HOCHSCHULE ANHALT University of Applied Sciences

GERMAN-AFRICAN GREEN HYDROGEN FORUM

CONFERENCE PROCEEDINGS

2023

SACHSEN-ANHALT
Ministerium für Wissenschaft, Energie, Klimaschutz und Umwelt

Conference Proceedings:

German-African Green Hydrogen Forum
May 23rd - 24th, Bernburg (Saale)

Hochschule Anhalt of Applied Sciences
Faculty of Economics
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SACHSEN-ANHALT
Ministerium für
Wissenschaft, Energie,
Klimaschutz und Umwelt

October 2023

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Preface

Green hydrogen is incredible versatile as an energy carrier and has the potential to decarbonize a wide-range of sectors that can't normally use electrification for that end. It's worldwide support is increasing rapidly, and so are the possibilities of use in different industries.

This growth in the hydrogen economy and global need for clean energy enables African coastal countries to become net exporters and key players in the renewable energy markets.

In our forum we've discussed Africa's great potential of regenerative energy in the form of hydrogen and its derivatives that can be a path both to forming a global supply of green hydrogen and to enable better economic growth and generate wealth on the African continent.

I would like to thank our speakers and participants for the engaging and dynamic discussions proposed during the forum, contributing for its success.

We plan to establish the German-African Green Hydrogen Forum as a regular event, with an important partnership alongside the University of Namibia.

I look forward to seeing you again at the second German-African Green Hydrogen Forum, set to take place in the capital of Namibia, Windhoek, from September 10th to 11th 2024.

Prof. Dr. Markus Holz

“German-African Cooperation for Green Hydrogen development and cooperation”

Till Mansmann, MdB

Germany

Click here for video presentation

CHAPTER 1. FINANCING GREEN HYDROGEN INFRASTRUCTURE AND EQUIPMENT INVESTMENTS

“Financing Green Hydrogen Projects In Ghana”

Dr. Gertrude Amoakohene
Ghana Communication Technology University

Ghana

Financing Green Hydrogen Projects In Ghana

Presented by Dr. Gertrude Amoakohene

Senior Lecturer

Ghana Communication Technology University

Presentation Outline

- Brief Description of Ghana
- Financing Green hydrogen in Ghana
- Investment Climate in Ghana
- Comparison with other African Countries
- Cost/Benefit Analysis
- Challenges
- Private Sectors
- Recommendation

Ghana, a country of western Africa, situated on the cost of the Gulf of Guinea

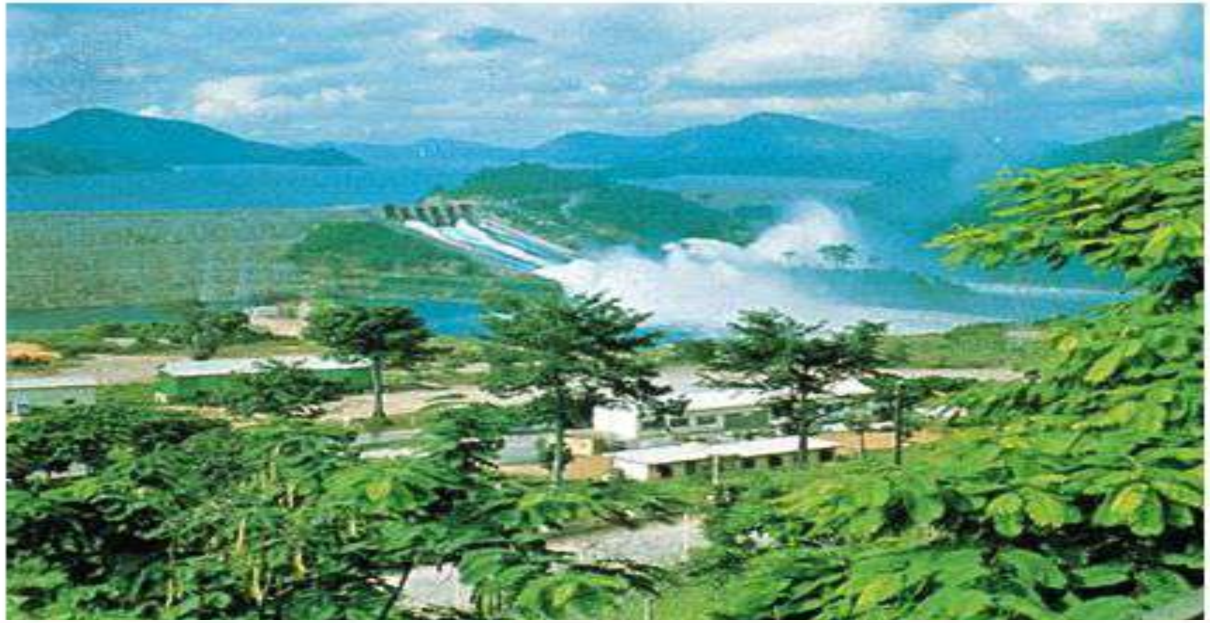
Population is estimated at 31,072,940 people, according to 2020population census report

The city of Accra, the capital of Ghana

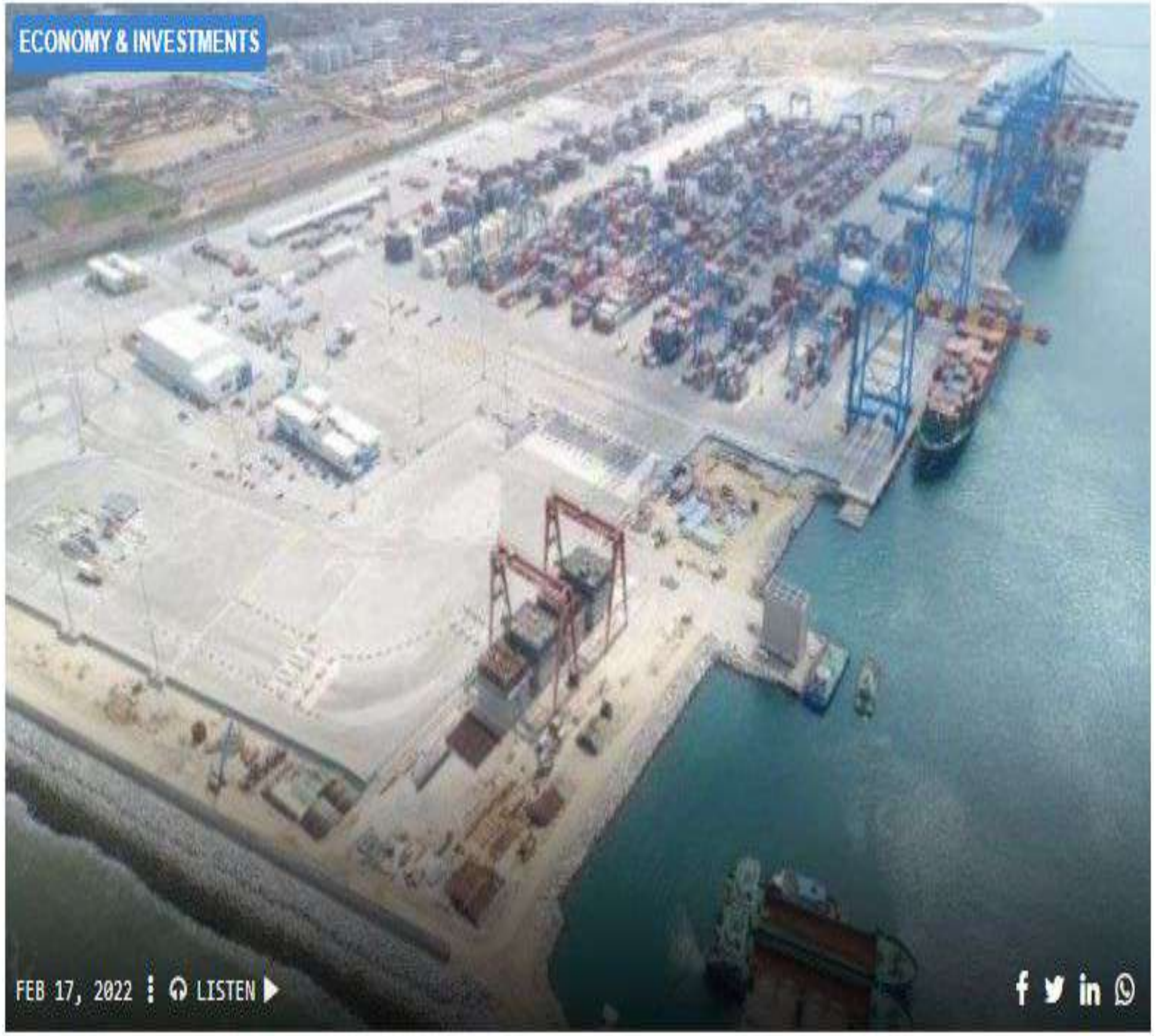
cocoa continues to provide an important export for Ghana

Vegetation in Ghana

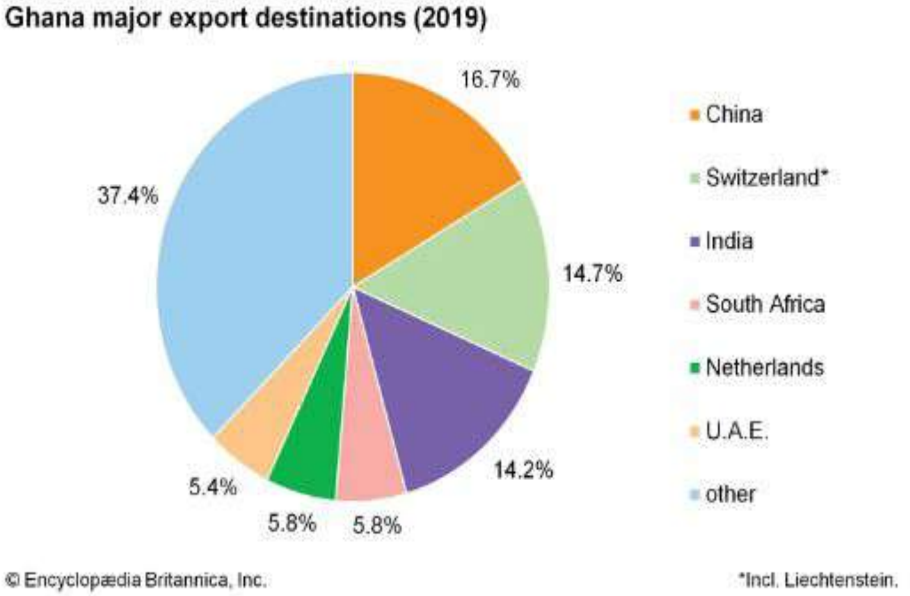
Drainage System In Ghana



International Trade Tides

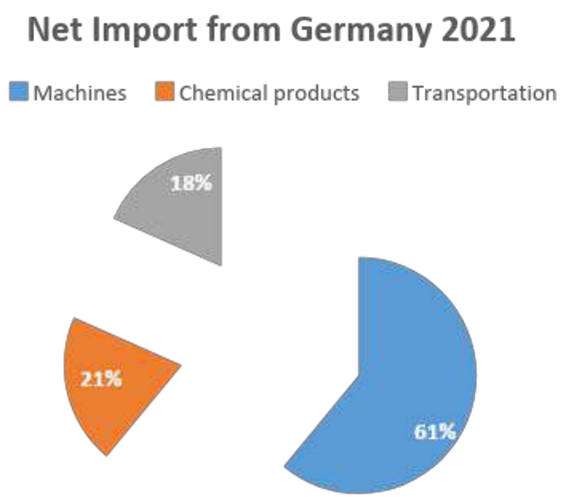


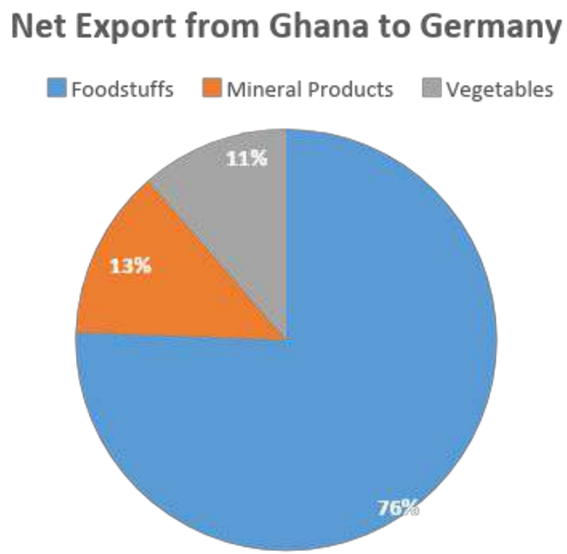
The new 1.4-km-long quay at Tema Port will house four container berths



Trading Between Germany and Ghana

- Ghana is one of Germany's most important trading partners in sub-Saharan Africa
- The main exports from Ghana to Germany are petroleum and natural gas, agricultural and hunting products, food and animal feed, and metals.





Financing Green Hydrogen Project in Ghana

Green hydrogen might represent a shift of paradigm. If we succeed in increasing investments in green hydrogen, it could be a turning point in our efforts to achieve the global climate goals. It will also make a significant contribution to increased food security in Africa."

By Bård Vegar Solhjell

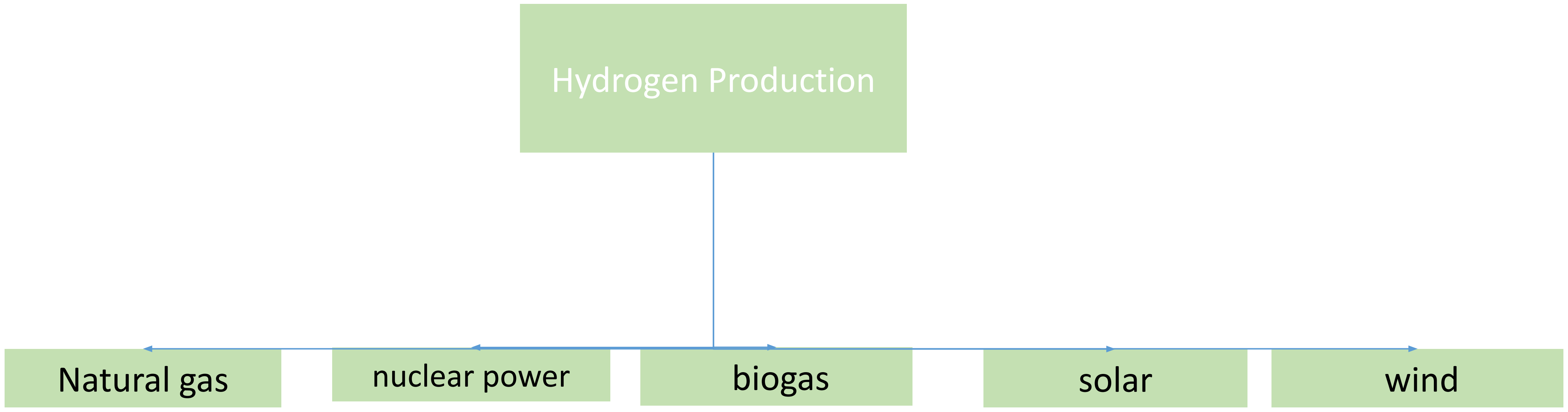
(Director General, Norwegian Agency for Development Cooperation)

Hydrogen-The Green Fuel for the Future?

