **well-suited for scaling H_2 ecosystems**
- Existing H_2 user
- Location by ports and hubs
- May co-locate with fertilizer facilities (e.g. Africa's largest fertilizer facility by Lagos shares complex with its largest petroleum refinery)[10]

Deep dive: Industrialization (1/2)

The region hosts significant bauxite and iron ore reserves[1]



Despite rich natural resources, ECOWAS relies on exporting raw materials and importing value-added intermediate goods due to limited downstream industries

Large bauxite reserves, but limited downstream aluminium value chain

- Annual raw bauxite production: 70 Mtpa from Guinea, 1.8 from Sierra Leone and 1.1 Mtpa from Ghana.[2] **Guinea is a major global producer**, with the world's largest bauxite reserves, supplying 19% of global production[2] and half of China's imports[3]
- However, the region has **little processing capacity**: only 440 ktpa[4] alumina refining capacity in Guinea and 45 ktpa[2] smelting capacity in Ghana

Large iron ore reserves, but limited downstream iron & steel value chain

- Annual production of iron ore is 2.7 Mtpa from Liberia, 8 ktpa from Nigeria[2] and large volumes planned from the world's largest untapped reserves in Guinea[5]
- However the region has **no ironmaking industry** and limited steelmaking capacity in Nigeria (650 ktpa) and Ghana (400 ktpa)[6]

Government policies target downstream industrial development to shift the economy away form raw materials export dependence

E.g. Guinea

- Government is pushing bauxite mining companies devise timelines to construct alumina refineries[3]

E.g. Ghana

- Parliament established GIADEC* in 2018 and GIISDEC** in 2019 to develop an Integrated Aluminium Industry and Integrated Iron and Steel Industry, respectively, the former planning to build 2 refineries and one new smelter[7]

Source: 1 S&P Global (2023): 'Iron ore spend to buoy development capital in 2024 against overall decline'; 2 World Mining Data 2021; 3 Reuters (2022): 'Guinea bauxite miner CBG backs alumina refining push; 4 Statista (2024): 'Production of alumina worldwide in 2022'; 5 Bloomberg (2024): 'Guinea Lawmakers Approve JV for Simandou Iron Ore Development'; 6 World Steel Association (2024): 'Total production of crude steel'; GIADEC (2022): 'GiADEC's Master Plan for Ghana's Integrated Aluminium Industry'
* Ghana Integrated Aluminium Development Corporation; ** Ghana Integrated Iron & Steel Development Corporation

Deep Dive: Industrialization (2/2)

Green steel

Ironmaking is a high-priority H_2 use-case

- The switch from BF-BOF* to H_2-fuelled DRI** in ironmaking can fully substitute coking coal as both a reducing agent and for thermal energy
- DRI is technology ready, already used in the Middle East albeit with natural gas. DRI facilities can be built 'H_2 ready', with the ability to use natural gas initially to be gradually replaced with renewables-based H_2 [1]

There is a rising opportunity to attract ironmaking processes to West African countries abundant in both renewables and high-grade iron ore

- Low-cost renewable power and DRI-grade iron ore – a scarce resource representing only ~4% of global iron ore supply[2] – are needed for DRI
- International metals companies are increasingly considering relocating their ironmaking processes to more favourable geographies with these resources, e.g. the head of ArcelorMittal's European arm recently stated considering moving out of the EU due to high costs[3]

Green aluminium

High-temperature heating is a medium-priority H_2 use-case

- In the intermediary step of alumina refining, H_2 can substitute fossil fuels to provide high temperature heating
- However, H_2 has a smaller role in the overall aluminium value chain: only around 4% of emissions come from high-temp heating processes and medium- and low-temp heating is better suited for electrification.[4] The smelting process that converts alumina into aluminium is already electrified and therefore has no use case for H_2, despite being responsible for 80% of total production emissions[5]

Nevertheless, H_2 in alumina refining remains a key opportunity in West Africa due to the region's important role in global bauxite production

ECOWAS members have a unique opportunity to negotiate favourable public-private partnerships to develop their iron and steel industries, as public and private sector goals align for developing H_2-fuelled DRI

Trading H_2-derived goods is also beneficial because it circumvents the difficulties of long-distance H_2 transport

See **Technical appendix** (slides 60, 62 and 63) for an assessment of H_2 use-cases across steel and aluminium production

Source: 1 Expert interviews; 2 IEEFA (2022): 'Solving iron ore quality issues for low-carbon steel'; 3 H2 Insight (2023): ''Green H2 is too expensive to use in our EU steel mills, even though we've secured billions in subsidies'; 4 Mission Possible Partnership (2021): 'Closing the Gap for Aluminium Emissions'; 5 McKinsey (2023): 'Aluminum decarbonization at a cost that makes sense'
* Blast furnace with basic oxygen furnace; ** Direct reduced iron

However, scaling sustainable H_2 ecosystems in ECOWAS countries face significant headwinds

General Uncertainty

Obstacles: technology performance and price uncertainty[1,2]

1 Nascent and costly technology

- Scaling efforts are slower than expected - Of the 360 GW H_2-linked new renewable capacity announced by 2030 globally, **only 12 GW has reached FID* or began construction**[1,2]
- There are significant uncertainties around the extent and speed of **cost reductions and efficiencies**

See slides 8 and 9 for further general H_2 -related pain points

ECOWAS Region-Specific Uncertainty

Obstacles: Uncertain demand and lack of credible offtakers[2]

2 Risk of insufficient regional market

- Limited presence of downstream industries to use sustainable H_2
- **Affordability constraints** – many potential end-users may not be willing to pay the green premium associated with using sustainable H_2, e.g. farmers for green fertilizers

3 Risk of being outcompeted on export markets

- Unlike international oil and gas markets, higher export competition will mean **limited economic rent**** for clean H_2 producing countries
- ECOWAS exports may be outcompeted by exports from other locations with relatively **more favourable characteristics** for H_2 scaling, e.g.:

Brazil: High energy access and decarbonised power sector, so less competition for use of renewable power capacity

Namibia: Abundant land and low population density, so less land use competition; Lower financing cost from lower country risk (in contrast to certain ECOWAS countries with recent coups and weaker credit ratings from data gaps and credit rating agency bias[1,3])

Mauritania: Higher solar *and* wind potential

Egypt: Closer proximity to export markets like Europe

Source: 1 Key Informant Interviews; 2 McKinsey and H2 Council (2023) sourced from EnergyPost.eu (2024): 'Scaling H2 financing in Emerging Markets and Developing Countries'; 3 UNDP (2023): 'Lowering the cost of borrowing in Africa'

* Final investment decision; ** Rent defined as the difference between local production cost and the international market price

B. Structure value chain to maximize development benefits at minimum costs

Scaling a H_2 ecosystem requires building out the entire value chain, with several options at each step

First priority
Second priority

PRODUCTION

- Steam methane reforming (SMR)
- SMR + carbon capture and storage (CCS)
- Electrolysis powered by renewable electricity
- Electrolysis powered by nuclear energy
- Methane pyrolysis
- Geological hydrogen

STORAGE

- Salt caverns
- Depleted gas fields
- Aquifers
- Lined hard rock caverns
- Pressurized tanks

TRANSPORT

- **Pure hydrogen**
  - Gaseous form via blending in or repurposing existing pipelines, or building new dedicated pipelines
  - vs
  - Liquid form via shipping
- **Liquid organic H_2 carrier** (LOHC)
- **Derivatives**
  - Ammonia
  - Methanol
- **H_2-linked products**
  - DRI/hot briquetted iron/green steel
  - Green cement
  - Green aluminium

END-USE

- Fertilizer production
- Iron and steelmaking
- Cement production
- Aluminium production
- Shipping
- Aviation
- Trucking

Production (1/2): CCS- versus renewables-based H_2 production

CCS-based production for shorter-term affordability

CCS-based production is only relevant for countries with access to low-cost natural gas

- **Nigeria, Ghana, Côte d'Ivoire, Senegal and Niger** all have natural gas resources available
- The **West African Gas Pipeline** extends natural gas resources from Nigeria through Benin and Togo to Ghana

CCS-based production is an attractive shorter-term option due to lower costs, and is especially suitable for scaling domestic use

- The ability to leverage low-cost natural gas resources and existing infrastructure means lower production costs, and therefore a **lower cost gap** to conventional H_2 and end-use products
- This is especially beneficial for developing a domestic H_2 market, as **affordability is a particular obstacle for the region**

However, CCS-based production may be more constraining

- Building CCS-based facilities will **lock-in H_2 production as the process**, with no ability for power or clean water generation
- Certain export markets will only consider renewables-based H_2 for import (e.g., Germany's H2Global), thereby **limiting the options for export markets and external financing**

See **Technical appendix** (slide 65) for more detail

Renewables-based production for versatility and development

Renewables-based production is possible across all countries in the region

- **All countries** have either solar, wind, hydro or other renewable potential

Although having a high green premium today, renewables-based production has stronger export and cost reduction potential

- It widens the range of options for **exports to and external financing from** geographies like Europe
- There is also stronger cost reduction potential, contributing to better **medium-to long-term affordability**. Efficiency being less of a constraint in the renewables-abundant West African region, costs may be reduced by **using cheaper alkaline electrolysers sourced from China** (see Technical Appendix, slide 66)

Renewables-based production has stronger development synergies

- Building new renewable power capacity and desalination plants to feed electrolysis-based H_2 production can generate excess power and water output to **expand energy and clean water access** for local populations. To ensure scaling supports rather than compromises such goals, **upfront planning** is necessary based local consultations to understand development needs
- Channelling resources and experience towards renewables technologies can unlock efficiencies and economies of scale, which can also **better support rural electrification**: renewable technologies are better suited for decentralised energy systems used in remote areas relative to centralised natural gas systems

Production (2/2): To avoid unintended consequences…

Scaling renewables-based H_2 production must **mitigate unintended consequences**

Electrolysis for H_2 production drives added electricity demand – **ensure increased demand is met with renewables and not fossil fuels**

Opportunity costs of power – ensure **electricity used is not diverted from energy access or power sector decarbonization**

Opportunity costs of water – ensure water **used is not diverted from clean water access and irrigation** for food security

… criteria can be applied for renewables-based H_2 production

Criterion	Definition[1]	EU targets[2]	US 45V tax credit[3]
Additionality	H_2 produced using electricity from **new rather than existing** renewable energy capacity	Power plant **began operations ≤3 years H_2 facility began operations***	or uprates (new additions in existing plants)
Geographic correlation	H_2 produced **close to** its electricity source	Plant in either: • **Same bidding zone** • **Interconnected** bidding zone with higher power price • Offshore zone **interconnected** to bidding zone	Plant in **same region** as defined in DOE's 2023 National Transmission Needs Study
Temporal correlation	H_2 produced **when** specified power source is generating electricity	**Monthly matching** until 2029, and hourly matching afterwards**	**Annual matching** until 2028, and hourly expected afterwards

Sources: 1 BNEF (2023): 'US H2 Guidance: Be Strict or Be Damned'; 2 EU (2023): 'EU rules for renewable H2'; 3 US Treasury (2023): 'IRS Release Guidance on H2 Production Credit to Drive American Innovation and Strengthen Energy Security'

*Does not apply until 2038 for installations starting operations before 2028; **option for Member States to adopt hourly matching from July 2027 onwards

Transport: A framework for governments to prioritize H_2 transportation methods

	Pure H_2	Derivatives	Semi-finished or finished goods
Options	In gaseous form via **pipelines** or liquid form via **shipping**	**Ammonia** (NH_3), **methanol** (CH_3OH), **synthetic kerosene**	H_2-derived **steel, cement, aluminum**, etc.
Key takeaway	**Uncertain future role for liquid H_2** as a scaled traded commodity due to H_2's inherent properties*[1] **Pipeline transport is the only economical method** today[1]	Opportunity to leverage and **scale existing shipping and port infrastructure**: • Today, 10% of global NH_3 production is traded globally[1]	Transporting H_2-derived goods **circumvents the question of H_2 transportation**
Key challenge	Requires **reconfiguring** existing or building new pipelines, but there is **limited experience** with long-distance H_2 pipelines	Requires **additional process step** • adds costs and further reduces end-to-end efficiency rates[1]	Requires going down **further in the value chain**, including redesigning or building new facilities that are H_2-suitable
Most suited for	Domestic and regional transportation, especially where there are **existing natural gas pipelines** to leverage	**End-users** of derivative product[1] • NH_3 to fertilizer producers • CH_3OH to plastics producers • Synthetic kerosene to airlines	Jurisdictions aiming to **develop downstream industries**

See **Technical appendix** (slide 67) for full transport options assessment. This slide communicates the key takeaways.