- Hydrogen is a clean alternative to methane, also known as natural gas.
- It's the most abundant chemical element, estimated to contribute 75% of the mass of the universe.
- Countries with some experience on the use of hydrogen energy
  - China has the highest number of hydrogen fuelling stations for road vehicles
  - Japan
  - South Korea,
  - Germany and
  - US.

- A fuel is a chemical that can be ‘burnt’ to provide useful energy. Burning normally means that chemical bonds between the elements in the fuel are broken and the elements chemically combine with oxygen (often from the air).
- For many years, we’ve used natural gas to heat our homes and businesses, and for power stations to generate electricity. In the UK, 85% of homes and 40% of the country’s electricity currently relies on gas; in the US, 47% of households rely on natural gas and 36% on electricity[1].

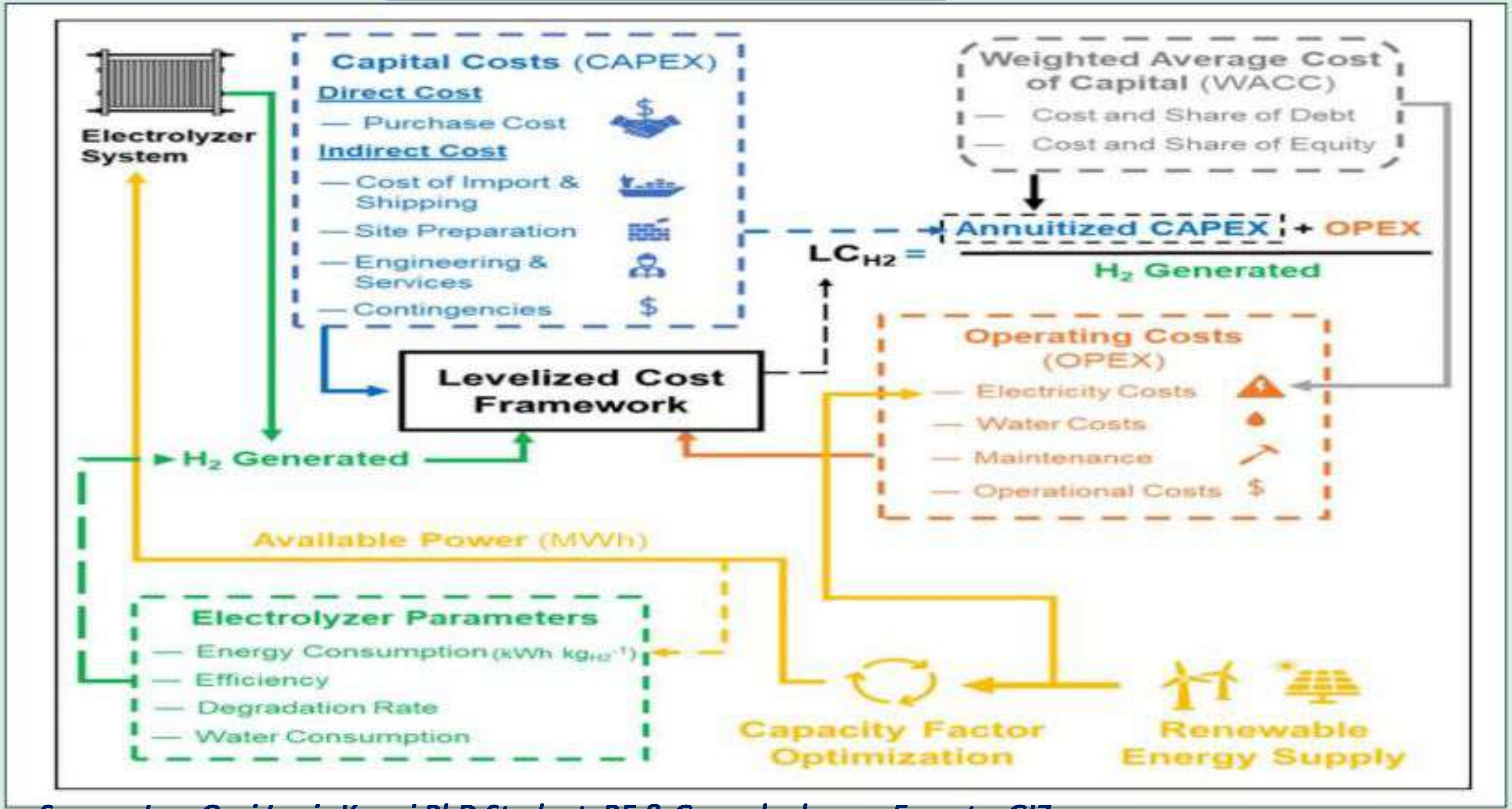
Hydrogen Fuel can be produced from several sources



Is Ghana Ready for Green Hydrogen Project

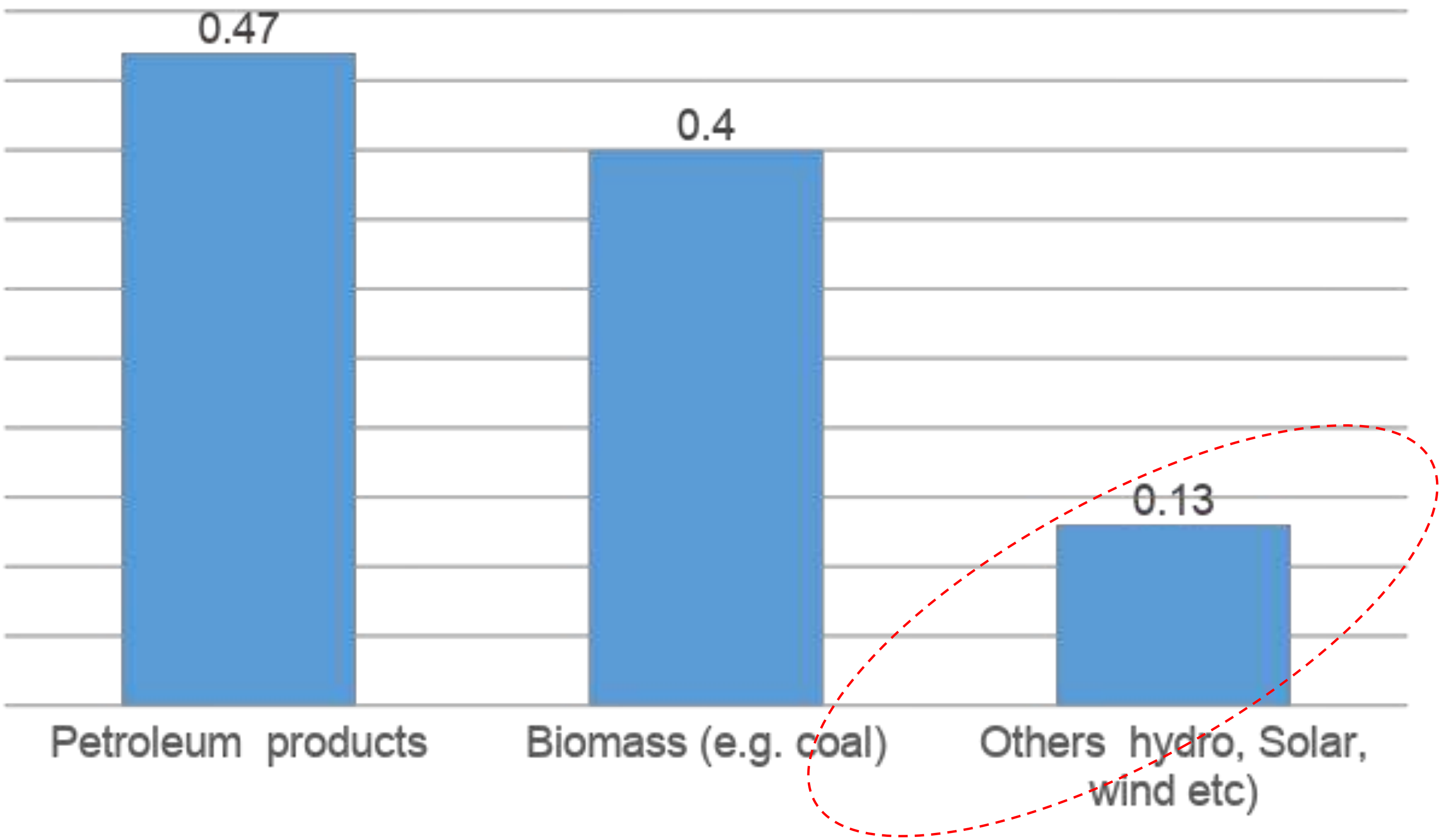
Government is presented with a huge opportunity in stimulating capital spending on new infrastructure, which establishes hydrogen as one of the sectors

Green H2 Production Cost



Source: Ing. Osei Louis Kwasi PhD Student, RE & Green hydrogen Expert – GIZ

Current state of energy production & use in Ghana

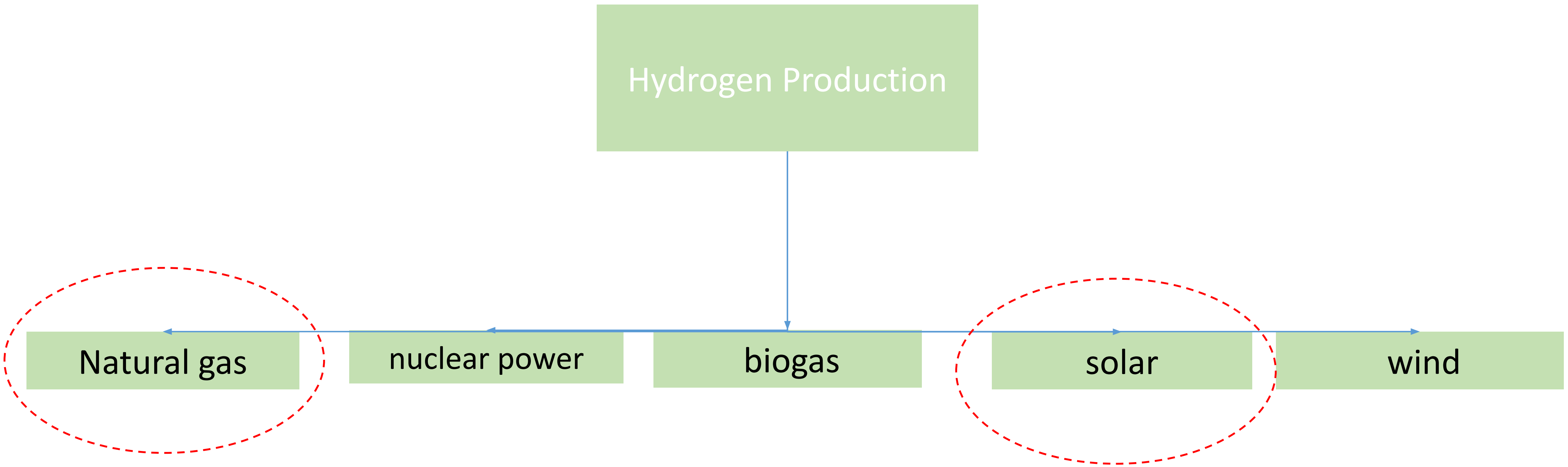


Source: Energy Commission, 2016

Cont’d

- “The Government of Ghana has identified renewable energy as one of the options that could contribute to the overall energy supply mix and minimise the adverse effects of energy production on the environment”
- To understand the financing green hydrogen project in Ghana, three questions are raised
  - Is Ghana Ready?
  - What have been done?
  - Should Ghana Do more?

Key Sources of Hydrogen Fuel Production



Is Ghana Ready?

Regulation/ Policies	Documentation	Goals
Ghana’s Regulations on Green Hydrogen	No Document	In the new “Green” economy, the approach is to include the use of hydrogen as an energy carrier to store large amounts of surplus renewable energy for long periods of time— and even to export renewable energy to different geographies
Ghana Renewable Energy Policy	Ghana Renewable Energy Master Plan(REMP)	The REMP aims to achieve the following by 2030: Increase the proportion of renewable energy1 in the national energy generation mix from 42.5 MW in 2015 to 1363.63 MW (with grid connected systems totalling 1094.63 MW)
National Energy Policy In Ghana	National Energy Transition Framework (NETF) 2022- 2070	Ghana had showed commitment to Paris Agreement, by establishing NETF which had plans set up to attain a net-zero emissions by 2070

What has been Done / Being Done in Ghana

- Training workshop organised GIZ, Project Development for Green Hydrogen in Ghana/German Training Week within the Project Development Programme (PDP)
- As part of effort to finance green hydrogen in Ghana the GH2GH project has been set up at Don Bosco University in Ghana aims at development of structure for implementation of green hydrogen technology in for decentralised energy system is Sub-Saharan Africa
  (Ziem-Milojevic, 2023)

Potential Renewable Energy Transition In Ghana

1	Cost reflective tariffs and financially sustainable service providers
2	Environment conducive to private sector investment in renewable energy
3	Technology and structures for energy efficiency and system flexibility
4	Strong policies and regulatory frameworks, competent institutions and liberalisations
5	Affordable access and innovative business model
6	Robust grid coupled with competence in operation
7	De-commissioning of existing fossil fuel

Challenges of Green Hydrogen Projects in Ghana

- *"One thing is that we do not see the market in Ghana because feasibility studies haven't been done to be able to know the possible target market." (Ministry of Energy, 2023)*

This is because there have been no feasibility studies, however, the challenges we foresee include the following

- Cost
- Technology
- Expertise
- Policies & Regulations

- Regulatory Framework
  - The main enabling instruments comprise:
  - The Renewable Energy Act, 2011 (Act 832);
  - Renewable Energy Sub-Code for National Interconnected Transmission System connected Variable Renewable Energy Power Plants in Ghana;
  - Renewable Energy Sub-Code for Distribution Network connected Variable Renewable Energy Power Plants in Ghana;
  - Net Metering Sub-Code for Connecting Renewable Energy Generating Systems to the Distribution Network in Ghana;
  - Feed-in-tariff for electricity generated from RE sources;
  - Guidelines and modalities for the Renewable Energy Purchase Obligation (REPO);
  - Standardised Power Purchase Agreement (PPA) Template.

My Interactions with Key stakeholders

- "*Hydrogen, no matter the colour is part of our transition but recently we have realised that green hydrogen has taken the centre stage even at the ECOWAS level. Ecowas has passed a policy on green hydrogen production of which Ghana is to play a very critical role*." (Environmental Protection Agency, 2023)

- *"there was a hydrogen training in partnership with the German government through GIZ" (Ministry of Energy, 2023)*

My Interactions with Key stakeholders

- Cost/Benefit of Hydrogen Projects in Ghana

“The only thing which is obvious is the production of fertiliser, using hydrogen to produce ammonia to make fertiliser.”(Ministry of Energy 2023)

“So if the economics of hydrogen is good and is far better than using natural gas or fertiliser then naturally we would switch but then we are going from, so it means that you have to put in some incentives to make it a bit cheaper than the normal fossil fuels and that is why we are looking for investments than to be”. (Environmental Protection Agency 2023)

My Interactions with Key stakeholders

- Potential Green Hydrogen Market in Ghana

  “Currently the hydrogen market is purely for exports markets if you look at it”. (Ministry of Energy 2023)

  “We also have to look at the commercial viability because looking at our current pipelines that we have built, they are not meant to carry hydrogen”.(Ministry of Energy 2023)

  “The ECOWAS region actually even knows that Ghana is the best place to start strategically because of our policies, our political stability and our commitment to renewable energy because we don’t just do it but we make sure that we look at the whole value chain,” (Environmental Protection Energy 2023)

My Interactions with Key stakeholders

- Infrastructure Needs

“Hydrogen is very volatile so we need specialised containers in order to transport it and all that so we need special logistics and since we look at our markets and we don’t see the viability of hydrogen, hydrogen transition is to be incorporated into our fuel mix somewhere in 2040 going especially in” (Ministry of Energy 2023)

The Big Question

- Should Ghana Do More?
  - Risk Management
    - Fear of the unknown
    - Cost per every 1kg of hydrogen produced
    - Pricing of hydrogen compared with other forms energy options

Financial Needs for Implementing the Revised Nationally Determined Contribution

- Ghana requires between US$ 9.3 and US$ 15.5 billion contribution measures from 2020 to 2030.
- US$ 3.9 billion would be required to implement the 16 unconditional programmes of action till 2030.
- The remaining US$ 5.4 billion for the 31% conditional programmes of action would be mobilised from the public, international, of investment to implement the 47% nationally determined and private sector sources and carbon markets.
- Ghana will need an additional US$ 3 million biennially to support coordination actions and the regular international reporting of the nationally determined contribution.

Nationally Determined Contribution under the Paris Agreement (2020 - 2030)

Private Sector Participation (PSP)

- Private sector investment is seen as the centre of development
  - Government commitment to private sector participation and growth in the renewable energy space needed.
  - Incentives given to private sector should be made clear in the form of policy and regulatory framework
  - Local Renewable Energies companies should be encouraged to partner with foreign investors as they are given priority in procurement for government supported programmes or projects

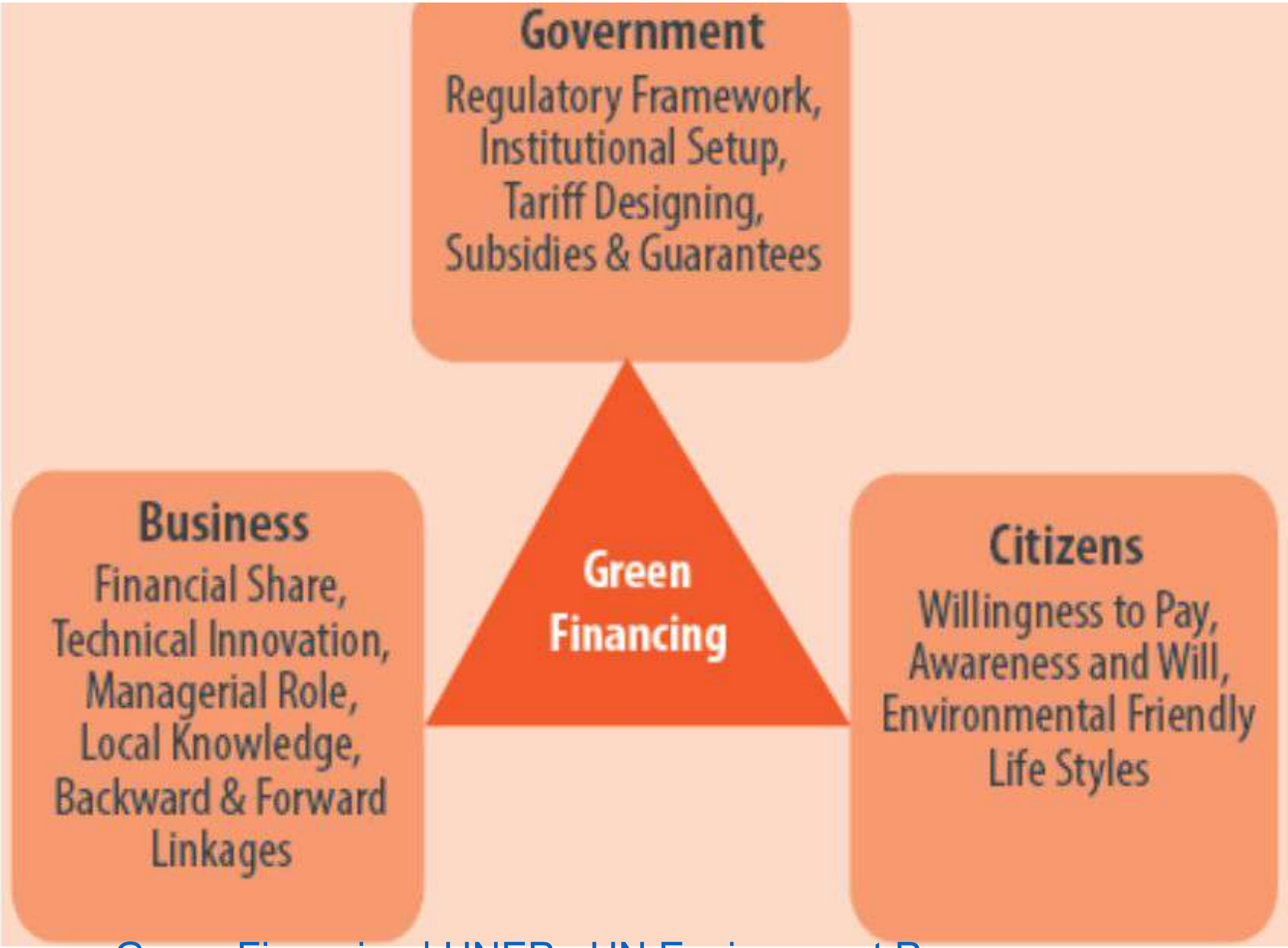
Financing Options for Green Hydrogen Project in Ghana

PRIVATE SECTOR	GOVERNMENT SUPPORT NEEDED	COMMENTS
Public Private Partnership	encouraging collaboration between stakeholders in the public and private sectors.	Private sector partner government to able to produce hydrogen in a large quantities
Stakeholders engagement		addressing the financing gap and building a sustainable green hydrogen industry in Ghana
Bankable offtake schemes	Local Banks readiness to finance environmentally friendly project	
innovative financing mechanisms		private sector funding must devise programs that help to fund Renewable Energy projects

Recommendation

- Green Hydrogen finance is capital intensive as such
- There is the need for common understanding infrastructure financing and related risk, where
  - Private sector readiness to Finance
  - Government Support to Promote Long-term Investments in Infrastructure
  - Mapping Channels to Mobilise Institutional Investment in Sustainable Energy
  - Green Finance and Investment,

The ultimate goal for financing Green Hydrogen in Ghana is by Green Financing



Source: Green Financing | UNEP - UN Environment Programme

“Green Hydrogen: A New Opportunity for Africa”

Fred Kabanda
African Development Bank

Côte d’Ivoire

AFRICAN DEVELOPMENT BANK GROUP
GROUPE DE LA BANQUE AFRICAINE DE DÉVELOPPEMENT

Green Hydrogen:
A New Opportunity for Africa

At

The German-African Green Hydrogen Forum

Fred Kabanda

African Natural Resources Management and Investment Centre

23rd May 2023

Outline

- Relevancy of Green Hydrogen to Africa
- What Could Hinder Green Hydrogen Opportunities in Africa
- The Role of the African Development Bank and Partners
- Conclusion

Context

- Africa contributes **<4% global emissions** yet significantly 2020-2021, **131 disasters**.

- Africa **lost 5-15% GDP** Growth 1986-2015. Projection is **2-15% by 2100** compare 1% EU and 1-5% China

- Addressing climate change & promoting green transition is fundamental for Africa's sustainability. AEO 2022 **$1.3-1.6 trillion 2020-2030 implementation of NDCs**.

- **Abundant RE** sources could be leveraged **for green hydrogen** and address **intermittency.**

- Hydrogen **contains almost three times as much energy as fossil fuels**.
- **Hydrogen fuel cells** store **higher volume of clean electricity than batteries and capacitors.**

- Green hydrogen **consumption is expected to grow significantly** as transport (aviation, shipping, trucks) and heavy industry (steel, aluminum, cement, chemicals) decarbonize.

Relevancy of Green Hydrogen to Africa

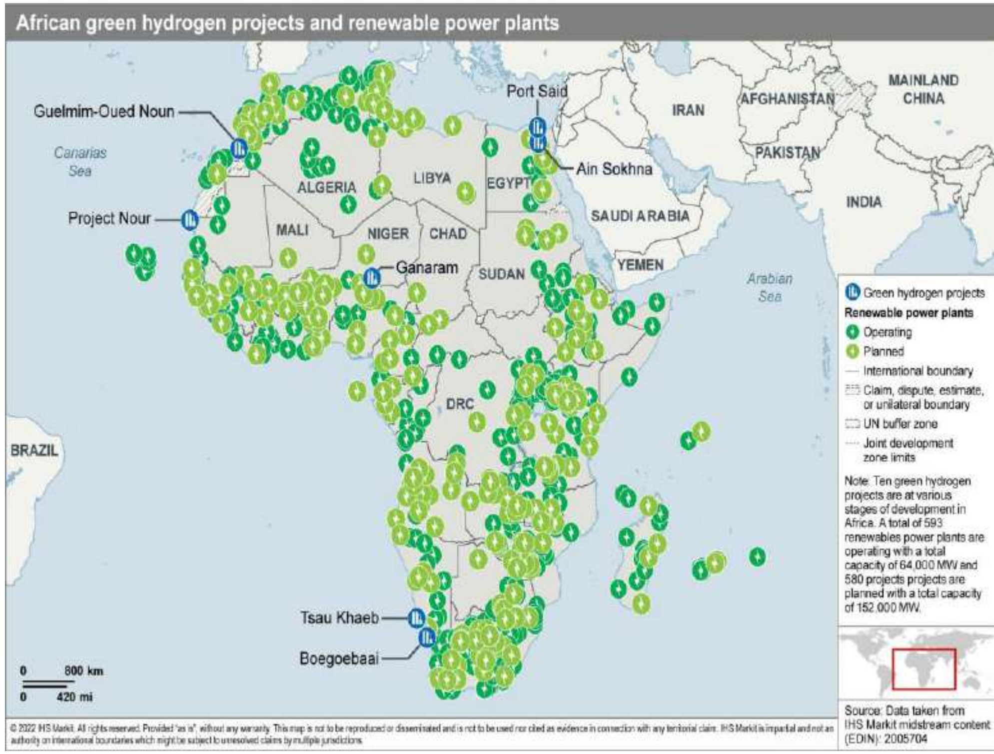
- Green hydrogen could **enhance access to affordable and clean energy, create jobs, provide public health benefits** such as cleaner air, promote new green industries and wealth creation, and open opportunities to export revenues.

- Production **cost for green hydrogen is not competitive but** expected to decline –ongoing global initiatives to ramp up production and economies of scale.

- Average cost **projected to decrease** from USD5 to USD1 / kg green H2 by 2050. This is facilitated **by decreasing cost of equipment**, **increasing efficiency** (scale) and **low cost of renewable power** production, including in Africa.

- The large **land mass**, **abundant solar** and **wind** give Africa the world's best potential to produce **cheap green hydrogen**. So far, clean hydrogen projects and investments have grown quickly, but **despite its competitive advantage.**

- Africa has a few green hydrogen projects: **Egypt, Mauritania, Morocco, Namibia, Niger, and South Africa** are planning **large-scale hydrogen projects**, and the momentum is building.



Source: IHS Markit (2022).

What Could Hinder Green Hydrogen Opportunities in Africa

- **Most Green H2 projects in Africa very ambitious and very early stage and thus not yet structured and bankable.** Model of production taking advantage of wind and solar power and then ultimate end-users based in EU,US, Asia...

- Bankability requires **long-term offtake/sales arrangements that ensure stable cashflows.** Contracts need to feature typical market standard provisions for project finance deals e.g **take or pay, events of default, a maturity sufficient** etc. It will take time for projects to become bankable through comfort on the ability to sell in the commodity market.

- **The market features both private and public offtakers, with varying levels of bankability:** Corporate offtake is bankable if backed by a strong balance sheet or parent company guarantee. Egypt offtaker is an ammonia company with its parent company Fertiglobe guaranteeing the payment obligations.

Could Hinder…..

- **Public offtake is bankable if the buyer is creditworthy or backed by government.** Egypt plans to establish a government owned utility for green hydrogen. In Germany, the creditworthy offtaker HINT.CO established.
- **Bankability can be enhanced through compliance with widely accepted green hydrogen certification and standards as customary in the target markets for end user.** It is necessary to ensure **an effective, secure, and straightforward tracking/certification system that guarantees its renewable origin.**
- **Bankability and investment attractiveness increase with enabling policy environment.** Governments of **Egypt and Namibia set tax incentives, waivers** to target them as regional hubs. The **EU is strengthening the Emissions Trading Scheme** (ETS) which increases the cost competitiveness of green products.

Role of African Development Bank and Partners

- The Bank **generates a pipeline of projects and engaging with respective project developers on providing project preparation and innovative financing for eligible projects**. Many GH projects still need support **towards preliminary analyses, feasibility.**

- Development partners committed to **assisting RMCs with their energy transition targets, leveraging hydrogen to accelerate the Just transition, create zero-emission jobs, establish domestic energy supplies, and export revenues fit for a decarbonized future of the continent**.

- AfDB Financing instruments: **Lending instruments, blended financing, credit enhancement solutions, equity participation** can benefit countries to support the development of their **Green Hydrogen policy interventions, project preparation efforts or mobilize funding for large-scale sovereign and non-sovereign operations. Also offer** grants, **guarantee instruments**, **mezzanine**, etc - eligibility criteria

- AfDB will play a **catalytic role** to ensure that African countries are given a seat.

Role of AfDB….