Transporting H_2 gas via **pipelines** for domestic/regional transport and its derivative **ammonia** via ships for longer distances is most economical today

Of the ~18 Mt/yr H_2 equivalent of global international and long-distance H_2 trade forecasted by 2030, **45% is via pipelines** and **35% via ammonia**[3]

Countries with ambitions to develop downstream industries can circumvent the question of H_2 transport by **trading in H_2-derived goods** instead

1 BNEF (2022): 'Liebreich: The Unbearable Lightness of H2'; 2 H2 Council (2023): 'Global H2 Flows - 2023 Update'
*Low liquefaction temperature at -253°C (versus 162°C for natural gas), low volumetric energy density and difficulties in handling[1]

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Storage: A framework for governments to prioritize H_2 storage options

	Tanks	Geological storage	Other
Options	Pressure vessel bundles, elevated tanks or underground cylindrical steel tanks[1]	**Store underground in gaseous form** in salt caverns, depleted gas fields, aquifers or hard lined rock caverns	Store as **derivatives** (ammonia, methanol), in **materials** (LOHC), or via H_2-derived **products**
Key takeaway	**Uncertain future role for liquid H_2** as a scaled traded commodity due to H_2's inherent properties Gaseous storage already exists	**Salt cavern storage** is most developed, cheapest and suitable for fast-cycling operation	Similar considerations as for transportation
Key challenge	**Costs vary** based on equipment used and optimization of outgoing and incoming processing times. **Space restrictions** and health and safety regulations add costs	**Geographical availability** of geological formations is a prohibitive factor (especially for salt caverns). Storage **capacity and characteristics are given** and hard to modify[2]	
Most suited for	**Short-term, smaller-scale storage** used to operate H_2 supply chain (refuelling stations, export/import terminals)	**Long-term, larger-scale storage** to manage intermittency of renewable supply, seasonality of demand, and for energy security	

1 TÜV Nord: 'H2 storage: overview of possibilities'; 2 IEA (2022): 'Global H2 Review 2022'

See **Technical appendix** (slide 68) for full storage options assessment. This slide communicates the key takeaways

Scaling a sustainable H_2 ecosystem will require building out both **short-term *and* long-term storage capacity**

Short-term storage capacity will be used to operate the H_2 supply chain via **specialised high-pressure tanks**

The choice of long-term storage will depend on:

- **Geographical availability** of geological formations in country
- **Required flexibility** (frequency in planned injections/withdrawals) – salt and lined hard rock caverns better suited for short-term demand-supply management, whereas aquifers/depleted fields better to manage seasonality and energy security

Longer-term H_2 storage can also **support power system reliability** by addressing supply intermittency issues from solar/wind

H_2 hubs serve to minimize and spread network infrastructure costs to drive competitiveness

The benefits of H_2 hubs / valleys / clusters

H_2 hubs involve "**working jointly to design, finance, build and operate the core storage and transport infrastructure**"[1] required for a sustainable H_2 ecosystem

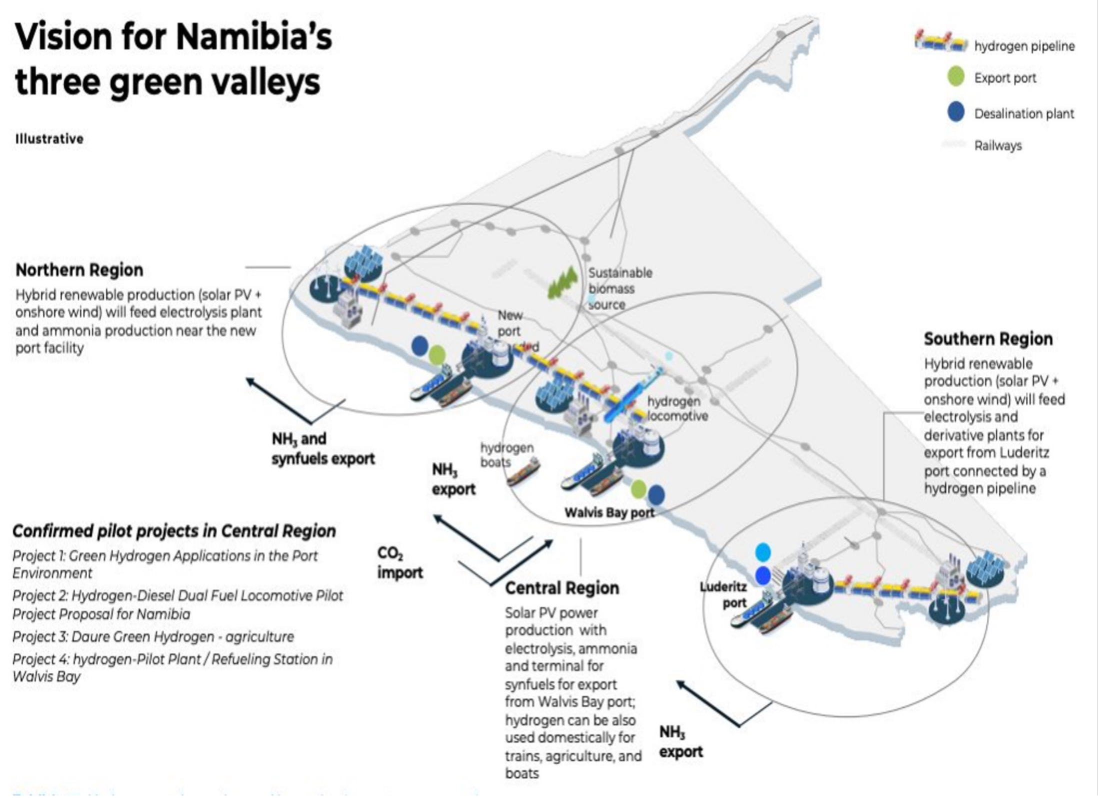
Key advantages

- Leverage existing, and optimize and minimize new **network infrastructure** for value chain build out
- **Share network costs** across several entities
- Contributes to **de-risking investments by involving a diverse range of off-takers from various end-users** with proximity to one another

H_2 leaders **across both developed and developing countries** are targeting building H_2 hubs:

- Regional Clean H_2 Hubs Program (H2Hubs) targeting up to $7 billion to establish 6-10 regional clean H_2 hubs across the US[2]
- H_2 Valleys Partnership in the EU
- UK HyNet North West H_2 hub
- Egypt's SCZone to become a green H_2 hub
- India plans to set up 2 green H_2 hubs by 2026
- Chile's Atacama H_2 Hub

Example: Vision for Namibia's three green valleys[4]



Sources: 1 EIB (2022): 'Africa's extraordinary green H2 potential'; 2 Energy Department website: 'Regional Clean H2 Hubs'; 3 Namibia Mines Ministry: H2 Strategy

C. Conduct stakeholder consultations to understand needs, mitigate risks, and maximize benefits

Government-led stakeholder engagement is vital for scaling

Stakeholder categories[1]	Goal of engagement	Points for discussion	Examples
Government agencies	Align policies, implement regulatory framework, and develop infrastructure	Potential conflicts and synergies with other policies and government priorities	Clearly defined government roles in Namibia's H_2 strategy document
Regulators, health and safety organizations	Implement environmental certifications, health and safety measures, etc.		
Local community	Negotiate land access and benefit sharing; communicate H_2 benefits (jobs, energy and water access); identify needs	Local development needs and constraints (e.g. land access); environmental concerns (deforestation, soil contamination)	US DOE hosted virtual community-level briefings for each H_2 Hub as a forum to learn about and provide input on H_2 projects[5]
Financing institutions (public and private)	De-risk H_2 projects to facilitate access to financing (see slide 38)	Identify financial risks for projects and highest-potential options for de-risking	In 2023, World Bank approved $1.65 billion in funding for renewable H_2 loans[6]
Private sector	Identify policy gaps, investment opportunities, and potential partnerships	Understand market needs from a private sector perspective	Mauritanian government signed an MoU with bp to explore large-scale green H_2 production[7]
Utility company (water, power, gas)	Gain access to utility-controlled inputs to production and infrastructure	Negotiate access to water/energy for H_2 production and infrastructure	EU to create new entity: an EU entity for H_2 Network Operators (ENNOH)[8]
NGOs	Alignment with SDG goals; funds	Socio-environmental impact assessments	NGOs push for additionality rules in EU[9]
Technology provider	Knowledge and technology transfer; collaboration on H_2 technology R&D[2]	Adapting best practice technology and knowledge to domestic/local context	The Green H_2 & Applications Park in Morocco includes R&D in Power-To-X sector[10]
Buyers/offtakers	Seek out offtake agreements	Understand willingness to pay for clean H_2	EU to import 10 Mt H_2/year by 2030[11]

Organizing roundtables, working groups, etc. to serve as focal points for discussion and coordination can bring together many stakeholders simultaneously[2]

Sources: 1 NREL (2023): 'H2 Considerations Tree Executive Deck'; 2 IRENA and UNIDO (2024): 'Green H2 for sustainable industrial development: A policy toolkit for developing countries'; 3 ; 4 ; 5 Office of Clean Energy Demonstrations (2023): 'H2Hubs Local Engagement Opportunities'; 6 World Bank (2023): 'World Bank Proposes 10 GW Clean H2 Initiative to Boost Adoption of Low-Carbon Energy'; 7 BP (2022): 'bp and Mauritania to explore green H2 at scale'; 8 EU (2023): 'Gas package: Council and Parliament reach deal on future H2 and gas market'; 9 Transport and Environment (2023): 'NGOs call for additional renewables to accompany H2 generation' ; 10 Green H2 Organization website accessed 31/03/2024: 'Morocco'; 11 EU (2023): 'H2'

Local community engagement for land-use is particularly important for scaling sustainable H_2 ecosystems

Land-use considerations

Land for sustainable H_2 production competes with alternative land uses

- H_2 production requires land for electrolysers, added renewable energy capacity, and wider network infrastructure
- This competes with alternative land-uses like agriculture, housing, biodiversity, etc.
- Construction also risks driving deforestation, soil contamination, erosion, and ecological imbalances, potentially undermining environmental benefits

It is crucial to avoid land expropriation from sustainable H_2 scaling, which would directly conflict with development

- Without safeguards, natural resource projects can lead to the expropriation of community lands, forests, and water resources, sparking conflicts and undermining traditional communal ownership
- Even where formal changes were made to land ownership laws, traditional practices may persist, exacerbating the potential for disputes
- Large energy projects like hydropower have historically displaced large populations to create reservoirs (e.g. Ghana's Okosombo dam displaced 80,000 people), driving poverty, landlessness, food insecurity, etc.[1]

Governments can leverage established consultation guidelines

Examples:

Development institutions: e.g. IFC's A Good Practice Handbook for Stakeholder Engagement[2]

Carbon crediting project certifiers: e.g. Gold Standard's stakeholder consultation requirements[3]

Private sector: The American Petroleum Institute (API)'s Community Engagement Guidelines[4]

Common themes:

- Continuous stakeholder engagement is crucial, emphasizing the UN principle of Free, Prior and Informed Consent (FPIC) to ensure community buy-in and address concerns of traditionally marginalized groups
- Development agreements should incorporate clear benefit sharing mechanisms including local job creation, infrastructure improvements and environmental protections, negotiated through transparent partnerships
- Projects should prioritize sustainable use of water and electricity, with governments and companies collaborating to ensure resources contribute to broader community development beyond project requirements
- Consider land-for-land compensation rather than monetary settlement if land access is impacted (especially for groups like subsistence farmers)

Sources: 1 Randell (2022): 'The challenges of dam-induced displacement: Reducing risks and rethinking hydropower'; 2 IFC (2007): 'Stakeholder Engagement: A Good Practice Handbook for Companies Doing Business in Emerging Markets'; 3 Gold Standard (2022): 'Stakeholder Consultation and Engagement Requirements'; 4 API (2014): 'Community Engagement Guidelines'

Local community engagement should also serve to identify opportunities for underserved communities

See **Case Studies Appendix** for overview of Mauritania and Namibia projects

Energy access[1]

Electricity is fundamental for economic development, as it provides…

- … lighting for studying at night and powers educational tools such as computers and internet access to **improve education**
- … power for medical equipment, refrigeration for vaccines and medicines and lighting for healthcare facilities, **improving public health** notably reducing maternal and infant mortality
- … power for **industrial production** and wider income-generating activities to generate jobs and economic growth

Opportunity: Build renewable power capacity for electrolysis-based H_2 production with upfront plans for **excess power output to expand energy access**

Water access and sanitation

Globally, **2 billion** people lack access to safe drinking water, and **3.6 billion** to safely managed sanitation, exacerbating health risks, food insecurity, etc.[2] Many sectors rely on water, e.g. the global energy sector used ~370 billion m^3 of freshwater in 2021, about 10% of global freshwater withdrawals[4,5]

Lack of access to water **exacerbates gender inequalities**. The absence of clean water affects menstrual health and education for girls, leading to higher school dropout rates, and complicates maternal and new-born health, as health clinics lack basic sanitation and hygiene facilities[3]

Opportunity: build desalination plants for electrolysis-based H_2 production with upfront plans for **excess water output to expand clean water access**

Unemployment and poverty

There are pronounced regional inequalities across and within West African countries

H_2 production can target underserved regions and localities with high unemployment and poverty, e.g.:

- **Retaining unemployed populations by closed mines**, e.g. unemployed workers of Orano's 2021 closure of COMINAK uranium mine in Niger[7]
- **Manage long-term job loss from oil and gas sectors** in countries like Nigeria due to global transition away from fossil fuels

Opportunity: building and scaling a sustainable H_2 ecosystem can **generate local employment and drive new skills development**