Collaborative work

- Africa needs **strategic collaboration Partners** as a way of achieving a strong, and inclusive green hydrogen global transformation. So far,
  - **Africa Green Hydrogen DFI Working Group** launched at COP27. Created as Africa's green hydrogen economy finance task force. **The task force includes AfDB, EIB, EBRD and GH2 and other partners**.
  - The Bank is also engaging with the **Africa Green Hydrogen Alliance (AGHA),** through its **African Energy Transition Catalyst Fund.** Activities include **capacity building, regional harmonization, regulatory frameworks, and project preparation activities**.
  - African Development Bank established the **Africa Financial Alliance on Climate Change (AFAC)** in 2018.
  - The **African Green Bank Initiative** (AG3F) launched at the COP27 supports the Bank's objective of increasing the level of climate finance,.

Role of AfDB.... Going beyond Green hydrogen

At AfDB, we know that the secret of the wealth of nations is clear: developed nations add value to everything they produce, while poor nations export raw materials. For green hydrogen;

- ✓ There can be use of hydrogen **in medium to long haul trucking**, shipping and heavy transport. The fuel cells have advantages over batteries for powering heavy transport.
- ✓ A market exists for ammonia, and **green ammonia** projects have been proposed/early stages.
- ✓ **Electricity generation** for new coverage or in areas still using coal or intermittent renewables.
- ✓ Hydrogen for **industrial processes**, creditworthy manufacturers of industrial products likes steel or concrete could be counterparties in bankable offtake arrangements.
- ✓ Potential as a future **replacement for natural gas** for residential and commercial heating. The advantage is that no new infrastructure would be required.
- ✓ Mining companies operate in environments where other energy sources may be expensive, carbon-intensive and subject to disruption. Several pilot projects are underway.
    - **Anglo American Platinum**: developed the world's largest hydrogen-powered mine haul truck
    - **Impala Platinum:** In 2016, developed first hydrogen fuel cell forklift and hydrogen refueling station
    - Africa Produces **over 80% platinum** required in green hydrogen electrolysis
    - There is an opportunity in Africa's green minerals for batteries in the renewables

Conclusions

- Africa has a **competitive** advantage for green hydrogen investment.
- Work on green hydrogen has been ongoing in Africa. **Bankability** of projects must be addressed collectively.
- **The price of green hydrogen is expected to come down**. Policy interventions such as taxation, subsidies, incentives as well as on the development of the industries for end-use of green hydrogen and its derivatives will help.
- **Collaboration** between private sector, different governments, regional blocks and other interested African parties will facilitate progress toward country and company-specific plans aligned with net-zero emissions targets.
- The African Development **Bank is available** to use its instruments to support feasible projects on green hydrogen.
- While most seem to be focused on exports, there are options to stimulate **local demand** in Africa which has significant potential. Green Ammonia, transport, mining, industry.
- Green hydrogen is a **new opportunity** for Africa but also for the world to decarbonize quicker and at a lower cost.

Thank you

For Further information relating to the presentation, please Contact:
f.kabanda@afdb.org

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“Green Hydrogen as a game changer for the energy transition”

Prof. Dr. Jürgen Peterseim
PricewaterhouseCoopers Deutschland

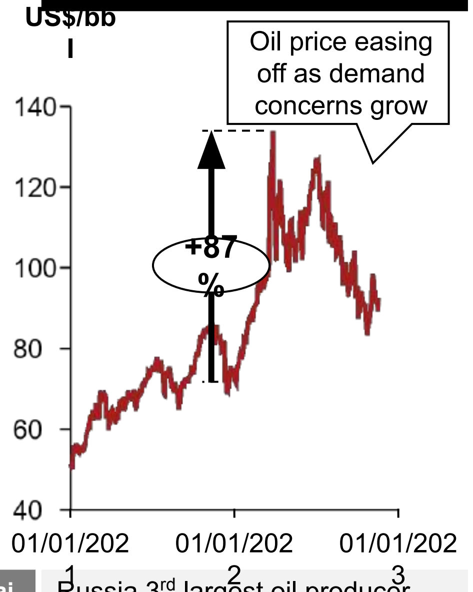
Germany

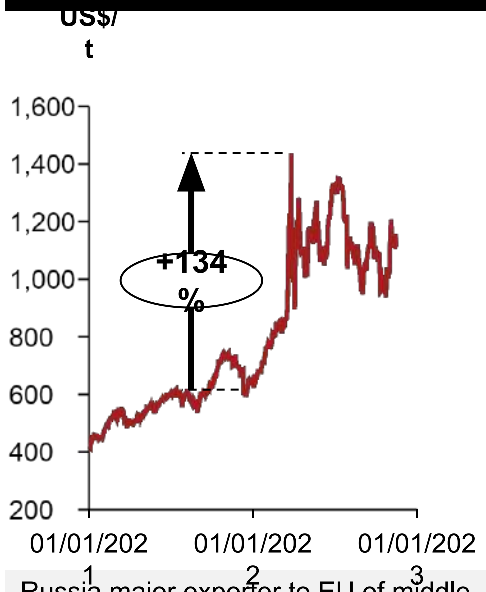
Green Hydrogen as a game changer for the energy transition

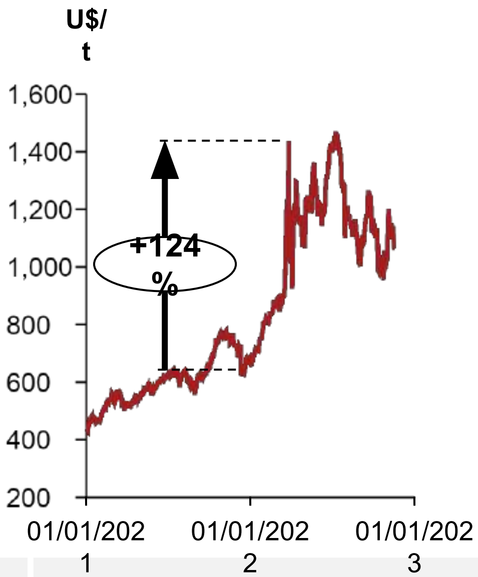
Adj. Prof. Jürgen Peterseim
Global lead Fuelling our Future Initiative

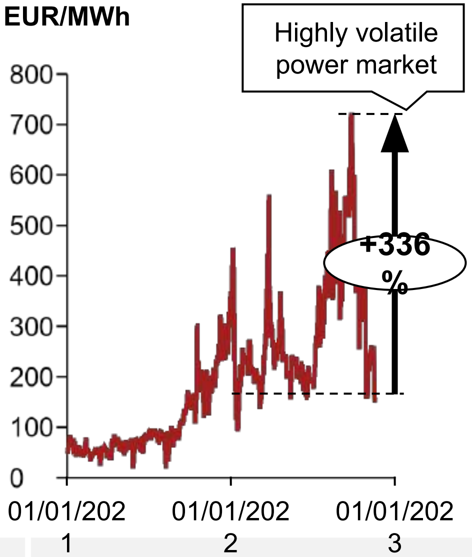
pwc

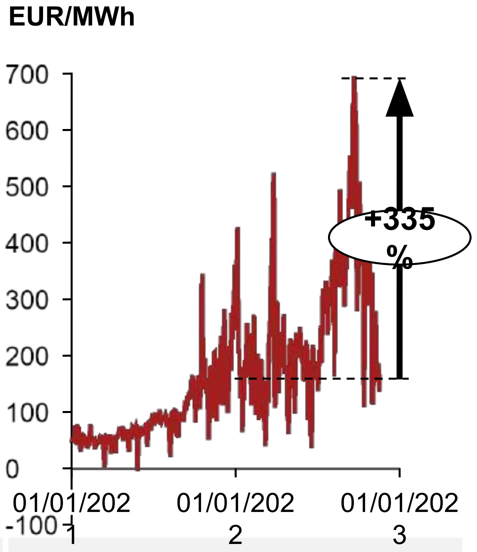
Trends that have existed for some time have been further exacerbated by the Russia-Ukraine war











	Dated Brent Price	European Diesel	European Jet Fuel	FR Baseload Power	GER Baseload Power
Ukraine crisis relevance	Russia 3rd largest oil producer. 2nd largest crude oil exporter	Russia major exporter to EU of middle distillates Russia largest diesel exporter to UK (34%)	-	-	-
Business Impact	High oil price stoking inflation and driving price of related commodities upwards	Higher costs for transport companies. Bus companies and logistics firms profitability impacted High pump prices for consumers	Aviation profitability impacted. Fuel represents 30% - 40% of operating costs Higher fares for consumers	Highly volatile power prices impacting consumers and businesses. Financial distress across value chain. Increased energy costs for business. Liquidity concerns for margin calls	Highly volatile power prices impacting consumers and businesses. Financial distress across value chain. Increased energy costs for business. Liquidity concerns for margin calls

The EU has established ambitious decarbonization targets as well as independence from Russian gas

EU Green Deal
Jan - 2020

- **EU** to become **climate neutral** ł **2050, net zero emission of green house gasses**
- **Reduction** of **50% of GHG** (vs. 1990) **by 2030**
- Roadmap covering all sectors of the economy
- Targets signed by all EU countries
- Total **financing** stream **of at least €1 trillion**

EU H2 Strategy
Jul - 2020

- EU H2 role for aimed decarbonisation
- **2025: Market initiation**
  - 6 GW ELY
  - 1 Mtons renewable H2
  - Regulatory framework
- **2030: Market develop**
  - 40 GW ELY
  - 10 Mtons renew. H2
  - Regulatory framework
- **2050: Market matured**
  - Hard to decarb. sectors
  - Up to €470 billion
  - Expected REs demand for H2 reach 25% of EU electricity prod.

EU Gas Package
July/Dec - 2021

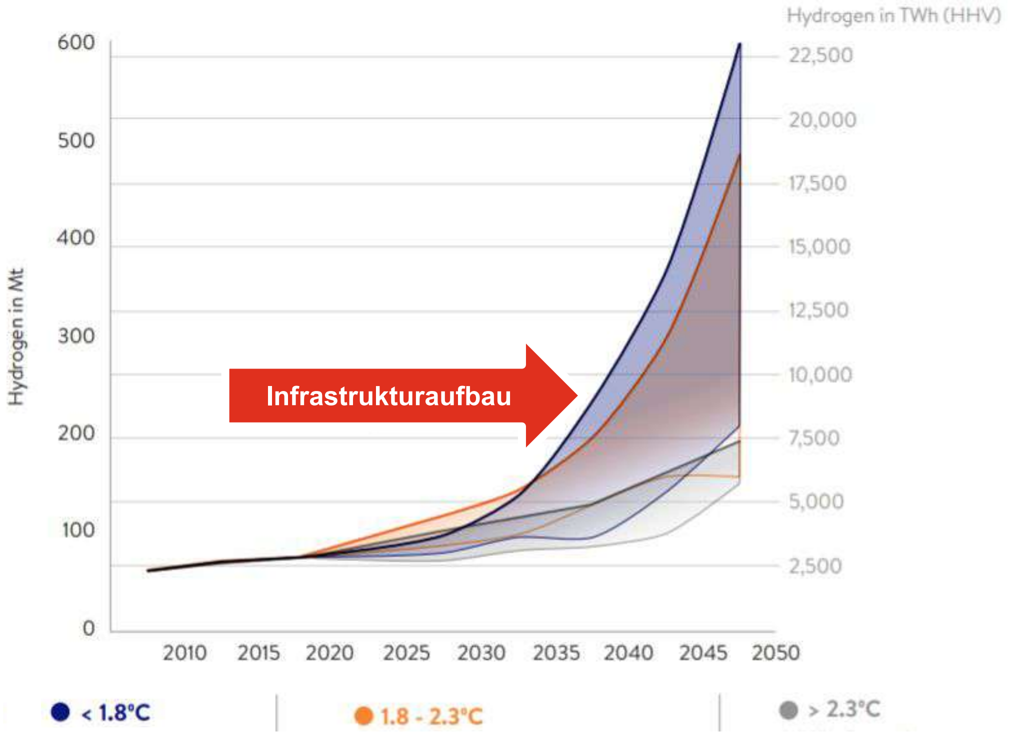
- **Definition of main axes of H2 network regulatory framework**
- Part of Fit455 (-55% of GHG vs. 1990 by 2030). Other initiatives:
  - RED revision
  - EU ETS
  - Energy Efficiency
  - Energy Taxation
  - Alternative Fuel Infra.
  - ReFuel EU Aviation
  - Fuel EU Maritime

Re-Power EU
Mar-2022

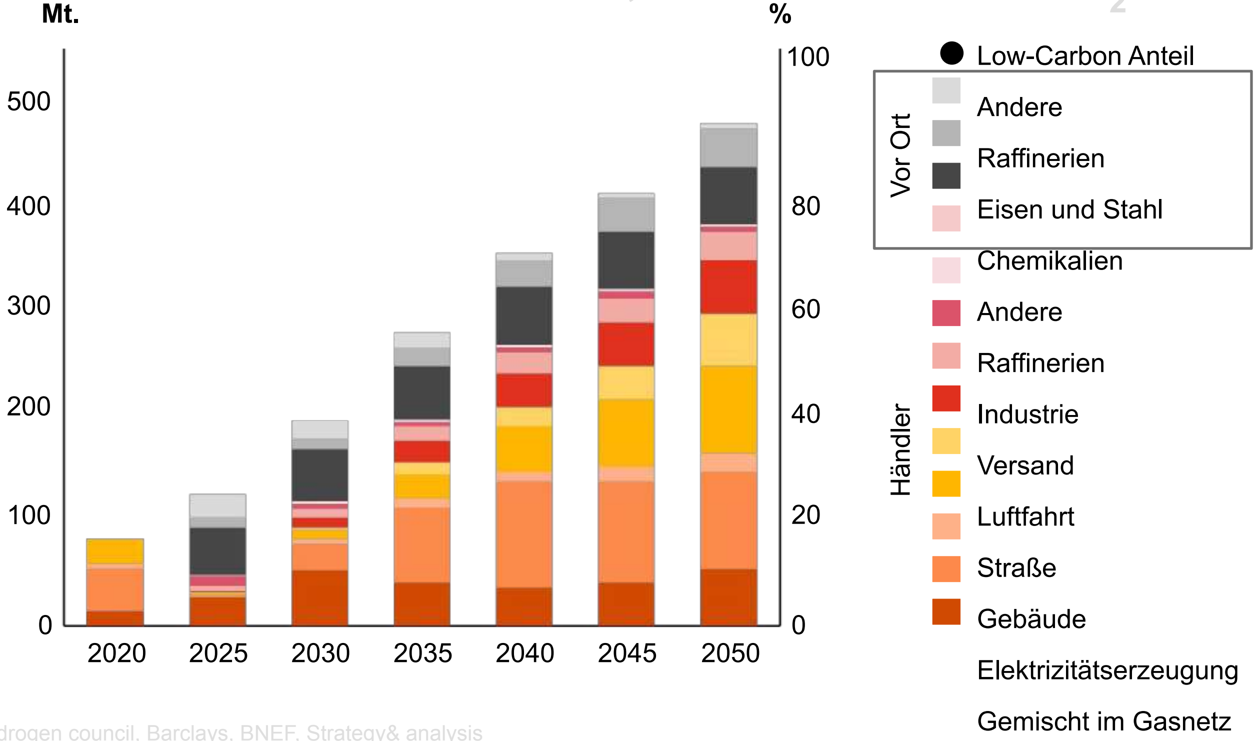
- Joint EU action for reducing dependence on Russia fossil fuels
- Industry decarbonization through electrification and renewable H2
- **Accelerate biomethane & H2 production**, together with speeding of REs permitting
- Implementation of the Carbon Border Adjustment Mechanism: tariff on carbon intensive products, such as cement and some electricity imported by the European Union.

Hydrogen demand will increase strongly from 2030 depending on the ambition of the pursued climate target and the infrastructure

Global hydrogen demand



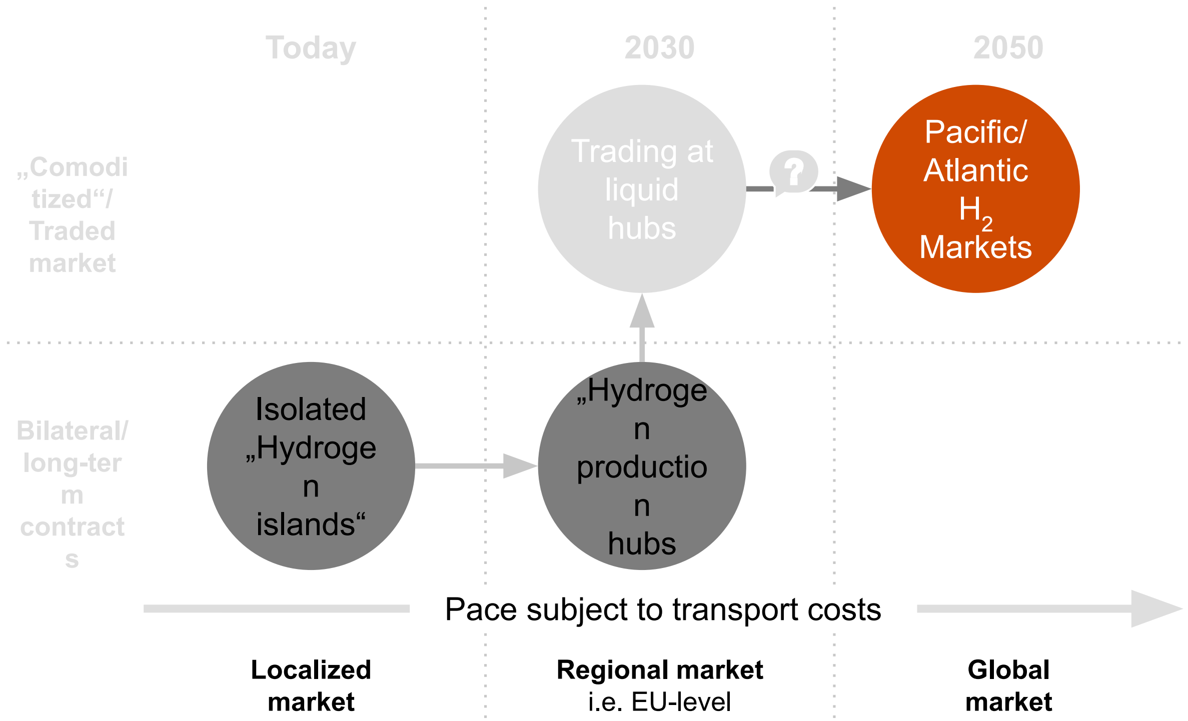
Global hydrogen demand by sector in the IEA NZE scenario, 2020 - 2050 – in MtH_2



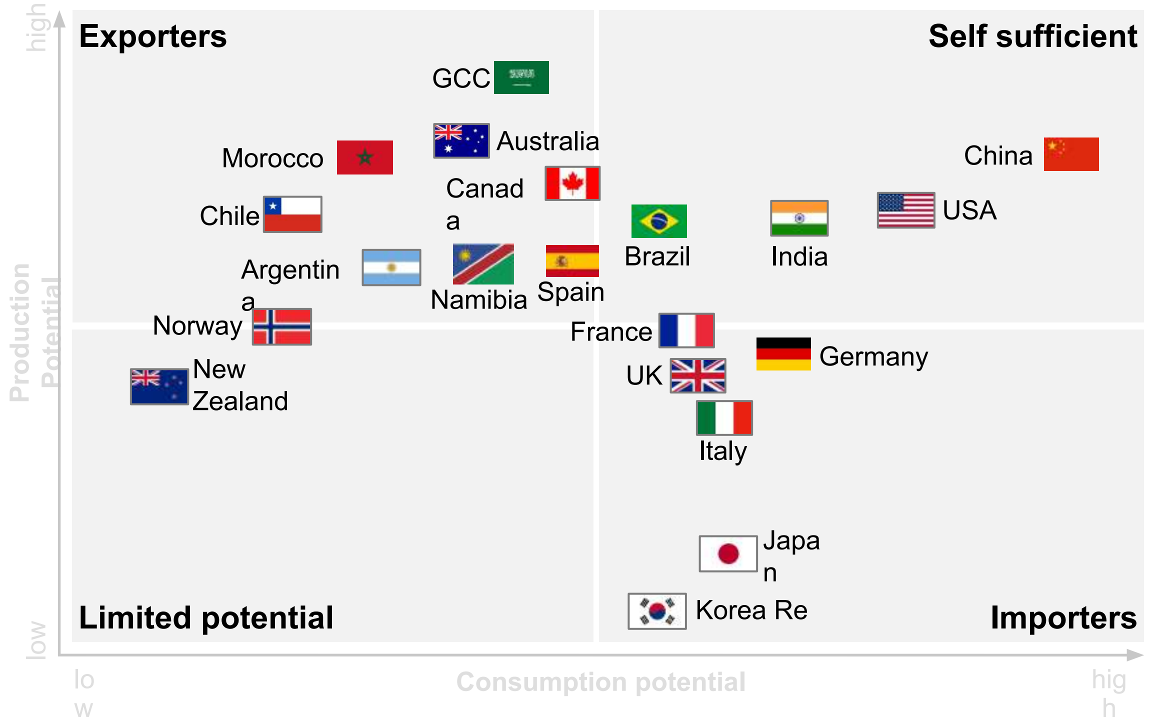
Note: umfasst Wasserstoff und in Ammoniak und synthetischen Brennstoffen enthaltenen Wasserstoff | Quelle: IEA, Hydrogen council, Barclays, BNEF, Strategy& analysis

H2 market will gradually evolve from local demand pools to commoditized which will result in a global trading system

Potential development routes for H_2 market



Green hydrogen production/consumption potential



1) Including investment costs and O&M costs for plant liquefiers; 2) Costs from electricity usage for liquification of hydrogen; 3) Based on LNG transport data from Agora (2018); Source: Agora (2018), Department of Environmental Science and Policy (2007), sea-distance.org

Europe already has more than 220 renewable H2 projects. However, in the future imports are essential to meet decarbonization goals.

Current H2 project development in the EU States

Currently there are **more than 220 projects** in the member states of the European Union

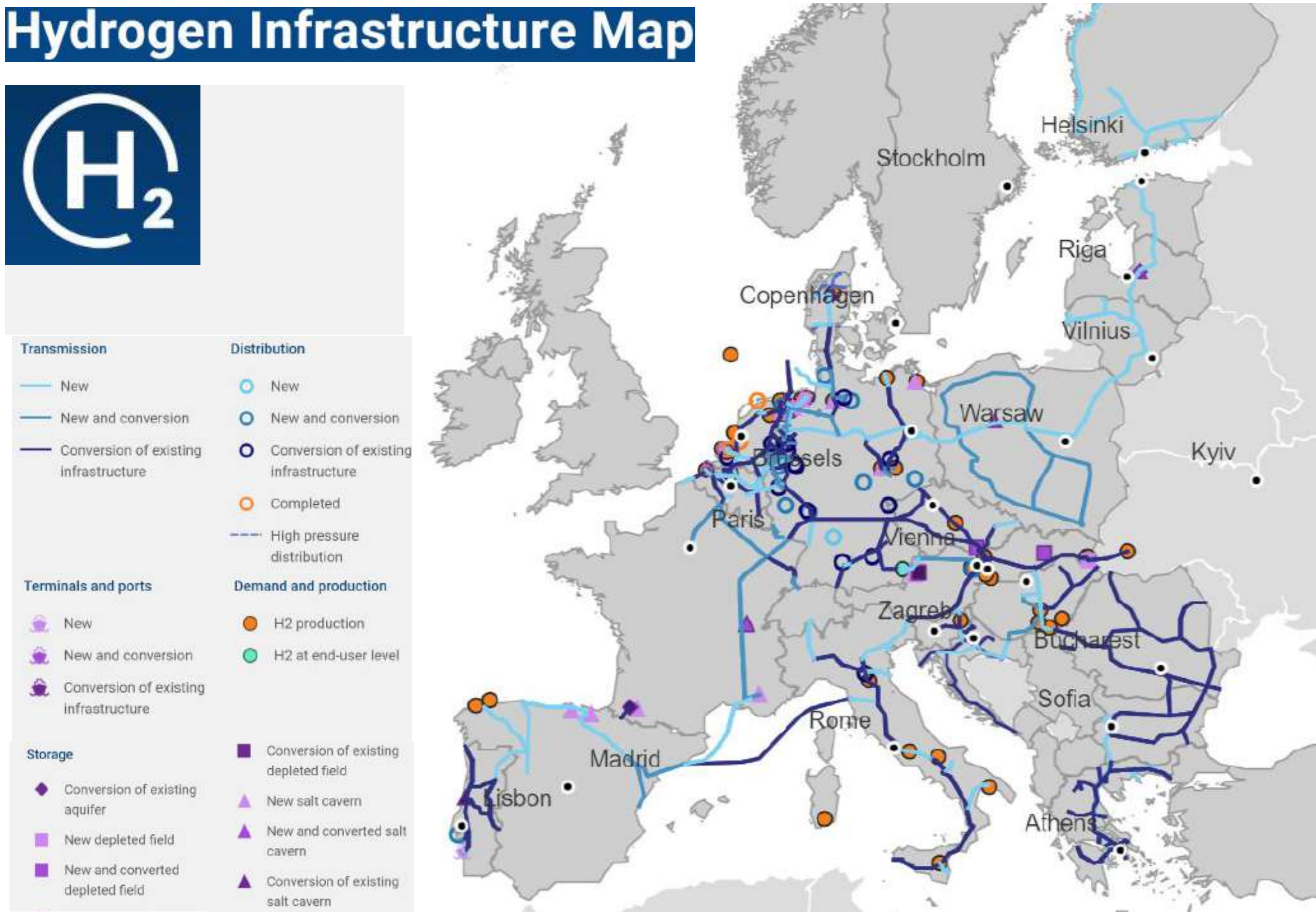
Around **120 Hydrogen transmission and distribution** projects distinguish between:

- new pipelines,
- conversion of existing natural gas pipelines
- mixture of new construction and conversion

More than **40 Hydrogen storage** projects

10 Hydrogen **terminals & ports** projects

40 Hydrogen **demand and production**



Source: h2inframap.eu 2022, Energate messenger 2022

In Germany the first H2 Global tender procedure for the market ramp-up of green hydrogen was already launched in 2022

Green hydrogen support instrument

- The German Federal Ministry for Economic Affairs and Climate Action (BMWK) provides funding of **EUR 900 million** for this initiative
- The goal of H2Global is to accelerate the international **market ramp-up for sustainable hydrogen products**
- The production of the hydrogen derivatives must take place outside the EU and EFTA states
- The price is set in a competitive international bidding process
- The period of the long-term purchase agreements is 10 years

- **In 2022 HINT.CO GmbH** launched the first H2Global tender procedure for the procurement of **green ammonia** for import into Europe
- The **first deliveries** of these sustainable hydrogen derivatives to Europe are planned for the end of 2024 or early 2025
- The tenders for **green methanol and e-SAF** will follow in the short term, 2023

H2Global Stiftung

Source: H2Global Stifftung 2022; BMKW 2022

Projects with high investment volumes are increasingly being realized in the market

Recent projects

One of the largest green hydrogen projects in the world: thyssenkrupp signs contract to install over 2GW electrolysis plant for Air Products in NEOM

Key insights

- Thyssenkrupp Uhde Chlorine Engineers, a joint venture between ThyssenKrupp AG and Industrie De Nora specialising in electrolysis, **has won a 2-GW electrolyser supply order for a huge green hydrogen project in Saudi Arabia**.
- Industrial gases major Air Products has awarded a contract that calls for thyssenkrupp to engineer, procure and fabricate the plant based on its 20-MW alkaline water electrolysis module.
- As announced in the summer of 2020, Air Products teamed up with ACWA Power to build a **USD-5-billion green hydrogen-to-ammonia complex in Neom**
- The facility will produce hydrogen to be synthesized into **carbon-free ammonia for export exclusively** by Air Products to global markets, the latest announcement says.