Case study: Mauritania's Megaton Moon project exemplifies the joint targeting of H_2 scaling with expanding energy and water access: at least 10 TWh of the 190 TWh/year of wind and solar generation will be channelled to developing a large-scale desert farming industry, and only a third of the 70 million tonnes of desalinated water will be used for H_2 production, the rest channelled to water access and irrigation[6]

Case study: Namibia's HYPHEN project to create 15,000 direct jobs from construction over the first four years and 3,000 permanent jobs. 90% of jobs to accrue to locals[8]

Sources: 1 PwC (2023): 'Accelerating renewable energy investment in West Africa'; 2 UNESCO (2023): 'Imminent risk of a global water crisis, warns the UN World Water Development Report 2023'; 3 World Vision (2024): 'Global water crisis: Facts, FAQs, and how to help'; 4 IEA (2023): 'Clean energy can help to ease the water crisis'; 5 IEA (2020): 'Introduction to the water-energy nexus'; 6 H2 Insight (2024): ''Visible from space' | Danish developer plans to build 35GW moon-shaped green H2 plant in Mauritanian desert'; 7 ARTE.tv (2023): 'Niger: Ghosts of Uranium | ARTE.tv Documentary'; 8 Green H2 Organization website

An H_2 ecosystem will require specific human capabilities

Human skills and capabilities

The safe production, storage, transport, and use of sustainable H_2 requires **bespoke knowledge and safety protocols**

- There is a **shortage of qualified engineers** to install, monitor, operate, and maintain H_2 systems, generally across the world and especially in many developing countries[1]
- Academic and research institutions are well-placed to launch and scale H_2-specific training and retraining initiatives to fill the skills gap
- **Domestic oil & gas expertise** are relevant capabilities and can be leveraged to building H_2 capabilities[2]

Developing expertise in **H_2 end-use sectors** is equally important

- Moving downstream in a value chain **relies on new capabilities**, e.g. differences in capabilities between bauxite mining and alumina refining[2]
- Training and retraining programs should also focus on developing skills for not only H_2 but also its relevant end-use applications, e.g., in direct iron reduction, alumina refining, cement production, etc.

Local content policies

Multinational companies (MNCs) may bypass local impact by importing workforce and materials, reducing local employment and skill growth opportunities, and knock-on benefits to the local economy

Local content policies can ensure utilization of local labour and resources to drive local impact:

- **Economic growth**: stimulate economic development by fostering the growth of local industries and businesses
- **Job creation**: generate employment opportunities within the local community by encouraging the use of local labour and suppliers
- **Skills development**: facilitate the transfer of knowledge and skills to enhance the competitiveness of the local workforce, by involving local businesses and workers
- **Resilience**: makes the economy more resilient to external shocks and disruptions in global supply chains by reducing dependence on imports

Sources: 1 ESMAP and World Bank (2020): 'Green H2 in Developing Countries'; 2 Key Informant Interviews

D. Create a policy and finance enabling environment

Countries are focussing on three sustainable H_2 policy categories to pursue simultaneously[1]

	Legal and Regulatory Framework	Incentives and Enabling Conditions	Standards and Certifications
Impact	**Decision Making** • Land-use and zoning • Fiscal investments • Accident liability	**Partnership Building** • Investors • Import/Export • Subsidies	**Quality Defining** • Terms: "low-carbon" or "sustainable" H_2 • Meet national climate and energy pledges • Measure performance • Market participation
Examples	**EU, China:** Committee oversight, delegation to member governments **Egypt:** PM-led central task force **Namibia**: Directed by technocratic task force, previous economic minister **Mauritania:** H_2 delegation integrated in Ministry of Petroleum and Energy	**Egypt**: 33-55% revenue deducted from tax **US**: Production credit - $3/kg H_2 produced **EU**: EU Emissions Trading System (ETS) **Australia**: Commissions with India, China **Morocco:** Favourable tax treatment, R&D support, planned subsidies	**India**: "From renewable sources" **US**: "Less than 2 kg/CO_2 per 1 kg/H_2 produced" **Mauritania:** "Low-carbon H_2" as a mix of green, blue and turquoise H_2
Considerations	State capacity and agency resources will drive policy execution • All countries studied planning "**H_2 Hubs**" • Goals vary. **Namibia** plans exports, **Kenya** focus on domestic fertilizer production	Carbon taxes can fund H_2 investments • **Incentives**: Change given value chain focus • **Production**: Subsidies • **Distribution**: Tax deductions	Market interoperability requires consensus, with first-movers able to influence direction of travel **DIN**: Relatively comprehensive quality standards, less global recognition **ISO:** International collaboration, less sophisticated standards

The most effective policy tool for supporting sustainable H_2 depends on country goals and political-economy context, with many options tested globally[1]

Sources: 2023-2024 Policy Strategy Sources Hyperlinked: EU, China, USA, India, Australia, Egypt, Kenya, Namibia, Morocco, Mauritania

H_2 projects add unique challenges to the risks of major infrastructure projects in emerging economies

	Risks	Mitigation
Infrastructure Assets Generally		
Macroeconomic	Currency depreciation, inflation, interest rate spikes	FX Hedging, interest rate swaps, fixed rate loans
Regulatory / Political	Expropriation, contract breach, legal framework changes	Political risk insurance, regulatory and judicial predictability
H_2 Projects Specifically		
Energy Offtaker	Uncertain H_2 demand, limited credible offtakers, default risk	Purchase agreements, policy guarantees, demand aggregation
Technology	Defective components, electrolyser degradation, system disintegration	National infrastructure master plans, construction, performance guarantees

Once West African governments confirm H_2 infrastructure feasibility, they can adopt OECD's integrated risk & finance playbook[1] for H_2 system development in emerging economies:

- Partial credit and risk guarantees
- Political risk insurance
- Liquidity accounts

Adopt a **"no-regret"** strategy to **"right-size"** H_2 market:

- Rely on electrification for most needs
- Estimate domestic consumption use cases
- Broker and execute international trade agreements

Sources: 1 OECD Scaling H2 Financing for Development (2024)

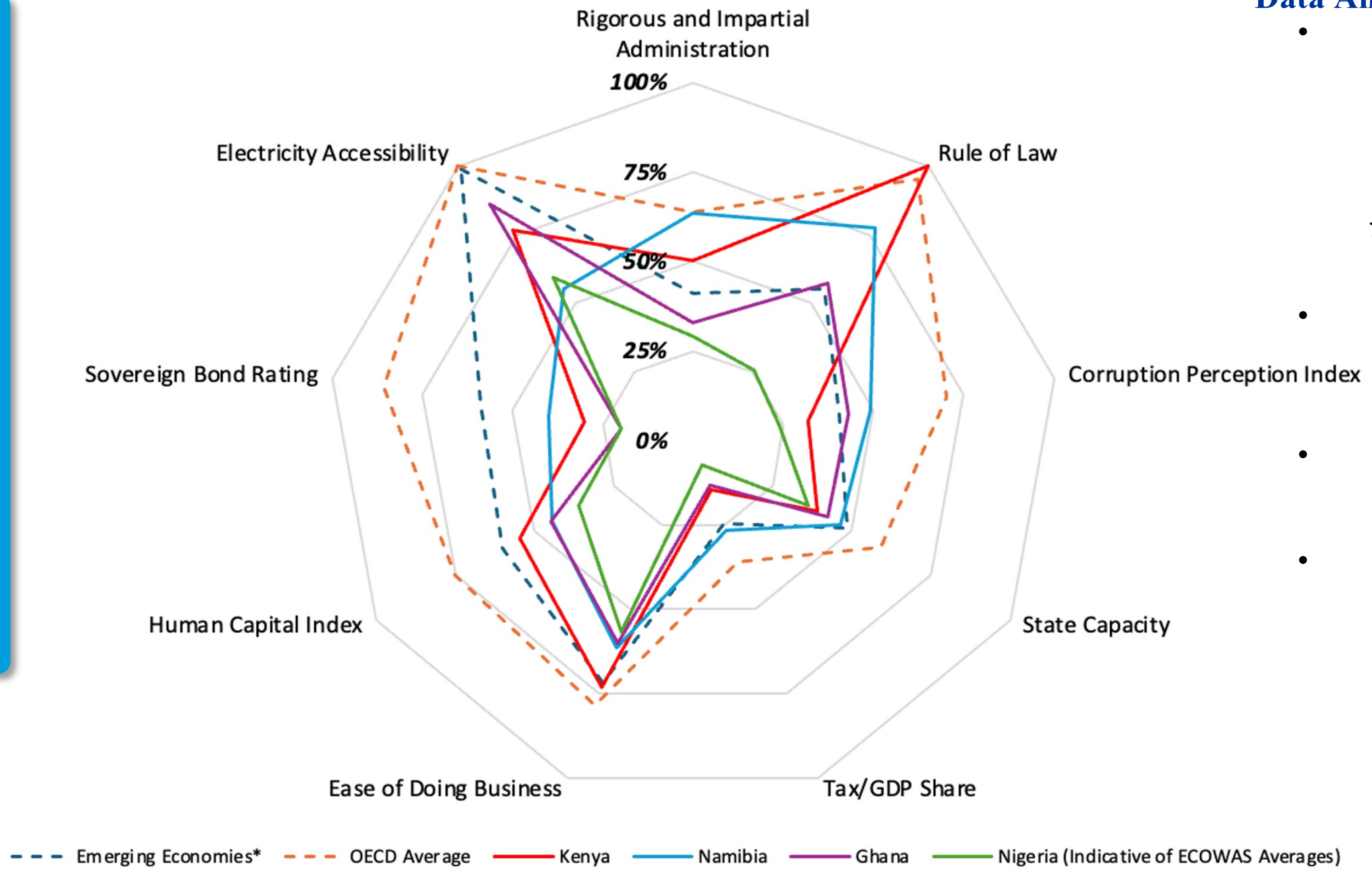
West African states face more H_2 scaling obstacles than many other political-economy contexts, leading to more policy work, de-risking efforts, and higher costs of capital

Key limitations in the power and financial sectors limit H_2 infrastructure development in West Africa more so than in other developing regions.

Sustainable development requires improving many indicators simultaneously to accelerate virtuous cycles in human health and education, economic growth, infrastructure build-out, and energy availability.

These data indicate inputs that will improve the potential for sustainable H_2 systems in West Africa.

Graph compares select African country averages to Emerging Economies and OECD averages on indicators conducive to H_2 system development (2022 or latest)*



Data Analysis Takeaways:

- On average, West African states lag furthest in debt ratings, human capital, electricity access, and taxation ability. Ghana aligns with emerging economies now, justifying further investigation. Nigeria is representative of ECOWAS statistics.
- There are key policy actions member states can take to create and execute investment opportunities.
- Percentages reflect regional averages with "optimal" values as denominator.
- Definition for optimal depends on the variable. For example, "full electricity access" for electrification and "risk-free" for sovereign debt are optimal outcomes, scaled to 100%.

*From JP Morgan: *"The GBI-EM Global Diversified 15% Cap 4.5% Floor (GBI-EM Global 15/4.5) is designed to track the performance of bonds issued by emerging market governments and denominated in the local currency of the issuer... The index includes only those countries that are accessible by most of the international investor base and selects bonds from each of the emerging market countries set forth below that are fixed-rate, domestic currency government bonds with greater than 6 months to maturity"*

West African states can conduct three initial activities to prepare for H_2 infrastructure financing and policy design

Stimulate market activity to address multilateral development bank & institutional investor* needs

Power and Finance Incentives

- Build-out solar, wind, water capacity and supply estimates
- Define tariffs and constraints on tariff changes
- Define credible bidder selection criteria
- Motivate oil & gas incumbents to investigate H_2 infrastructure opportunities

Broad-based Data Collection and Analytical Research

- Estimate electric capacity and energy endowments
- Assess credit risk for governments and subnational polities
- Identify human capital status and gaps
- Gauge water stress at the locality level

Forward-Looking Commodities Expansion

- Project future ammonia, fertilizer, sustainable aviation fuel, steel demand, shipping needs
- Expand trade capacity (harbour, rail, road, piping infrastructure)
- Lean into CBAM-enforced export markets
- Local labour force training as part of energy company and MNC investments

H_2 production and consumption entail key infrastructure and financing risks common to all emerging economies.

Given West Africa's additional H_2 development obstacles, these initial de-risking mechanisms will prepare the region to pursue best practices in emerging economy H_2 market expansion.

West African governments will benefit from clearly defining H_2 markets and regulations before advancing financial instruments and risk strategies.

Publishing robust feasibility studies on the ROI for H_2 outputs will help West African governments gain multilateral development bank commitments, reduce cost of capital, and start virtuous circles.

*Multilateral Development Banks, Multinational Corporations, Development Finance Institutions, Private Equity Managers, Export Credit Agencies, Commercial Banks, Pension Funds, etc.

Blended finance brings together public and private sector capital to bridge the sustainable H_2 financing gap

There is a yearly ~$10 billion financing gap in the African H_2 space.[1] Finding the optimal mix of debt, equity, and donations from public, private, and non-profit sources for the project, depending on its payback, risks, and timeframe. Blended finance expands funding access across the project lifecycle. Inviting more financing stakeholders, however, multiplies communication and legal complexities.

Public Private Partnerships

PPPs are increasingly popular collaborations that **reduce risk across many actors and align profit with social impact goals**. Necessary as projects expand into infrastructure assets

Development Finance Institutions

DFIs recognize the need for scaling critical infrastructure to create self-reliant, developed economies and markets. **Experience working with private sector partners**

Build-Own-Operate-Transfer

In **BOOTs**, project developers define innovative arrangements with governments to justify investing in initiatives, earning a **reasonable profit**, and then providing the finished assets **back to the community**

Climate Bonds

Like traditional bonds, but with **higher prices and environmental expectations**. Increasingly standardized with emission reduction goals. Some major asset managers **require a percentage of their money placed in climate bonds**

Illustrative Examples

The Namibian government and German corporations are developing the Hyphen H2 project in Namibia.[2] The $10 billion project has offtake agreements signed by well-funded entities like the Dutch Port of Rotterdam. The project suffers from perceptions of an opaque tendering processes

The **European Bank for Reconstruction and Development** lent $80 million to **Egypt's** sustainable H_2 facilities, focused on ammonia production and export.[3] The **International Development Association** has committed $2 billion to the **West African Power Pool**

India-based Hygenco has set up a green H_2 generation plant on a BOOT basis in the state of Madhya Pradesh.[4] The alkaline electrolysis-based plant includes a solar project

Last year, **Barbados announced a clean energy bond facility** of $150M.[5] The Nature Conservancy and the IADB co-guarantee the securities, which indirectly finance a 50 MW solar facility with sustainable H_2 and battery storage. CIBC FirstCaribbean and Credit Suisse arranged the dual-currency deal

Sources: 1 OECD Scaling H2 Financing for Development (2024); 2 The Namibian, (2024); 3 EBRD (2022)'; 4 PV Magazine (2022); 5 Business Barbados (2023)

The H_2 system project financing partners change across the infrastructure development lifecycle

Project lifecycle stages

Project Scoping	Feasibility, Proposal, Approval	Construction, Commissioning	Operation
Donors: Foundations, Trusts, Government Aid Agencies		Institutional Investors: PE, MNCs, Pension Funds, Infrastructure REITs	
Governments: Sovereign Wealth Funds, National Development Banks		Export Credit Agencies	
High-Yield Investors: Asset Managers, Angels, Venture Capitalists		Low-Risk Liquidity Investors: Commercial Banks, Mutual Funds	
Project Developers			
International Public Investors: Multilateral Development Banks, Development Finance Institutions			

Example partners

UNDP Rockefeller Foundation	USAID, GIZ		
Ghana's SWF China Construction Bank	International Finance Corporation	JP Morgan, Goldman Sachs Nigeria Export-Import Bank	Canadian Teachers' Pension Fund
Breakthrough Energy	Sequoia, BlackRock Air Products & Chemicals, Inc.	KKR, BlackStone	The Gaia Group Vanguard, Fidelity
DFC	African Development Bank	Africa Finance Corporation	NextEra, Clearway

Example financial instruments across the project lifecycle

Grants, Technical Assistance	Concessional lending	Commercial debt & equity, risk mitigation instruments	Exit to commercial buyers

Financing Categories: Donation | Equity | Debt | Blended

**Adapted from OECD Nov 2024 H2 Financing Report. This is an illustrative example of financing partnerships and is not intended to be comprehensive or exclusive*

West Africa's Sovereign Wealth Funds (SWFs) are well-positioned to unlock financing for sustainable H_2 ecosystems in the region

Governments across Sub-Saharan Africa have founded 15 new SWFs since 2010. **Nigeria ($2.5B), Senegal ($850M), Ghana ($650M), and Mauritania ($150M) have hydrocarbon wealth-capitalized SWFs.**

Upsides

- Remit already emphasizes public infrastructure, including power generation and transmission
- Government mandate to pursue the double-bottom line* and justified to spend oil revenues on sustainable development
- Catalyzes new investments and attracts private capital
- Long-term investment horizon (20+ years)
- Low WACC** relative to domestic private investments

Downsides

- Crowded remit: other critical investments compete with H_2 : Highways, water systems, schools, hospitals, and currency stabilization
- Complex bureaucracy slows permitting and investment decisions
- Perception and/or reality of corruption; need to partner with governments on goals but maintain independent investment risk and reward criteria and diligence processes

Nigeria's $2.5B assets under management NSIA* is highly capitalized and exploring the H_2 space.**

Overall energy strategy: Expand access, enhance efficiency, ensure security. On the ground greenfield developments

Immediate focus: Find sustainable development partners who will **match** NSIA's investment. Blended finance partnerships with DFIs and MNCs.

Current challenges: Complex, but comprehensive investment approval process includes 4 layers of committee review

Nov. 2023: Announced initial **$500M** platform with IFC to build renewable energy pilot projects

- Initial emphasis on diesel displacement, solar PV build-out
- Intent to develop **upstream technology manufacturing** - ammonia production, waste-to-energy, wind, hydroelectric
- Only **$25M** committed by NSIA to date; ongoing pilot research and partnership development

Santiago Principles signatory: International commitment to transparency, sound investments, open capital flows

*Find high-impact, profitable investments, **Weighted Average Cost of Capital
****Nigerian Sovereign Investment Authority. 50% of NSIA funds allocated to National Infrastructure Fund, remainder allocated to long-term development programs and currency stabilization (30% and 20% respectively)

Recommendations

Pursue a 'no-regret', multi-stage implementation:

1. Undertake significant preparatory work in setting up enabling conditions and regulatory framework for successful H_2 scaling
2. Renewables-based H_2 production is a more versatile option with stronger development synergies to enhance water and energy access
3. Start by demand centres to minimize value chain costs and target existing H_2 users like oil refineries and ammonia/fertilizer producers as anchor buyers
4. Over the long term, scale regional trading corridors in power, water, minerals and H_2 to drive cost competitiveness and open opportunities for all ECOWAS members

Overall Recommendation: Pursue a ‘no-regret’, multi-stage approach to scaling H_2 ecosystems in West Africa

Recommendation (deep dives to follow):

1 Build Capacity

Set up **enabling conditions and regulatory framework**

2 Industrial Hubs

Initiate **demonstration projects by industrial hubs**

3 Regional Scaling

Scale **regional trading corridors** in power, water, H_2 and opportunity-relevant resources

Existing ECOWAS targets[1]

- 2025-26: 3 H_2 clusters and 5 scalable production projects
- **2030**: **Product 0.5 Mt H_2 /year**
- **2040**: Ghana starts H_2 DRI in iron & steel industry[2]
- 2045: Ghana starts producing clean hydrogen[2]
- **2050**: **Produce 10 Mt H_2 /year**

Key dates from outside ECOWAS

- 2026-27
  - Swedish H2 Green Steel launch
  - Namibia Hyphen Phase 1
- 2027-29
  - Mauritania AMAN project First Stage and exports
  - Mauritania Megaton Moon Project pilot launch
- 2033-35
  - Mauritania Megaton Moon project fully operational
- 2037
  - Mauritania AMAN project fully operational

Sources: 1 ECOWAS (2023): ‘ECOWAS Green H2 Policy and Strategy Framework’; 2 SEforAll (2023): ‘Ghana Energy Transition and Investment Plan’; 3 Hyphen website accessed 31/03/2024; 4 Rattan (2024): ‘Mauritania | $40 billion AMAN green H2 project’; 4 H2 Insight (2024): ‘'Visible from space' | Danish developer plans to build 35GW moon-shaped green H2 plant in Mauritanian desert’

Note: further stakeholders also mentioned in other slides; list non-exhaustive

1 Set up enabling conditions and regulatory framework (1/3): stakeholder engagement

Local communities

Local stakeholder engagement to understand needs, mitigate risks, and maximize benefits. In addition to direct engagement with specific communities, consultations can leverage cross-community organizations, e.g.

West Africa Coalition for Indigenous Peoples' Rights (WACIPR): NGO representing >**147 communities** on areas like legislative protection and transactions on Mutually Agreed Terms approved by the authorities of the communities[1]

THE MOVEMENT FOR COMMUNITY-LED DEVELOPMENT: Works with **civil society and governments to drive effective partnerships** to achieve voice for marginalized communities, community financing, local governance, public services, etc.[2]

Private sector and international companies

Private sector engagement to understand market needs and negotiate beneficial partnerships, e.g.:

RioTinto: Developing **Guinea**'s DRI-grade iron ore in Simandou is a core part of company's growth strategy[3,4]

ArcelorMittal: Expanding **Liberia**'s iron ore mining (to spend $800m on rail, port and processing facilities[5]). Signed MOU to jointly develop green steel plant in Mauritania[6]

Others mentioned across the report and annexes: LAFARGE, DANGOTE, HYGENCO, OCP AFRICA, DAWA INDUSTRIAL ZONE, elemental water makers

International partnerships

Enter international partnerships to build capacity, transfer technology, and seek funding, e.g.:

AGHA – The Africa Green Hydrogen Alliance: Formed by Egypt, Mauritania, Kenya, Morocco, Namibia and South Africa to drive collaboration and accelerate **renewables-based H_2 development in Africa**[7]

H4D: New **global initiative announced by the World Bank** to "foster capacity building and regulatory solutions, business models, and technologies toward the roll out of low-carbon H_2 in developing countries"[8]

Africa-EU Energy Partnership (African Union, EU): Part of EU Global Gateway programme: to **support 40GW of electrolysis capacity** in Africa[9]

Sources: 1 UNESCO website accessed 31/03/2024: 'West Africa Coalition for Indigenous Peoples' Rights (WACIPR)'; 2 MCLD website accessed 31/03/2024: 'Manifesto'; 3 Bloomberg (2024): 'Guinea Lawmakers Approve JV for Simandou Iron Ore Development'; 4 IEEFA (2024): 'Big iron ore's long-term strategies diverging in the face of steel decarbonisation'; 5 S&P Global (2021): 'AM confirms Liberia iron ore expansion to 15 million mt/year with potential to double; 6 ArcelorMittal (2022): 'ArcelorMittal signs MoU with SNIM'; 7 AGHA website accessed 31/03/2024; 8 World Bank (2022): 'World Bank Group Announces International Low-Carbon H2 Partnership'; 9 H2 Insight (2023): ''Produce green H2 and you will find reliable buyers in us' | Germany pledges €4bn for African energy projects'

1 Set up enabling conditions and regulatory framework (2/3): forward-looking policy, financing, and regulatory agenda for West African governments

Feasibility

Delineate
- water and energy access needs
- renewables capacity and consumption
- feasibility studies on domestic and external H_2 demand
- human capital needs
- infrastructure needs

Responsibility

Develop
- a regulatory framework
- ministry responsibilities
- financial incentive system
- land permitting

Standards/certifications

Determine
- environmental/safety standards
- measurement and monitoring
- data collection, management and analysis systems

Leverage:
- national certification bodies
- ECOWAS Standards and Harmonization Model (ECOSHAM)
- international standards (DIN, ISO 19870:2023)

Strategy

Integrate H_2 strategy with:
- Infrastructure development goals
- Industrial policy, e.g. GIADEC* and GIISDEC** Master Plans (see slide 74)
- Polices to enhance water and energy access, food security
- Nationally-Determined Contributions (NDCs)
- Additionality rules

West African governments can collaborate within ECOWAS's institutional guidelines and framework[1] in order to …

… conduct detailed, standardized resource assessments to identify optimal locations for an H_2 ecosystem based on resources, land use, competitive advantage and offtake potential

… set clear, transparent processes for H_2 development to create a predictable environment in which project developers can operate

… implement stringent safety, technical and GHG emissions standards for the production, storage, transport and use of H_2 and its derivatives

… justify targeted equity investment and enhanced debt ratings; provide material for policy community to refine strategy and incentives in an iterative loop; identify strategic regional hubs and trading corridors

Sources: 1 ECOWAS (2023): 'ECOWAS Green H2 Policy and Strategy Framework'
* Ghana Integrated Aluminium Development Corporation; ** Ghana Integrated Iron and Steel Development Corporation

1 Set up enabling conditions and regulatory framework (3/3): local content policies and training initiatives

Local content policies

There are already several local content policies in ECOWAS countries applied to mining and oil & gas sectors, e.g.:[1]

- **Local hiring policies** in Benin, Guinea, Liberia, Sierra Leone or **priority hiring** of nationals in Côte d'Ivoire
- **Training programs to phase out expatriate staff** in Burkina Faso, Ghana, and Guinea-Bissau
- Continued training for national employees to **quality them for skilled positions** in Liberia and Mali
- **Submit annual reports** with national/expatriate staff composition and status of training programs in Sierra Leone
- **Local procurement policies** in Benin, Burkina Faso, Côte d'Ivoire, Ghana, Guinea-Bissau, Mali, Niger, Senegal, Sierra Leone and Togo

See Tables 3.6, 3.9 and 3.10 in World Bank report[1] for details

Many of these policies have been **successful in ensuring domestic investments generate local jobs, skills**, etc. for West African countries.[2] Existing local content policies could be extended to H_2 development

Training initiatives

Training initiatives should build **domestic capabilities** in the entire H_2 value chain, as well as in end-use sectors (e.g. ammonia and fertilizer production, oil refining, ironmaking, alumina refining, etc.)[2]