Shell has already taken the FID for the largest renewable hydrogen project in Europe to supply its refinery processes

Recent projects

Companies
Shell

Location
- Tweede Maasvlakte in the port of Rotterdam

Project
- Production of renewable hydrogen to supply the Shell Energy and Chemicals Park Rotterdam **by 2025**
- The renewable hydrogen will be transported by the HyTransPort pipeline, where it will replace some of the grey hydrogen usage in the refinery
- This will partially decarbonize the facility's production of energy products like petrol and diesel and jet fuel
- The renewable power for the electrolyzer will come from the offshore wind farm Hollandse Kust (Noord)

Capacity
- 200MW electrolyzer
- 21900 tonnes of hydrogen per year

Project development stage
- FID taken in 2022

Source: Shell 2022, Port of Rotterdam 2022

Four km pipeline infrastructure for the supply of green hydrogen into the steel production process in Germany

Recent projects

Companies

Air Liquide

ThyssenKrupp

Location

- Duisburg, Germany

Project

- 20 MW PEM electrolyzer in operation by 2023 connected to both existing hydrogen and oxygen pipelines
- Four km pipeline to connect the Thyssenkrup Duisburg steel mill site with Air Liquide's hydrogen network in the Ruhr district with a transport capacity of 2,900 tons of renewable hydrogen per year
- Injection of hydrogen into a blast furnace for the first time on a test basis to reduce CO_2 emissions from conventional steel production

Capacity

- 20 MW industrial-scale water electrolysis plant (2023) with a 10 MW provision of expansion

Project development stage

- Hydrogen pipeline already constructed
- First large-scale industrial direct reduction plant with melting units is scheduled for 2026

Source: Air Liquide 2022, Thyssenkrupp 2022, Hydrogen Tech 2022

First offshore green hydrogen production through the Lhyfe pilot project

Recent projects

Companies
Lhyfe

Location
- Le Croisic, Centrale Nantes, France

Project
- This project is the first of its kind and aims to produce renewable hydrogen by the electrolysis process at sea
- Renewable electricity is provided by a floating wind turbine and it includes a desalinating seawater process

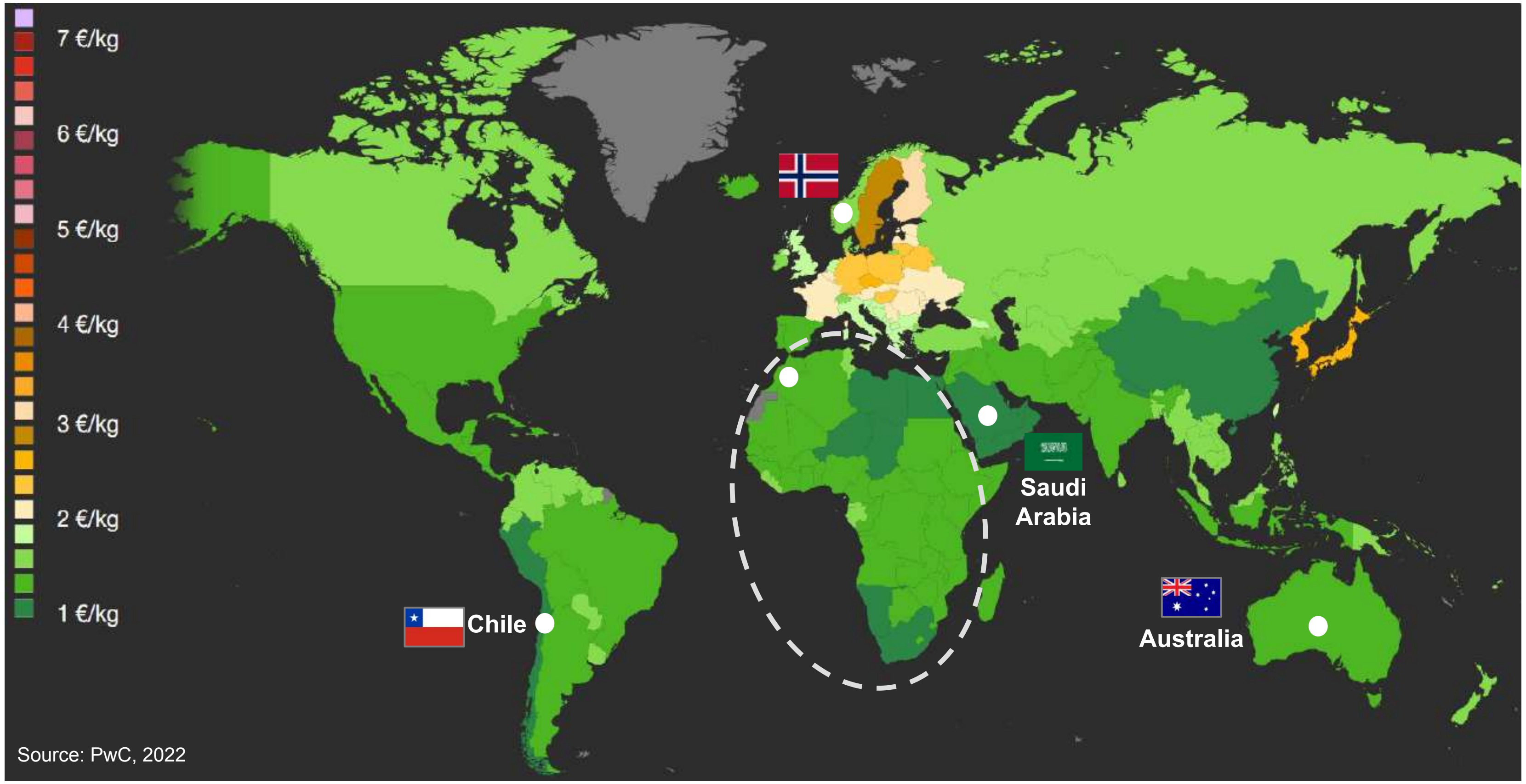
Capacity
- up to 400 kg of renewable green hydrogen a day
- by 2030-2035, offshore could represent an additional installed capacity of around 3 GW

Project development stages
- A first six-month trial phase to test all systems (desalination and cooling systems, stack behavior, remote control, energy management, resistance to environmental conditions, etc.)

Source: Lhyfe 2022

Low LCOE set African countries in a unique position to become a major hydrogen suppliers for Europe

However, several nations with the same competitive advantage will participate in the market.



Germany is agreeing hydrogen partnerships not only with Africa, first hydrogen shipments come from Middle East

06/2020

Morocco and **Germany** signed an **agreement** on the development of the **green hydrogen** production sector. The agreement aims to **develop** the sector of **green hydrogen production** and to set up projects **research and investment** in the use of this material.

06/2021

In June 2021 the **Australian** and **German** governments announced the **Australia-Germany Hydrogen Accord** – a forward-leaning initiative to deepen our **collaboration on climate change action and emissions reduction**. The initiative's ambition is to produce the cheapest **green hydrogen** in the world, which will transform entire industries, such as transport, mining, resources and manufacturing.

07/2021

Germany and **Chile** on Tuesday signed a letter of intent for a **bilateral alliance** on hydrogen production and trade to try to facilitate a **renewable energy hydrogen supply chain** between the countries, the economy ministry said in a press release.

10/2022

The national oil company of the **United Arab Emirates** (UAE) has delivered a **first shipment of ammonia** derived from **hydrogen** to **Hamburg**. Germany plans to satisfy its growing demand for hydrogen **largely through imports**.

Air Products and Mabanaft announced their intention to build Germany's **first large-scale**, green energy import terminal in the **Port of Hamburg**.

First hydrogen projects between Africa and Europe are already announced and several achieved FID

S&P Global
Commodity Insights

ENERGY TRANSITION — 02 Feb 2023 | 10:45 UTC

Hyphen Hydrogen signs further offtake MOUs for Namibia green ammonia project

HIGHLIGHTS

Offtake from hydrogen, chemical companies

Total offtake agreements over 1 million mt/year

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2 minute read · October 18, 2022 12:55 PM GMT+2 · Last Updated 7 months ago

Sasol, ArcelorMittal to jointly explore green hydrogen, carbon capture projects

Reuters

[1/2] A general view shows ArcelorMittal South Africa , Johannesburg, South Africa, May 12, 2022. REUTERS/ Sumaya Hisham

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Renewable Fuels | Hydrogen | Clean Energy

1 minute read · March 8, 2023 1:44 PM GMT+1 · Last Updated 2 months ago

Consortium signs $34 billion MoU for hydrogen project in Mauritania

Reuters

Companies

Frankfurter Allgemeine Zeitung GmbH — Follow

Morocco: First Green Hydrogen Production System Installed in Benguerir

North Africa Post September 17, 2022 12:35 pm

A first green hydrogen production system at the micro-pilot scale has been installed in Benguerir, the Research Institute for Solar Energy and New Energies (French acronym IRESEN) announced, explaining that the system is part of its "Power-to-X µPilot" project.

The cost of intercontinental maritime transportation of hydrogen would represent up to 100% of the production cost

Current status of hydrogen transport by ship

- The world's **first liquid hydrogen transporter** was completed in **2020**
- **Suiso Frontier** is a 116-meter (381-ft) with a vacuum-insulated double-shelled tank capable of holding **1,250 m^3** of liquid hydrogen
- The hydrogen will be compressed to 1/800 of its regular gaseous volume, and cooled to **-253° C** (-423.4° F)

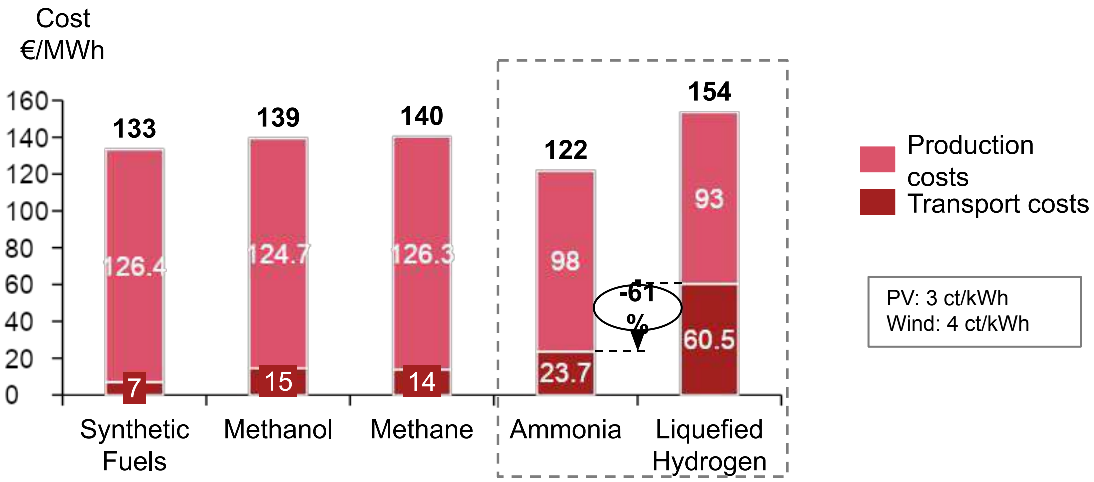
Kawasaki
丸紅株式会社 Marubeni
J-POWER

The **energy capacity** of the Suiso Frontier is **<1%** of the energy capacity of an **LNG** ship with the same size

NH_3

Solution today: transport of **green ammonia**. Currently **10%** of transport of ammonia is done by ship

Hydrogen transport cost from Australia to Germany in 2050



- The national oil company of the United Arab Emirates (UAE) has delivered in 2022 the first **shipment of ammonia** derived from hydrogen to Hamburg
- Green ammonia from Saudi Arabia will be produced by **Air Products** from **2026**

Note: Source: Fraunhofer; 2023; IRENA 2022, HESC 2022, Liebreich 2022; Offshore Energy 2022

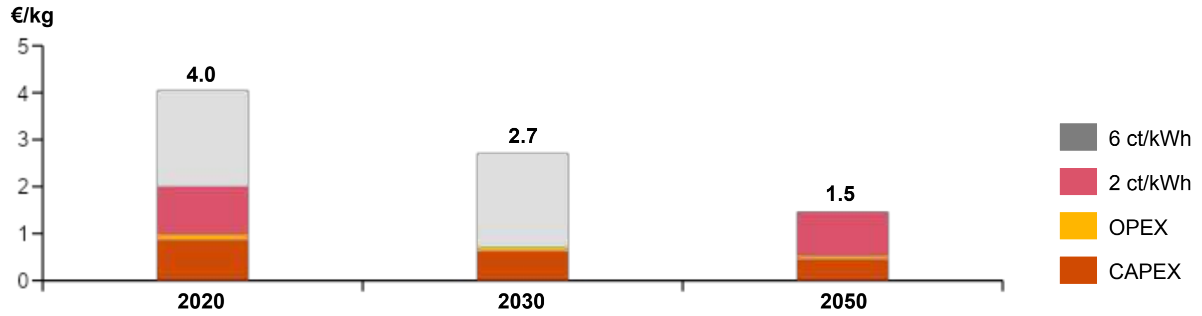
Hydrogen trains are already in operation and are expected to show a very positive cost development

Case study
with hydrogen powered Freight trains

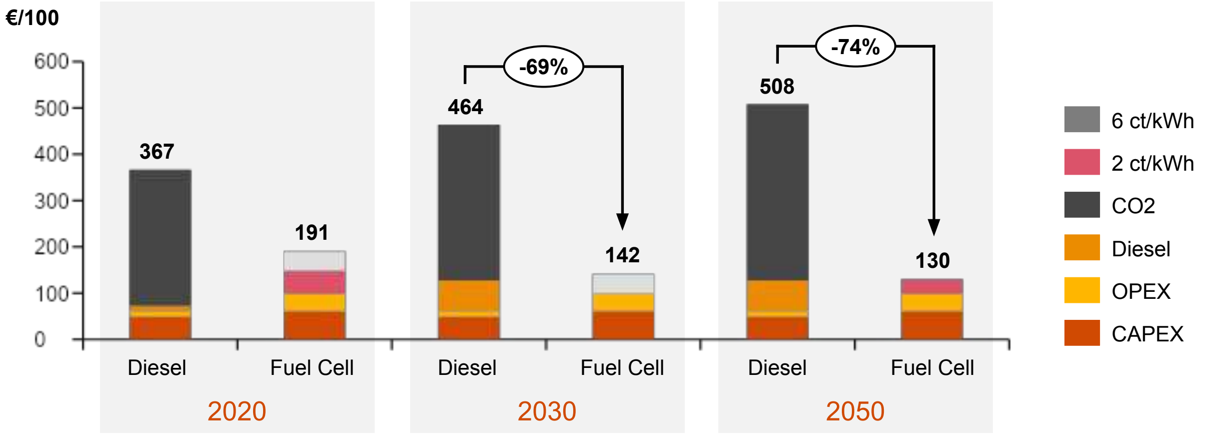
Canadian Pacific has launched a **hydrogen locomotive** program in 2020: a mainline locomotive using hydrogen fuel cells and battery technology to power the locomotive's electric traction. The locomotives will use Ballard fuel cell modules that will provide a total of 1.2 MW of electricity to power the locomotive.

Note: CO2 Cost €/t: 30 (2022), 180 (2030), 180 (2050) | Source: PwC Strategy& Analysis; Alstom 2020; Yara, 2021. "Renewable hydrogen and ammonia production" | EU, 2019. "Fertiliser in the EU - Price, trade and use.