Initiatives and organizations to leverage include but are not limited to:

WASCAL West African Science Service Centre on Climate Change and Adapted Land Use
Federal Ministry of Education and Research

International Master's Programme in Energy and Green Hydrogen[3,4]

- 4 universities across Côte d'Ivoire, Niger, Senegal and Togo, with 1 semester in Germany as a foreign practical semester
- In-person instruction by local educators complemented by online tools and on-site teaching visits

INPG SENEGAL INSTITUT NATIONAL DU PÉTROLE ET DU GAZ

"Aims to **develop national expertise** and promote the employment of Senegalese men and women in the oil and gas sector".[5] Like other energy institutes in the region with transferrable O&G expertise, INPG is well-suited to launch H_2-specific training initiatives

Sources: 1 World Bank (2023): 'Africa's Resource Future'; 2 Expert interviews; 3 WASCAL website accessed 17/12/23; 4 BMBF (2021): 'West Africa can become the climate-friendly energy powerhouse of the world'; 5 INPG website accessed 31/03/2024

Demand centre
Water resource
Pilot H_2 project
Infrastructure

Note: examples with high potential, non-exhaustive

2 Initiate demonstration projects by industrial clusters: Nigeria

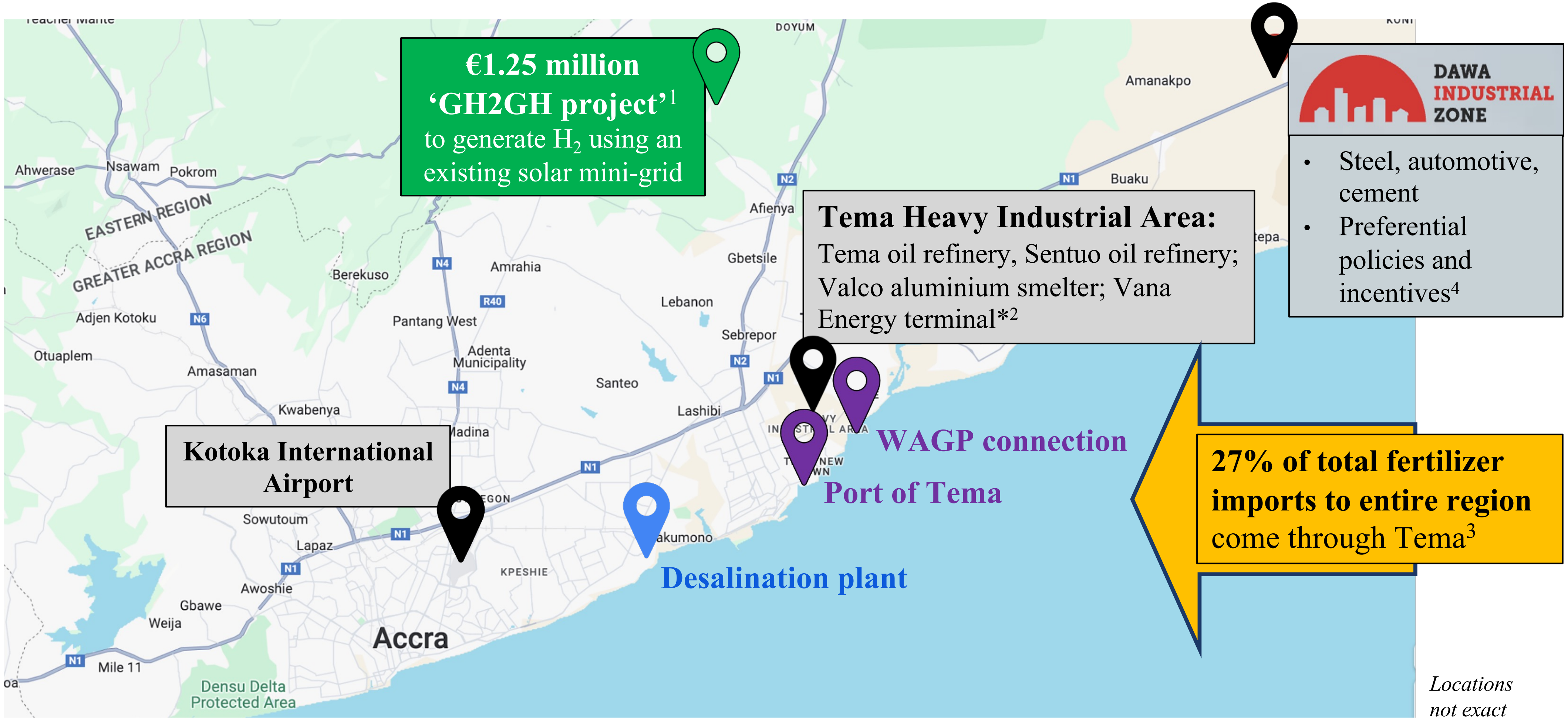
Sources: 1 Lagos Free Zone website; 2 FP (2022): 'Africa Needs More, Not Less, Fertilizer'; 3 IFDC (2021): 'Fertilizer Logistics in West Africa'; 4 Elemental Water Makers website accessed 31/03/2024

* West African Gas Pipeline

Demand centre
Pilot H_2 project
Water resource
Infrastructure

Note: examples with high potential, non-exhaustive

2 Initiate demonstration projects by industrial clusters: Ghana



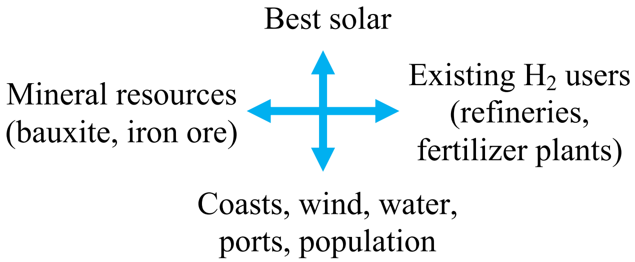
Locations not exact

Sources: 1 NowGmbh.de (2023): 'Green H2 technology for decentralized energy systems in Sub-Saharan Africa (GH2GH)'; 2 Vana Energy website accessed 30.03.2024; 3 IFDC (2021): 'Fertilizer Logistics in West Africa' ; 4 Dawa Industrial Zone website accessed 30.03.2024

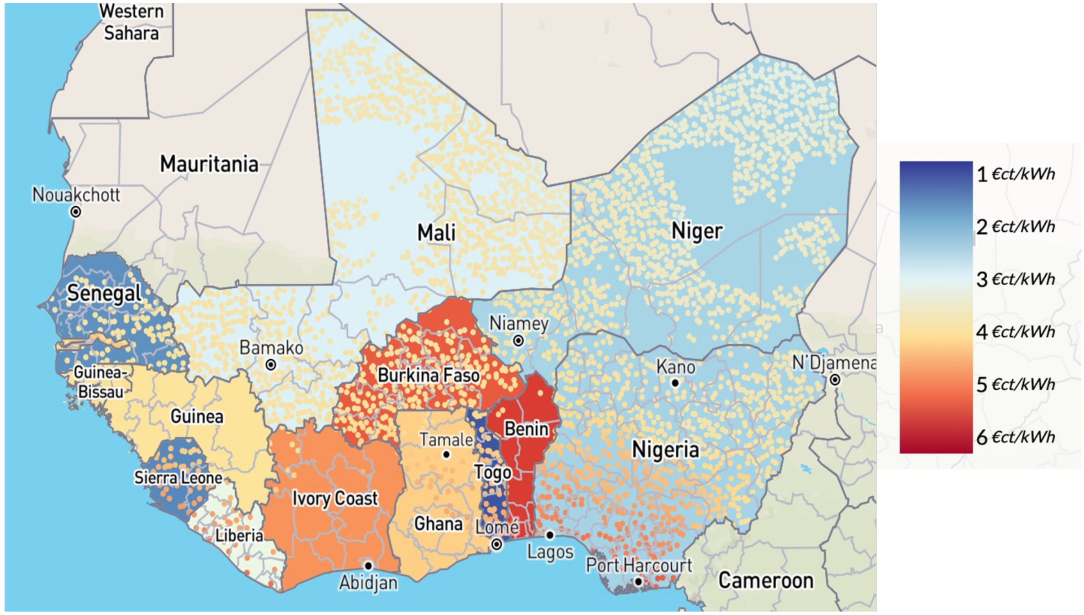
* 30 km^3 of storage capacity to store and load gasoil, gasoline and aviation fuel[2]

3

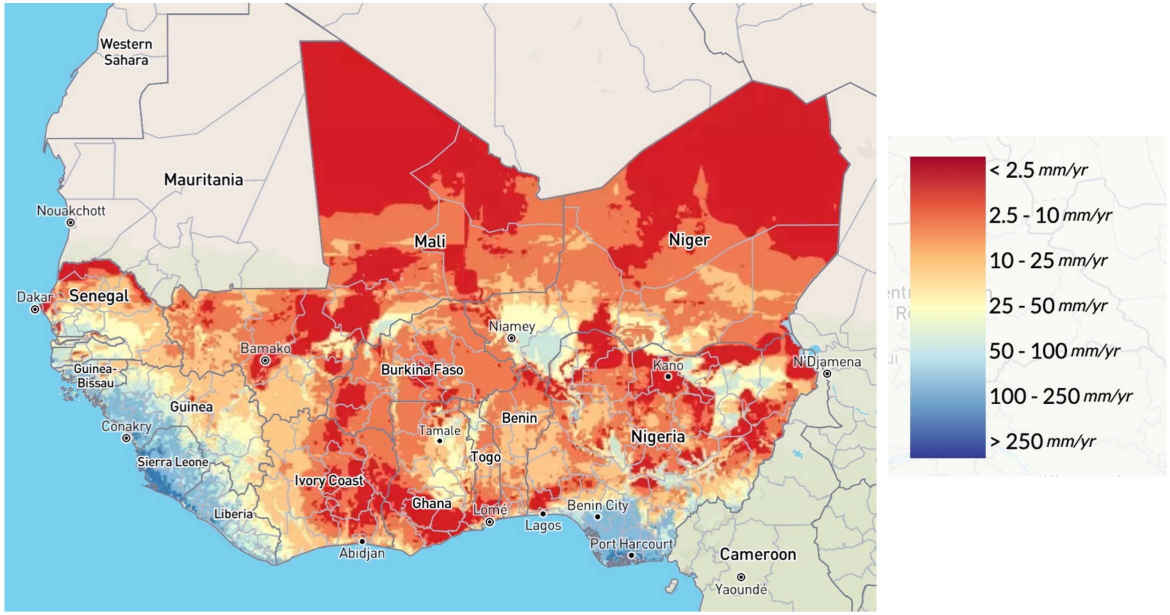
Opportunity-relevant resources are geographically dispersed across ECOWAS



Solar PV potential in West Africa (2020)[1]



Water availability in West Africa (2020)[1]



Renewable potential is abundant in the region

- Solar PV potential is best in the north, and its cost are expected to fall significantly to below 3 eurocent/kWh by 2050
- Wind potential is more constrained to coastal areas and northern dry regions, and its costs are not expected to fall to as low as solar PV by 2050

Water availability is a constraining factor for H_2 production in the region

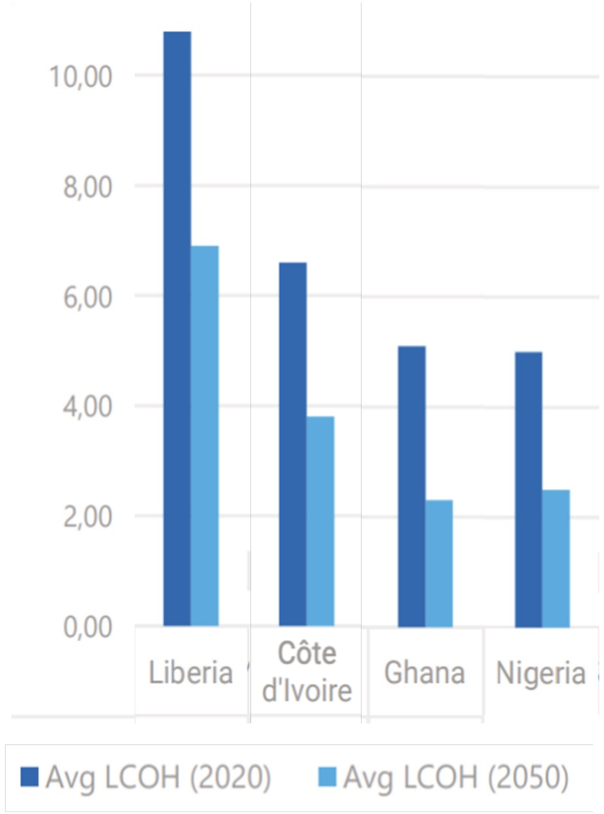
- Although groundwater scarcity is expected to diminish by 2050, WASCAL studies suggest **sustainable ground water could only support 20%** of ECOWAS' maximum technical potential of renewables-based H_2
- "**Desalinated instead of groundwater should be used**"[2]

"To bridge the regional disparity in the availability of resources such as [renewable energy], water, land and port availability, the Region will undertake necessary assessments to establish dedicated infrastructure corridors for easy transport of water, power, or H_2" (51)

Sources: 1 H2Atlas website accessed 17.03.2024; 2 ECOWAS (2023): 'ECOWAS Green H2 Policy and Strategy Framework
* This represents current groundwater availability for supplementary water usage (including green H2 production) after accounting for current groundwater recharge, medium environmental flow (60% of the simulated recharge) and all sectoral water consumptions

3 Scaling regional trade in opportunity-relevant resources opens development opportunities to all countries in ECOWAS

Levelized Cost of H_2 (LCOH), EUR/kg H_2[1]



H_2 scaling in country silos may exclude opportunities for certain countries

Côte d'Ivoire: **fertilizer opportunity**
+ Largest cocoa producer in the world, so development opportunity to enhance food security from building domestic fertilizer industry using H_2

Liberia: **iron and steel opportunity**
+ Large iron ore deposits and production, as well as large coast and 4 ports*, so industrialization opportunity from building green ironmaking industry using H_2

High costs of LCOH even in 2050 mean if either country scaled H_2 independently, they would be disadvantaged in terms of cost-competitiveness

Resource trading in water and power can lower the location and cost constraints of **H_2 production**

- Power trading via West African Power Pool (WAPP) – deep dive 1
- Water trading / desalination

H_2 and minerals trading can lower location and cost constraints of **H_2 end-uses**

- Options for West African Gas Pipeline (WAGP) – deep dive 2

Scaling regional trading corridors align with West African Common Industrial Policy (WACIP) goal to raise intra-ECOWAS trade from <12% today to 40% by 2030[2]

Sources: 1 ECOWAS (2023): 'ECOWAS Green H2 Policy and Strategy Framework'; 2 ECOTIS website: 'West African Common Industrial Policy (WACIP)'
*Freeport of Monrovia, Port of Buchanan, Port of Greenville, Port of Harper

3

Deep Dive 1: Leverage the West African Power Pool to scale intra-regional power trading

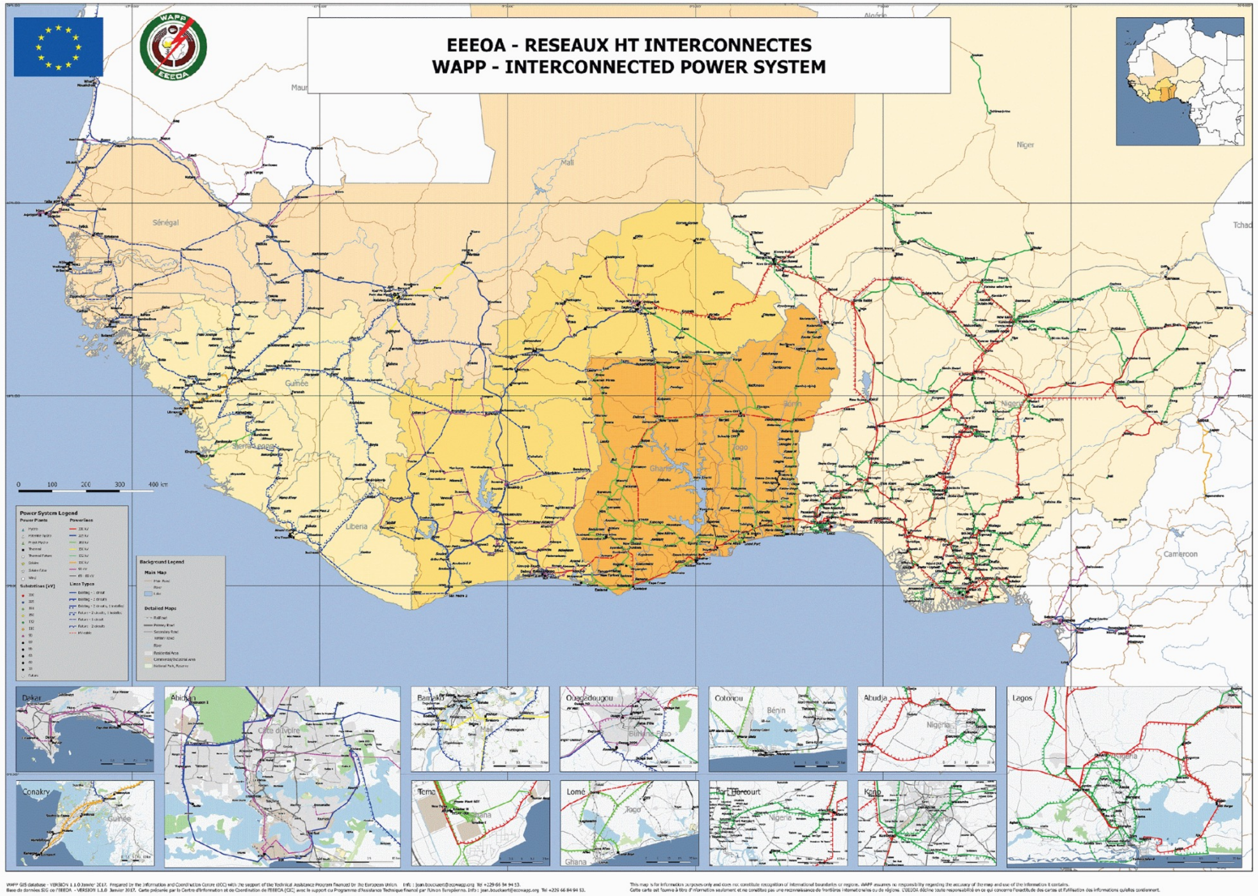
West African Power Pool (WAPP)

The WAPP is a "cooperation of the national electricity companies … with the vision to integrate the national power systems into a **unified regional electricity market**"[1]

- WAPP develops infrastructure for power generation and transmission, with primary interconnectors already linking the grids of all ECOWAS countries albeit not yet fully deployed[2]
- Scaling regional power trading could "tap into the region's diversity in generation resources and costs"[1]

"Supporting infrastructure development to transport energy or resources to other favorable regions remains **key to overcome the challenge of cost-effective green H_2 development in the region**"[1]

- Scaling intra-regional power trading through the WAPP can provide access to low-carbon, low-cost electricity for H_2 production closer to demand-centers and coasts: it is easier and cheaper to transport power than it is to transport H_2
- To avoid unintended consequences, H_2 production using grid electricity may require accompanying additionality rules (see slide 28)



Sources: 1 ECOWAS (2023): '[ECOWAS Green H2 Policy and Strategy Framework](); 2 Expert interviews; 3 ECOWAPP website

3

Deep Dive 2: Leverage the West African Gas Pipeline to scale intra-regional H_2 trading

West African Gas Pipeline (WAGP)

The WAGP is an **existing 100 MMcf/d natural gas pipeline** linking Nigeria, Benin, Togo and Ghana, with plans for a 5,600 km extension to Morocco by 2046[1,2]

- MOUs have been signed by all countries involved after the $13 billion Trans-Saharan gas pipeline project* was abandoned following the 2023 coup in Niger

Although currently transporting natural gas, the WAGP could transport H_2 in the future. The higher the share of H_2 blended, the costlier and more significant reconfigurations are needed for the pipeline to receive H_2 without leakage, embrittlement, etc (see Slide 9 and Technical Appendix slide 67). This leaves **different options available for different timescales**:

- *Immediate*: blend H_2 up to maximum 20% without major reconfigurations
- *Medium-term*: moderately reconfigure for higher share injections as traded H_2 volumes scale
- *Long-term*: significantly reconfigure for 100% H_2 transport or build new dedicated H_2 pipeline - Morocco is planning an 5,600km H_2 pipeline to run adjacent the WAGP through 11 West African countries[2]

To fund these reconfigurations and/or new pipelines, the region can **leverage the EU's Strategic Corridors for EU-Africa connectivity**: 4 of 11 proposed corridors focus on West Africa:[3]
1) ABIDJAN-LAGOS - Côte d'Ivoire, Ghana, Togo, Benin, Nigeria
2) ABIDJAN-OUAGADOUGOU - Côte d'Ivoire, Burkina Faso
3) PRAIA/DAKAR-ABIDJAN - Senegal, Gambia, Guinea-Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Cabo Verde
4) COTONOU-NIAMEY - Benin, Niger
€150 billion in funding is available between 2021-2027

Sources: 1 S&P Global (2024): 'Nigeria eyes 3 Bcf/d gas pipeline to Morocco after relations sour with Niger'; 2 H2 Insight (2023): 'Morocco plans 5,600km H2 pipeline from Nigeria, passing through 11 West African states'; 3 European Commission (2022): 'Strategic corridors to improve Europe – Africa Connectivity'
*The Trans-Saharan gas pipeline would have involved a 4,128 km pipeline from Warri in southern Nigeria through Niger to Algeria's Hassi R'Mel gas hub[3]

Conclusions

Opportunity for net-zero-aligned industrialization and import substitution but with careful preparation to avoid stranded assets

Key takeaways: a no-regret strategy for ECOWAS

1 Undertake **significant preparatory work** in setting up enabling conditions and regulatory framework for successful hydrogen scaling

2 **Renewables-based H_2 production** is a more versatile option with stronger development synergies to enhance water and energy access

3 **Start by demand centres** to minimize value chain costs and target existing H_2 users like oil refineries and ammonia/fertilizer producers as anchor buyers

4 Over the long term, scale **regional trading corridors in power, water, minerals and hydrogen** to drive cost-competitiveness and open opportunities for all ECOWAS members

Appendices

1) Technical Appendix
2) Case Studies Appendix

1) Technical Appendix

An overview of key H_2 use-cases

Sector	Leading H_2 application	Place on H_2 priority ladder	Redesign required?	Supply chain requirements	Synergies for hydrogen hubs
Ammonia	Low-carbon ammonia (NH_3) production	High – existing H_2 user - 63 Mt H_2 demand by 2030 and 83 Mt by 2050 for global net zero[1]	No - Simply replaces H_2 as input, so readily deployable - 10% of global production already traded globally[2]	Minimal - Haber-Bosch process takes nitrogen from air - Existing shipping and port infrastructure[6]	Significant - Wider offtaker potential: to produce fertilizers and shipping fuel, and to use in gas turbines and coal-fired plants to enhance power system flexibility[2,8]
Steel	H_2-powered direct reduced iron electric arc furnace (DRI-EAF)	High – limited alternatives - 19 Mt H_2 demand by 2030 and 54 Mt by 2050 for global net zero[1] - Commercial viability by 2026[3]	Yes - Requires new facilities that are 90% costlier[3] - Raises unit price of steel by 20-40%[4,5] and a car by $326[4]	Significant - Needs scarce high-grade iron ore (≥67 Fe content)[7] - Requires new H_2 supply network infrastructure	Yes - Water vapour from chemical reaction can be recycled for water electrolysis (closed cycle)
Cement	H_2 injections for thermal energy in kiln for clinker production	Moderate – alternatives - More advanced than electrification but less than clinker-to-cement reduction and CCS (which is crucial to address chemical reaction emissions)	Depends - Readily deployable drop-in for blending, but requires major burner redesign for full switch	Significant - Requires limestone and clay raw materials - Requires new H_2 supply network infrastructure	Yes - Steam from H_2 burning for heat can supply water for electrolysis - Captured CO_2 from chemical process can generate e-fuels if combined with renewable H_2[9]
Aluminium	Direct role in alumina refining to feed thermal energy processes	Moderate – alternatives - No direct role in smelting - In refining, medium-potential role to feed high-heat thermal energy but electrification better for low- and medium-heat	Yes - Requires retrofitting to avoid affecting product quality	Significant - Requires bauxite raw materials - Requires new H_2 supply network infrastructure	

Sources: 1 IEA (2020): "Net Zero by 2050'; 2 IEA (2021): 'Ammonia Technology Roadmap'; 3 Mission Possible Partnership (2022): 'Making Net Zero Steel possible; 4 Hydrogen Insight (2024): 'This new technology could kill the business case for hydrogen in green steel production'; 5 McKinsey (2022): 'Steel'; 6 Hydrogen World Expo (2022): 'Q&A with Hendrik Meller, Project Director of German Global Hydrogen Diplomacy'; 7 IEEFA (2024): 'Big iron ore's long-term strategies diverging in the face of steel decarbonisation'; 8 IRENA (2023): 'Geopolitics of the Energy Transformation; 9 DNV (2022): 'Why is the cement industry labelled hard-to-abate?'