Development costs for green hydrogen according to electricity price

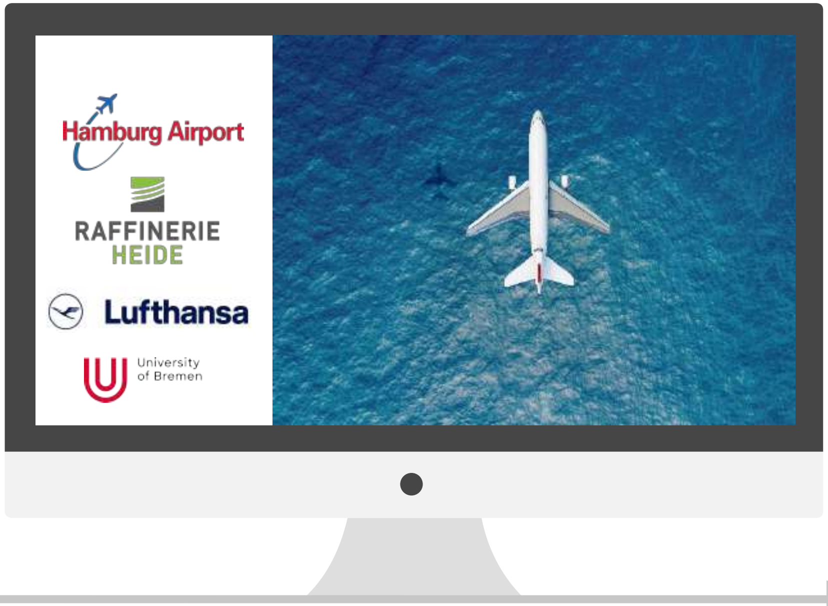


Cost comparison of freight trains



Flights will become more expansive due to SAF – however, costs can be distributed

Case study
Production of renewable synthetic kerosene

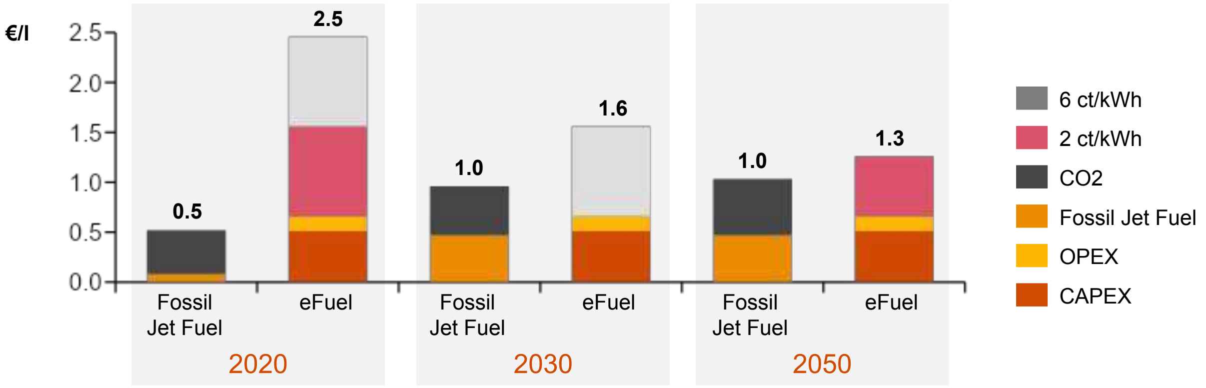


Pilot project Kerosyn100

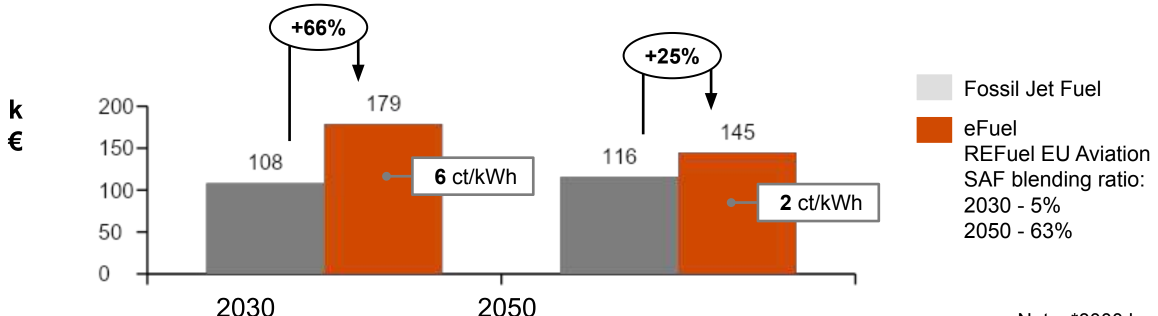
- Aims to produce renewable synthetic kerosene by the process **Power to Liquid (PtL)**.
- It uses **low-carbon hydrogen** and CO_2 as a feedstock in the process of **Fischer-Tropsch.**

Note: CO2 Cost €/t: 30 (2022), 180 (2030), 180 (2050); 1: Fuel consumption based on a Boing 777-9 | Source: PwC Strategy& Analysis; Hamburg Airport, 2019. Mit grünem Krafstoff fliegen; Kerosyn100, 2022; Boeing, 2022

Comparison of production costs for green steel (€/t)



Jet Fuel cost comparison of a long-haul flight* by fuel type (k€)[1]



Note: *8000 km

Based on a rising CO_2 price, the production of fertilizers with green H_2 is becoming increasingly competitive

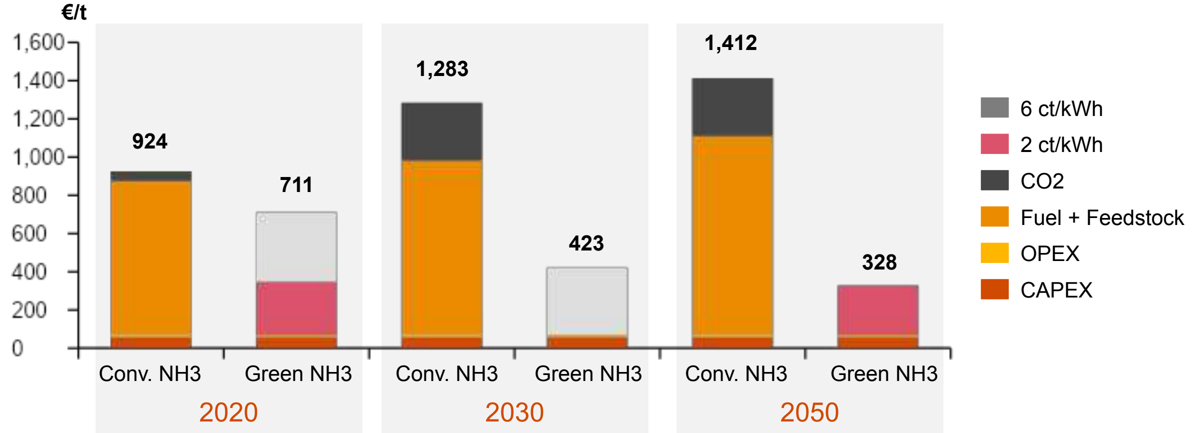
Case study
Production of renewable Ammonia

Renewable ammonia for power generation, marine, fertilizer and mining explosives customers.

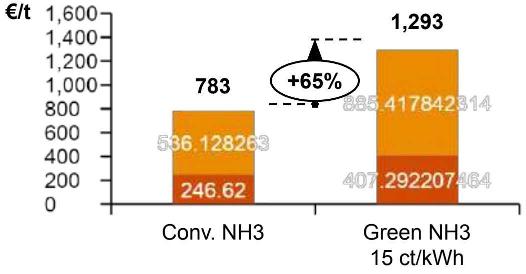
In the first phase of the project, up to 625 t of renewable hydrogen and 3,700 t of ammonia will be produced per year.

Note: CO_2 Cost €/t: 30 (2022), 180 (2030), 180 (2050) | Source: PwC Strategy& Analysis; Yara, 2021. "Renewable hydrogen and ammonia production", EU, 2019. "Fertiliser in the EU - Price, trade and use.

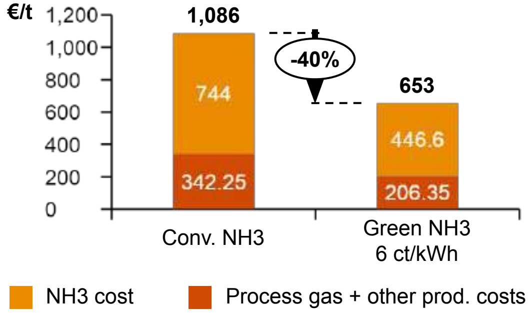
Comparison of production costs for ammonia



Cost of urea by NH3 type – 2022



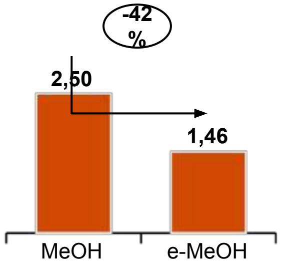
Cost of urea by NH3 type – 2030



With the help of green hydrogen, one of the most important basic chemicals is already being decarbonized today

Case study
Production
of "e-methanol

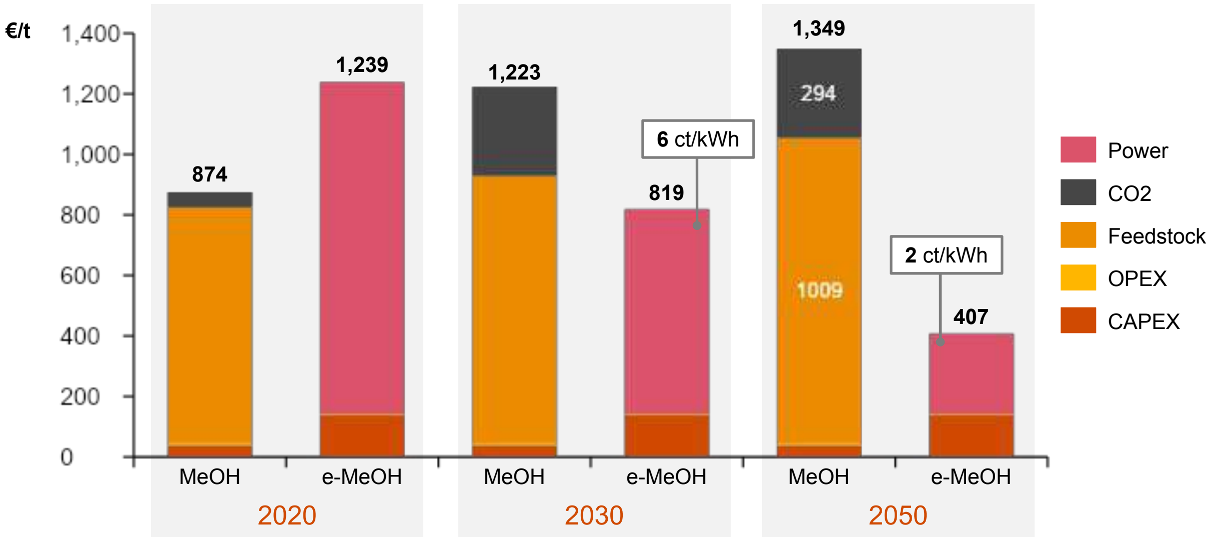
Comparison of CO_2 intensity (g CO_2 /t $)_{MeOH}$



The use of green hydrogen can reduce the life cycle emissions of methanol by 42%.

Due to the rising CO_2 prices, the prices of the two methanol variants will already equalize in 2030.

Comparison of production costs for "e-methanol" (€/t)



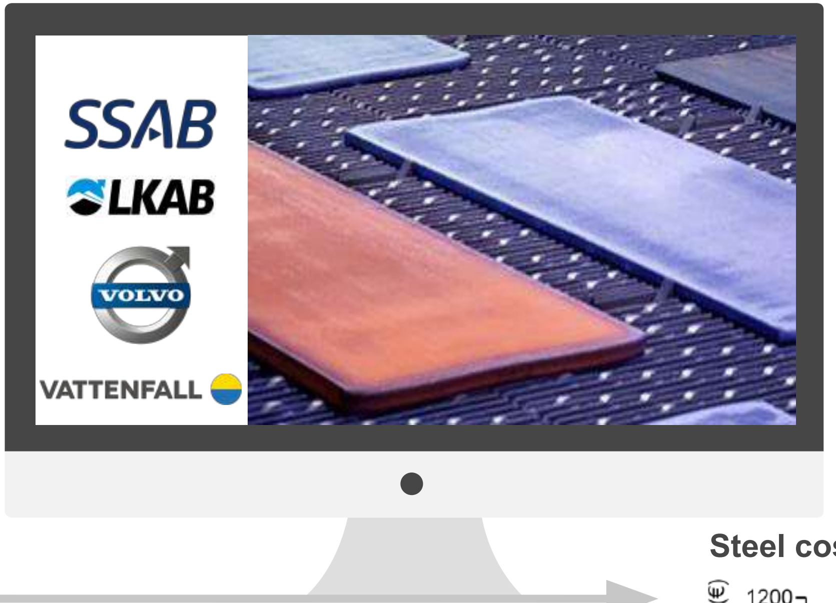
Methanol with a reduced carbon footprint can help decarbonize diverse value chains as a fuel and energy feedstock.

At the Stade Chemical Park, Dow Chemicals produces up to 200,000 metric tons of e-methanol per year on the world's largest scale.[1)]

1) Lower Saxony Hydrogen Network: "Green methanol: green MeOH", 2021

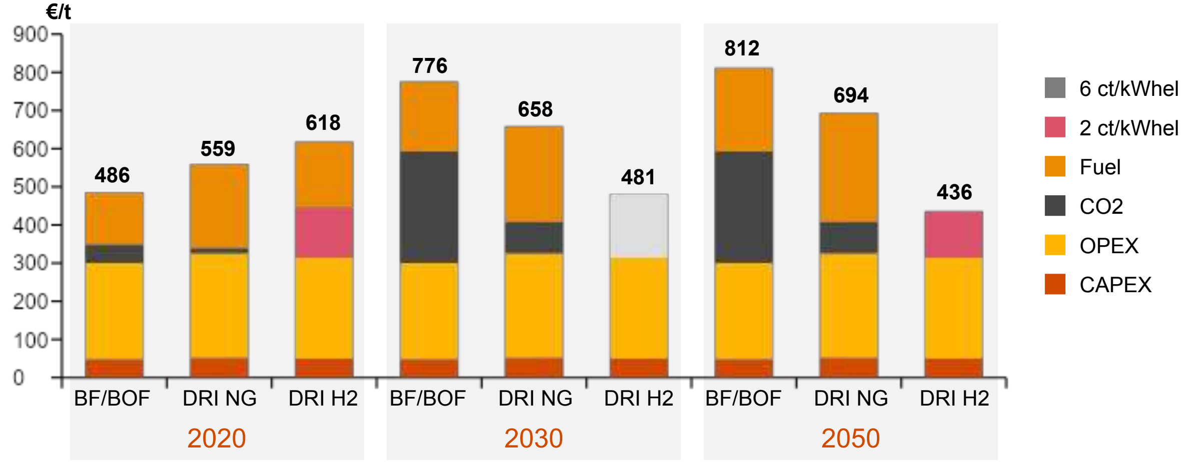
The additional costs for green steel only have a minor impact on premium products

Case study
Green steel
Through use from renewablem Hydrogen

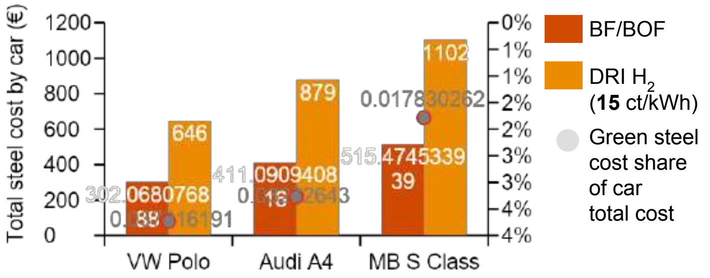


The aim is to create the first fossil-free steel value chain.
Capacity of over 1 million tons per year.