Conventional ammonia

Today's ammonia production process

70% of global production used to make **nitrogen fertilizers**, rest in plastics, explosives, synthetic fibres, and pharmaceutical industry[1]

Steam reforming

Natural gas* → H_2
- At high temperature/pressures, methane reacts with steam to produce syngas (H_2 and CO)
- CO_2 emitted from heating and as a by-product

Ammonia synthesis

H_2 + nitrogen → ammonia (NH_3)
- Haber-Bosch process combines nitrogen from air with H_2 in presence of an iron-based catalyst

Fertilizer production

Ammonia → nitrogen fertilizers
- Ammonia converted to nitrogen fertilizers through chemical reactions with other substances, e.g. combing with CO_2 to produce urea or with nitric acid to produce ammonium nitrate[1]

Production responsible for 1-2% of global emissions
- 2.4 tCO_2 emitted per tonne of ammonia produced[1]

1 IEA (2021): 'Ammonia Technology Roadmap'

Green ammonia

Potential role of H_2

As a readily substitutable input, low-carbon hydrogen has high potential in ammonia production

Clean H_2 production

Low-carbon H_2 production
- Renewable powered electrolysis-based or CCS-abated fossil-fuel based hydrogen production
- Limited alternatives available other than demand-side measures (plastics recycling, efficient fertilizer application)

Ammonia synthesis

Fertilizer production

IEA's Net Zero scenario sees 95% of total 2050 production from near-zero emissions technologies
- ~20% from natural gas with CCS, >40% from electrolysis

* 70% of ammonia production via natural gas-based steam reforming and remainder via coal gasification: 170 bcm of natural gas demand and 75 Mtce of coal demand[1]

Conventional steel

Today's steel production process

70% of global steel production today* via blast-furnace-basic oxygen furnaces (BF-BOF)[1]

Mining → **Raw materials: iron ore**
- Quarrying/mining raw materials

Iron-making → **Iron ore → molten (pig) iron**
- Coking coal used as both a reducing agent** and a source of heat in blast furnace for smelting

Steel-making → **Molten iron → molten steel**
- O_2 mixed with molten iron in basic oxygen furnace, to oxidize impurities and add alloying elements***

Casting, forming → **Molten steel → final products**
- Molten steel cast into shapes and processed into final products

Production responsible for 7% of global emissions[1]
- 1.8 tCO_2 emitted per tonne of steel produced

1 Mission Possible Partnership (2022): 'Making Net Zero Steel possible'; 2 SSAB website: 'Not all green steel is fossil-free steel'; 3 Hydrogen Insight (2024): 'H2 Green Steel secures €4.5bn of additional funding for world's first large-scale green-hydrogen-based steel plant'; 4 IEA (2020): 'Net Zero by 2050'; 5 IEEFA (2022); 'Solving Iron Ore Quality Issues for Low-Carbon Steel'; 6 Hydrogen Insight (2024): 'This new technology could kill the business case for hydrogen in green steel production'

Green steel

Potential role of H_2

H_2-based DRI-EAF will play a key role in decarbonizing iron and steel, as there are limited alternatives

Mining → Iron-making → Steel-making → Casting, forming

H_2-based direct reduced iron (DRI)
- Implies overhaul of production process: direct reduction of iron without melting, using H_2 as a reduction agent to eliminate use of coke[3]
- Needs high-grade iron ore (≥67% iron content) that is scarce (only ~4% of global supply today)[5]
- Alternatives: natural gas, biomass, electrolyser,[1] molten oxide electrolysis[6], etc.

Electric arc furnaces (EAF)
- replace BOF, powered by renewables
- Combines with H_2-based DRI to fully decarbonize iron & steel sector: H_2-based DRI-EAF

IEA's Net Zero scenario sees 29% of 2050 global primary steel production via H_2-based DRI-EAF [4]

* Remaining 30%: 20% via electric arc furnace (EAF) using electricity to melt scrap steel and 5% via direct reduced iron electric arc furnace (DRI-EAF)
**CO_2 emitted from both heating *and* chemical reaction: iron-oxide ore (Fe_2O_3) + 3CO → iron (2Fe) + $3CO_2$
*** E.g. manganese, nickel, chromium, etc

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Conventional aluminum

Today's refining and smelting process

Aluminum is a key input to electric vehicles, energy-efficient buildings, modernized power grids, etc.[1]

Mining — **Raw material: bauxite**

Alumina Refining — **Bauxite → alumina**
- Via burning coal/heavy fuels in thermal boilers
- 17% of total production emissions[1]

Aluminum Smelting — **Alumina → aluminum**
- Via electrolysis using electricity (usually from coal)
- Difficult to use intermittent renewable power as need large and constant electricity load[1]
- 80% of total production emissions[1]

Production responsible for 2% of global emissions[1]
- 15.9 tCO_2 emitted per ton of primary aluminum produced[1]

1 McKinsey (2023): 'Aluminum decarbonization at a cost that makes sense'; 2 Mission Possible Partnership (2021): 'Closing the Gap for Aluminium Emissions'; 3 Rio Tinto (2023): 'Could hydrogen help reduce emissions in the aluminium industry?'

Green aluminum

Potential role of H_2

Although H_2 could feed all thermal energy processes in refining, it is most efficient for high-heat thermal energy[2]

Mining

Alumina Refining — **Shift to H_2 to feed thermal energy processes**
- Requires retrofitting to avoid affecting product quality[2,3]
- Alternatives: electrification, MVR*, aluminum recycling[1,2]
- To feed thermal energy, H_2 more efficient for high heat (4% emissions) versus electrification for low or medium heat (12% emissions)**[2]

Aluminum Smelting — Minimal role in smelting as already electrified
- Potential indirect role in addressing renewable intermittency, but hydropower and storage options also available

Potential to address 183 $MtCO_2e$ in annual global emissions if feeding all of sectors' thermal needs[2]

*Mechanical vapor recompression (MVR) where waste heat from steam otherwise discharged is recovered and used, allowing for energy savings[2]
** e.g., bauxite digestion, casting, remelting[2]

Conventional cement

Today's cement production process

Cement is the **number one building material**, with 4 billion metric tonnes produced globally each year[1]

Mining and prep

Raw materials: clay and limestone
- Quarrying/mining raw materials
- Grinding, blending, etc. to get ideal composition

Dry kiln process

Clay + limestone → clinker[1]
- Most energy-intensive segment (90% of emissions)[2]
- 60% emissions from **chemical reaction in kiln:** calcium carbonate ($CaCO_3$) → clinker + CO_2
- 40% emissions from **thermal energy for kiln***

Cement mill

Clinker → cement powder
- Grinding: cooled clinker ground with gypsum/additives

Production responsible for 7% of global emissions[2]
- 0.6 tCO_2 emitted per ton of cement produced[3]

1 McKinsey (2023): 'Decarbonizing cement and concrete value chains: Takeaways from Davos'; 2 DNV (2022): 'Why is the cement industry labelled hard-to-abate?'; 3 IEA (2020): "Net Zero by 2050' page 127; 4 Cemex (2022): 'CEMEX to introduce hydrogen technology to reduce CO_2 emissions in four cement plants in Mexico'

Green cement

Potential role of H_2

Using H_2 can abate thermal energy emissions, but CCUS is required to address chemical reaction-based emissions

Mining and prep

Dry kiln process

Cement mill

Fuel switching in kiln to H_2
- Blending H_2 with fossil fuels is a readily deployable drop-in, but requires redesigning burner for full switch[2,4]
- Alternatives for thermal energy emissions: thermal efficiencies, reduce clinker-to-cement ratio**, fuel switch to biomass, waste recycling, electrification[1,2,3]
- CCUS crucial*** to mitigate chemical reaction-based emissions, even after a full switch to emissions-free fuels for thermal energy[2,3]

IEA's Net Zero scenario sees H_2 supplying ~10% of kilns' thermal energy needs globally post-2040s, with smaller blending before[3]

*Via burning fossil fuels, usually coal and petroleum coke
**Via using alternative materials, e.g. fly ash, metal slag, or calcined clay[1,2]
***Responsible for 55% of emissions reductions in 2050 relative to today[3]

CCS- versus renewables-based production

	CCS-based production	Renewables-based production
Requires **different value chain** components	✔ Ability to **leverage existing infrastructure**, e.g. natural gas transport, hydrogen production and transport ⚠ CCS-based facilities **locked into H_2 production**	⚠ Requires **building out significant new renewable capacity**, in addition to general power sector needs ✔ Renewable capacity built **retains versatility**: H_2 production or power generation generally
Implies different **environmental performance**	⚠ Risk of **upstream emissions**, notably fugitive emissions ⚠ **Underperformance of CCS** technology[1]	✔ **Lowest emissions** from production process when produced using dedicated renewable capacity ⚠ **Land required** for renewable and electrolyser build-out
Faces **different costs today and in the future**	✔ **Lower costs in short- to medium- term**: $1.80-4.68/kg H_2 produced today[2] ⚠ **Lower cost reduction potential** – risk of being outcompeted in medium- to long-run ⚠ **Vulnerable to natural gas price volatility**[1]	⚠ **Higher costs in short- to medium-term**: $3-12/kg H_2 produced today[2] ✔ **Stronger cost reduction potential** – BNEF anticipates renewables-based production will outcompete CCS-based production by 2033 in all jurisdictions and 2028 in those using Chinese electrolysers[1]

There are significant uncertainties around cost forecasts for renewables- versus CCS-based hydrogen production

- "projections of $0.5/kg costs do not stand up to rigorous, techno-economic assessment". Some argue $2/kg is already optimistic, requiring halving of renewable energy costs and a 75% reduction in electrolysis system costs[3]

Sources: 1 Guardian (2022): 'Carbon capture is not a solution to net zero emissions plans, report says'; 2 Hydrogen Insights (2023): 'Blue hydrogen cheaper than green H2 in all markets except China amid falling gas prices: BNEF'; 3 Hydrogen Insight (2023): 'Switch to green hydrogen will lead to 'significantly higher energy prices in 2050 than today''

Type and source of electrolysers

Type	Source	Cost	Technology	Efficiency
Alkaline electrolyser	China	**Lowest** - $2.38-5.89/kg[1] - Up to $500-1,400/kW upfront CAPEX[2] - **Longest** stack lifetime*: 60,000-90,000 hours	**High** - Market ready	**Lowest** - Up to 77% efficiency[3] - Takes 50 minutes to get to operating speed[4]
	Europe, North America	**Medium** - As above, but more expensive: $4.18-11.07/kg[1]		**Medium** - As above, but higher efficiency and slower stack degradation[1]
Proton Exchange Membrane (PEM) electrolyser	Europe, North America	**High** - $4.57-12/kg[1] - Up to $1,100-1,800/kW upfront CAPEX[2] - **Medium** stack lifetime*: 30,000-90,000 hours		**High** - Up to 80% efficiency[3] - Takes 5 minutes to get to operating speed[4]
Solid oxide electrolyser		**High** - Up to $2,800-5,600/kW upfront CAPEX[2] - **Shortest** stack lifetime*: 10,000-30,000 hours	**Low** - Demo stage[6]	**High** - Up to 90% efficiency[3] due to higher temperatures[5] - High heat requires installing additional electric boiler or coupling production with industrial waste heat[4]

Sources: 1 Hydrogen Insights (2023): 'Blue hydrogen cheaper than green H2 in all markets except China amid falling gas prices: BNEF'; 2 IEA (2019): 'The Future of Hydrogen' ; 3 CGEP (2023): 'Demystifying Electrolyzer Production Costs'; 4 Hydrogen Insight (2023): 'Which type of electrolyser should you use? Alkaline, PEM, solid oxide or the latest tech?'; 5 Hydrogen Newsletter (): 'PEM vs Alkaline electrolyzers'; 6 IEA https://www.iea.org/energy-system/low-emission-fuels/electrolysers; 7 Lazard (202X): 'Levelized Cost of Hydrogen'; 8 Expert interviews

* Stacks convert chemical energy to electricity through an electrochemical reaction, their lifetime being important as they account for 19-60% of electrolyser costs[3]

Choosing the most suitable electrolyser is important as they equal **30-45% of LCOH**[7]

Cheaper, less efficient electrolysers are most **suited where there is access to low-cost renewable power and more financial constraints**

- There is a trade-off between electrolyser costs and efficiency
- Chinese alkaline electrolysers are cheapest but also least efficient
- Lower efficiency requires higher volumes of power – power costs drive 30-60% of LCOH[8]

More efficient but more expensive **PEM electrolysers often chosen in areas with higher renewable power costs**

- Also suited to warmer climates as they work with lower temperatures, and conducive to production from seawater[3]

An overview of transport options

Option	Distance[1]	Sub-option	Description	Cost[2]	Key advantages	Key disadvantages
Pipelines	< 2,500 - 3,000 km	Blend in natural gas pipelines	Transport H_2 in gaseous form		• Requires only minor modifications[5]	• Maximal blending limit of 20%[3,5] • End-use restricted to direct/indirect heating[3]
		Repurpose existing pipelines		$0.08/kg per 1,000 km	• Can carry 100% hydrogen after modifications[5] • Reduces costs by 60% relative to new pipeline[5]	• Option only relevant where pipelines exist • Requires stricter leak detection system than natural gas due to higher safety risks[5]
		Build new pipelines		$0.18/kg per 1,000 km	• Potential to create new transport routes	• Hold-up problems • Risk of social and environmental harm
Shipping	> 3,000 km	Liquid H_2 (LH_2)	Liquified and regasified H_2	4-6x more than cost of LNG per unit energy[4]	• Enables transport via ships • May be only option for remote islands[4]	• **Low liquefication temperature (-253°C, lower than natural gas) makes liquid transport harder and less economical[4]**
		Liquid organic H_2 carrier (LOHC)	H_2 loaded into chemical (e.g., benzyl toluene) or metal carrier and released on arrival[4]		• Transport at ambient temperatures & pressures[4] • Best to fill long-duration storage tanks where no gaseous storage options[4]	• Low energy density = 4x as many trips per energy cargo as with LNG[4] • Unneeded heat released for loading vs. energy needed for H_2 extraction (300°C, using up 30% of energy delivered)[4]
		Ammonia (NH_3)	Derivative: H_2 combined with nitrogen	$1 - 2.75/kg	• Existing dedicated ships and loading/unloading infrastructure at ports[6] • Potential to fuel ships[4]	• Highly toxic, requires strict safety measures • Additional process steps add costs and further reduce end-to-end efficiency[4]
		Methanol (CH_3OH)	Derivative: H_2 combined with carbon	$1 - 2.75/kg	• Liquid at room temperature, so easier to transport	• Requires a source of carbon that may be better used for storage via CCS or DACCS[4]

Mature technology

Pilot/development stage

Sources: 1 IEA website accessed 12/01/2024; 2 Brookings Institute (2022): 'The promise of African clean hydrogen exports: Potentials and pitfalls'; 3 Rystad Energy (2023) : 'Building the Future: Hydrogen Pipelines Start to Materialize in Europe'; 4 BNEF (2022): 'Liebreich: The Unbearable Lightness of Hydrogen'; 5 CSIS (2023): 'Exploring the Hydrogen Midstream: Distribution and Delivery'; 6 Hydrogen World Expo (2022): 'Q&A with Hendrik Meller, Project Director of German Global Hydrogen Diplomacy'

An overview of storage options

Option	Sub-option	Levelized cost of storage	Capacity	Geographical availability	Flexibility
Tanks	Specialized compressed high-pressure tanks	**Medium** • Specific capital cost €340-1040/kg[4] • Space restrictions and health and safety regulations add costs[4]	**Small**[3] • Suited for <10 tonnes (0.33 GWh)[4]	**Abundant** • Built, so not tied to natural formations • Space restrictions[4]	**High** • Designed specifically to be filled and emptied on a frequent basis
Geological formations	Salt caverns	**Low** • Specific capital cost as low as €7/kg[4] • Expedited permitting process, access to existing infrastructure and easier siting approvals where planned next to existing gas storage caverns[1]	**Medium**[1] • Needs ≥100 tonnes[4] • >7,000 tonnes stored in world's largest operating site in Beaumont (Texas)[3]	**Limited**[1]	**Medium**[1] • Fast-cycling operation (multiple annual cycles)[1] • Needs 25-35% cushion gas*[1]
	Porous reservoirs (depleted gas and oil fields)	**Medium**[1]	**Large**[1] • Largest storage capacity	**Variable**[1] • 76% of existing underground natural gas storage capacity[1]	**Limited**[1] (porous reservoirs and aquifers) • Operate only with few cycles per year[1] • Suited for longer storage to manage seasonality and energy security[1] • Needs 45-60% cushion gas*[1]
	Aquifers	**Medium**[1] • Requires extensive geological surveys to ensure gas cannot escape[1]	**Large**[1]	**Variable**[1] • 11% of existing underground natural gas storage capacity[1]	**Limited**[1] (see above) • Needs 50-70% cushion gas*[1]
	Lined hard rock caverns	**Medium**[1]	**Small/Medium**[1]	**Abundant**[1]	**Medium**[1] • Fast-cycling operation[1] • Needs 10-20% cushion gas*[1] • Suited to manage short-term S&D swings[1]

Commercial use exists

No commercial use yet

Storage in liquid form, as derivatives (ammonia, methanol), in materials (LOHC) or as semi-finished or finished products follows the same considerations as described for transport (see previous slide) and is suited to store smaller quantities

1 IEA (2022): 'Global Hydrogen Review 2022'; 2 TÜV Nord: 'Hydrogen storage: overview of possibilities'; 3 DOE (2022): 'National Clean Hydrogen Strategy and Roadmap'; 4 Moran *et al.* (2024): 'The hydrogen storage challenge: Does storage method and size affect the cost and operational flexibility of hydrogen supply chains?'; *Volume of gas needed as permanent inventory to maintain minimum operating pressure and thus not usable

2) Case Studies Appendix

African projects from the world's largest 11 H_2 projects

Project	Location	Developer	Estimated production	Electrolyser capacity	Use	Schedule	Cost
AMAN (1st phase)	Northwest Mauritania	CWP		2.5 GW powered by 5.5 GW of renewables	1 Mtpa green NH_3 + 2.5 Mtpa DRI by 2029	• Feasibility phase • First stage 2027, exports from 2029	$5-10 billion[2]
AMAN (full scale)	Northwest Mauritania	CWP	1.7 Mt per year	15 GW powered by 30 GW of renewables	50mill m^3 extra desalinated water created	• Full operations by 2037	$40 billion
Nouakchott project	Nouakchott, Mauritania	Infinity Power Holding* + German Conjuncta	8 Mt per year	10 GW	Export to Germany	• First 400 MW phase to start operations 2028	$34 billion
SCZONE Ain Sokhna project	Ain Sokhna, Egypt in Suez Canal Economic Zone	ACME (India)	2.1 Mt per year	18 GW	NA → potential refuelling ships	Construction on 100kt/yr pilot to begin early 2024	$12-13 billion

1 Hydrogen Insight (2023): 'Impossible dreams? The 11 biggest green hydrogen projects announced around the world so far'; 2 OECD (2023): 'Financing cost impacts on cost competitiveness of green hydrogen in emerging and developing economies'; *Joint Venture between Masdar and Infinity

Mauritania

AMAN Project to boost GDP 60-100% by 2037[1]

Advanced feasibility stage, to start First Stage operations **2027**, exports **2029** and full-scale operations by **2037**

Minerals
Pilot hydrogen project
Water resource
Infrastructure

$1.7–2/kg H_2 by 2035 among lowest-cost potential
- World-class solar ($19-25/MWh) and wind ($22-29/MWh)
- EOS from ultra-large scale

1 Mtpa* of green ammonia
- Dedicated synthesis ammonia reactors

2.5 Mtpa of direct reduced (DRI) or hot briquette iron (HBI)
- DRI-grade iron ore in north-eastern mines
- Mostly for exports: 10-15% lower price per ton than Asia, Europe, America

Leverage existing and build new infrastructure
- Located by rail linking Zouérat mines to Nouadhibou export terminal
- Build dedicated H_2 and ammonia pipelines

50 million m^3 of additional freshwater
- 20 million m^3 to meet 2030 water shortfall
- Excess 30 million m^3 to agriculture to raise domestic cereal production by 10%**

Source: 1 Rattan (2024): 'Mauritania | $40 billion AMAN green hydrogen project'; *2* OECD (2023): 'Financing cost impacts on cost competitiveness of green hydrogen in emerging and developing economies'
* By 2027 for First Stage, with plans to scale to 13 Mtpa green ammonia production by 2037; ** Currently relies on cereal imports to meet food demand

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Namibia

HYPHEN Tsau Khaeb Project

- **$10 billion** CAPEX project = Namibia's annual GDP[2]
- On ~4,000 km² land close to Lüderitz
- First phase (2 GW) to begin production in **2026-27**, full scale operations by **2030**[3]

$1.7–2.3/kg H_2 by 2030 among lowest-cost potential[3]

- 7 GW RE (world-class solar and wind) + 3 GW* electrolyser capacity[2]
- EOS from ultra-large scale

1 Mtpa of green ammonia by 2027, 2 Mtpa by 2029[4]

Total offtake agreements **≥1 Mtpa**:
- RWE (Germany energy firm)
- Approtium (South Korean chemicals firm)

HYPHEN won public tender in 2021

- Enertag (German renewable developer), Nicholas Holdings (UK infrastructure developer)[5]
- 24% equity stake by SDG One Namibia**

Local jobs creation[3]

- 15,000 direct jobs from construction
- 3,000 permanent jobs
- 90% local

Source: 1 GH2 Namibia website; 2 NewClimate Institute (2023): 'The landscape for green hydrogen in Namibia'; 3 Green Hydrogen Organization website; 4 S&P Global (2023): 'Hyphen Hydrogen signs further offtake MOUs for Namibia green ammonia project'; 5 Climate Fund Managers (2023): 'Hyphen Hydrogen Energy and SDG Namibia One Fund Agree on Equity Stake in Country's First Gigawatt-scale Green Hydrogen Project'

* 10x current installed renewable energy capacity; **Namibian government's blended finance vehicle

Morocco

Guelmim-Oued Noun Project[1]

$9.9 billion CAPEX project on ~1,700 km² land[1]

10 GW of solar and wind

By **Total Eren**: French independent power producer (subsidiary French TotalEnergies)

Active **2025** with production to begin in **2027**

Tarfaya Project[2]

State-owned **OCP plans to invest $7 billion** in an ammonia plant using renewable H_2

Targets import substitution:

- OCP spent **$2 billion** on ammonia raw material imports in 2022 as Russia-Ukraine war pushed up global prices

Goals: Produce 200 ktpa of green ammonia by 2026, 1 Mtpa by 2027 and 3 Mtpa by 2032

OCP and Fortescue to partner to develop H_2 and ammonia[3]

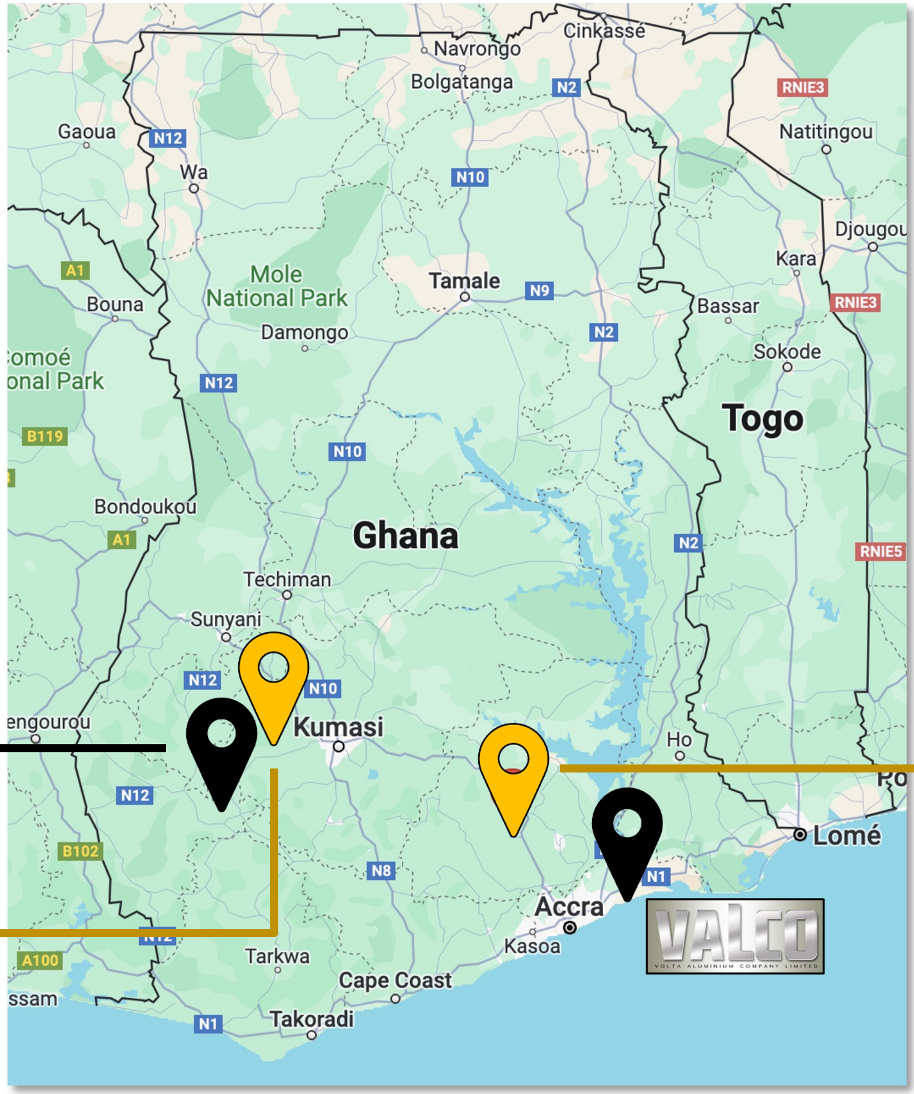
Moroccan government offers 10,000 km² land for renewable hydrogen projects as part of ‘Hydrogen Offer’[2]

Source: 1 Hydrogen Insight (2024): ‘Morocco promises a million hectares of land for green hydrogen project development’; 2 Reuters (2023): ‘Morocco's OCP plans $7 billion green ammonia plant to avert supply problems’; 3 Fortescue (2024): ‘OCP and Fortescue to partner to develop green energy, hydrogen and ammonia in Morocco’

Ghana Integrated Aluminium Development Company (GIADEC) Master Plan

Project 1:
- **Expand Awaso mine** from 1 Mtpa bauxite to 5 Mtpa
- **New alumina refinery** with capacity of 1.5 Mtpa

Project 2:
- **New mine + refinery solution**



Project 3:
- New **mine** by Kyebi: 5 Mtpa
- Second **mine** by Nyinahin: 5 Mtpa
- Construct alumina refinery

4-6 Mtpa combined capacity from two refineries

Source: GIADEC website: https://giadec.com/future-operations/