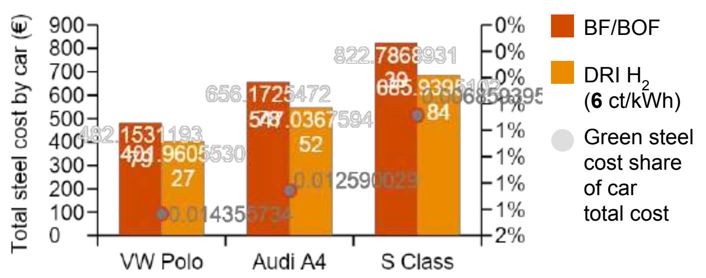
Comparison of production costs for green steel (€/t)



Steel costs by car segment (2022)



Steel costs by car segment (2030)



Source: PwC Strategy& Analysis; SSAB, 2022. A new revolutionary steelmaking technology; carlogos.org

Thank you!

Adj. Prof. Jürgen Peterseim
Global lead Fuelling our Future Initiative
juergen.peterseim@pwc.com

CHAPTER 2. EFFICIENT PRODUCTION OF GREEN HYDROGEN IN AFRICA

“Green Hydrogen from Renewables – What We Need”

Dr. Carsten Bührer
PNE AG

Germany

MAY 2023

GREEN HYDROGEN FROM RENEWABLES – WHAT WE NEED

DR. CARSTEN BÜHRER – HEAD OF TECHNOLOGY

PNE AG

PNE
pure new energy

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PNE – FULL OF ENERGY

WE ARE A LEADING DEVELOPER OF RENEWABLE ENERGY PROJECTS

- **> 25 years** of industry experience
- Active in **14** countries on **4** continents
- **Leading** developer of wind farms in Germany
- **Nr. 2** O&M manager in Germany with **> 2,200 MW**
- **> 6,300 MW** of renewable energy projects realized
- Clean energy for **> 3.5m** households; **> 10m tons** of CO_2 savings p.a.
- **> € 13bn** of investments initiated
- Attractive **Wind & PV pipeline** of **> 11.4 GW / GWp**
- **Own power generation portfolio of 283 MW**

We develop and implement projects and solutions for the planning, construction and operation of renewable power plants.

ROBUST BUSINESS MODEL THROUGH INTEGRATION ALONG THE VALUE CHAIN

PLENTY OF GROWTH POTENTIAL

approx. 3 – 6 years

> 20 years

Development
- Acquisition of site
- Analysis (wind / sun)
- Selection of equipment
- Permits

Financing
- Financial analysis
- Legal concept
- Sales/marketing
- Project financing

Construction
- Grid connection
- Infrastructure
- Assembly
- Start-up of operations

Sale* / IPP
- Utility
- Infrastructure fund
- Insurance companies
- IPP

Service
- Technical and commercial management

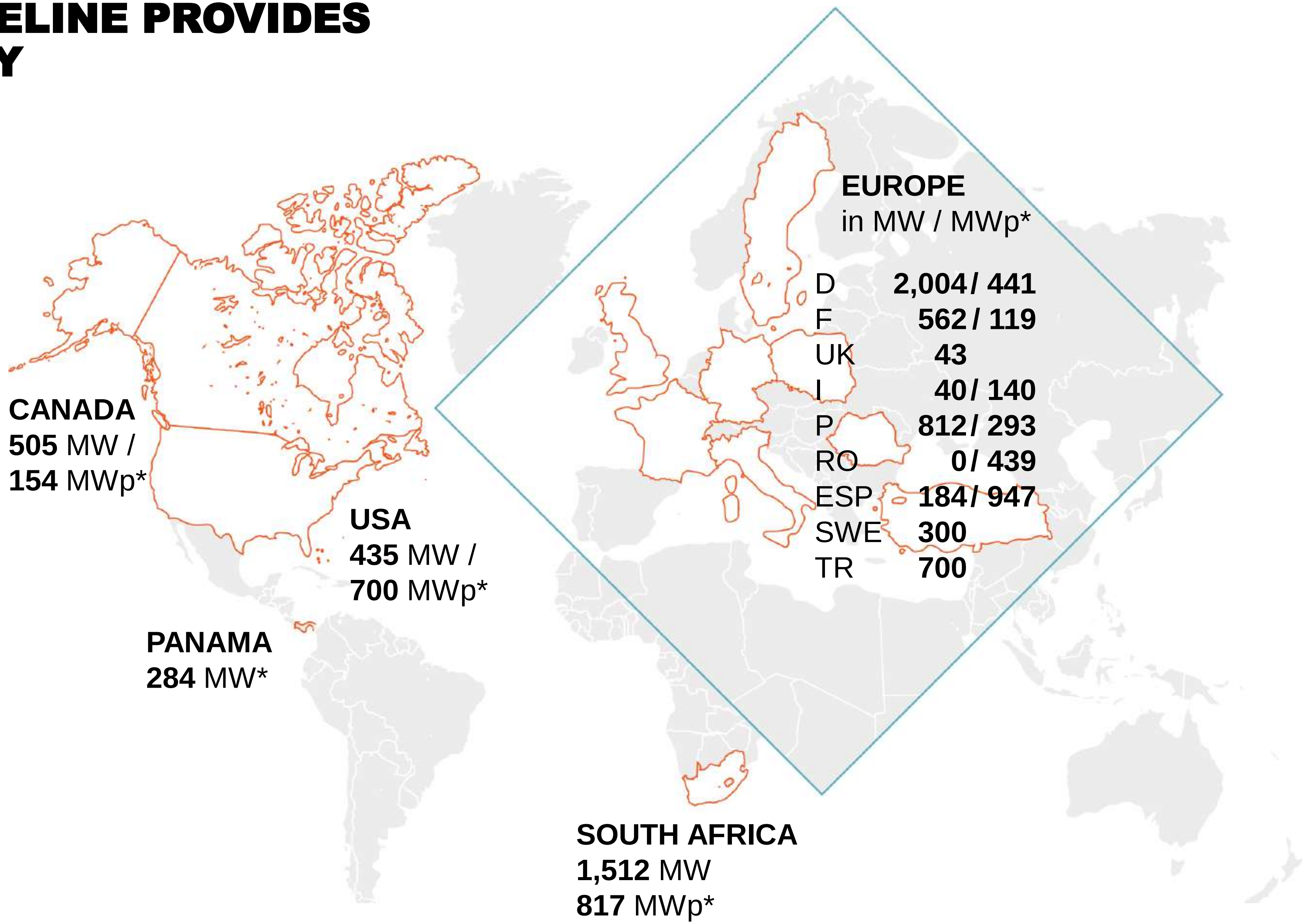
Wind — PV — Storage — Power-to-X

*sale as turnkey project or project right, as single project or project portfolio

11.4 GW PROJECT PIPELINE PROVIDES EXCELLENT VISIBILITY

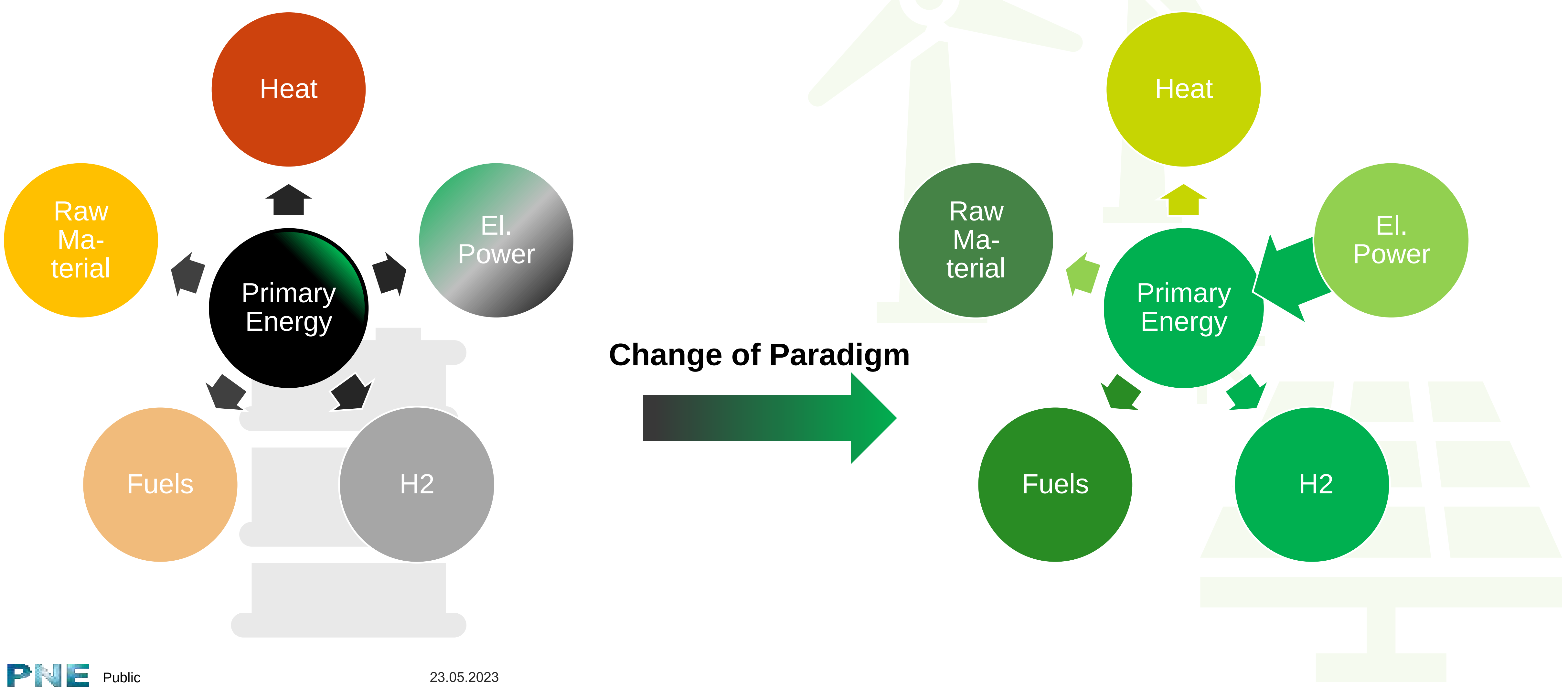
PV PIPELINE IS GROWING FAST

- **Onshore wind:**
  Large, high-quality project pipeline secures stable project output
- **PV:**
  Projects under development in nine markets;
  further internationalisation planned



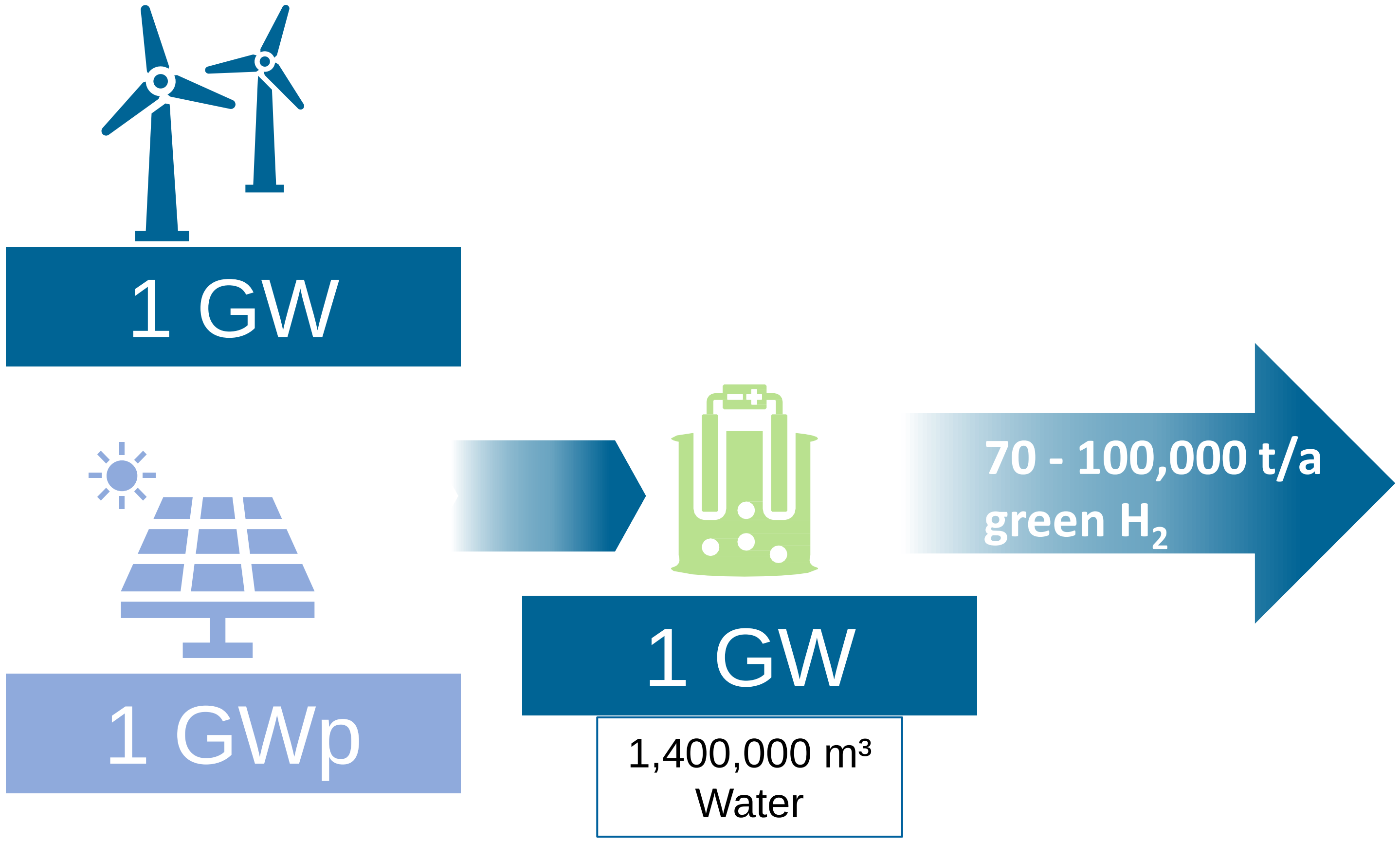
* numbers as of September 30, 2022

OUR CHALLANGE – TRANSITION OF PRIMARY ENERGY SOURCE



KEY FIGURES (RULE OF THUMB)

FOR SITES WITH VERY GOOD WIND & SOLAR RESOURCES



Product		Amount
Hydrogen	H_2	100,000 t/a
Methane (LNG)	CH_4	200,000 t/a
Methanol	CH_3OH	530,000 t/a
Ammonia	NH_3	560,000 t/a

Product		Typical Shipping Capacities
Hydrogen (Protoype)	H_2	1,250 cbm/ship 88 t/ship
Methane (LNG)	CH_4	180,000 cbm/ship ~80,000 t/ship
Methanol	CH_3OH	23-40,000 t/ship
Ammonia	NH_3	23-40,000 t/ship

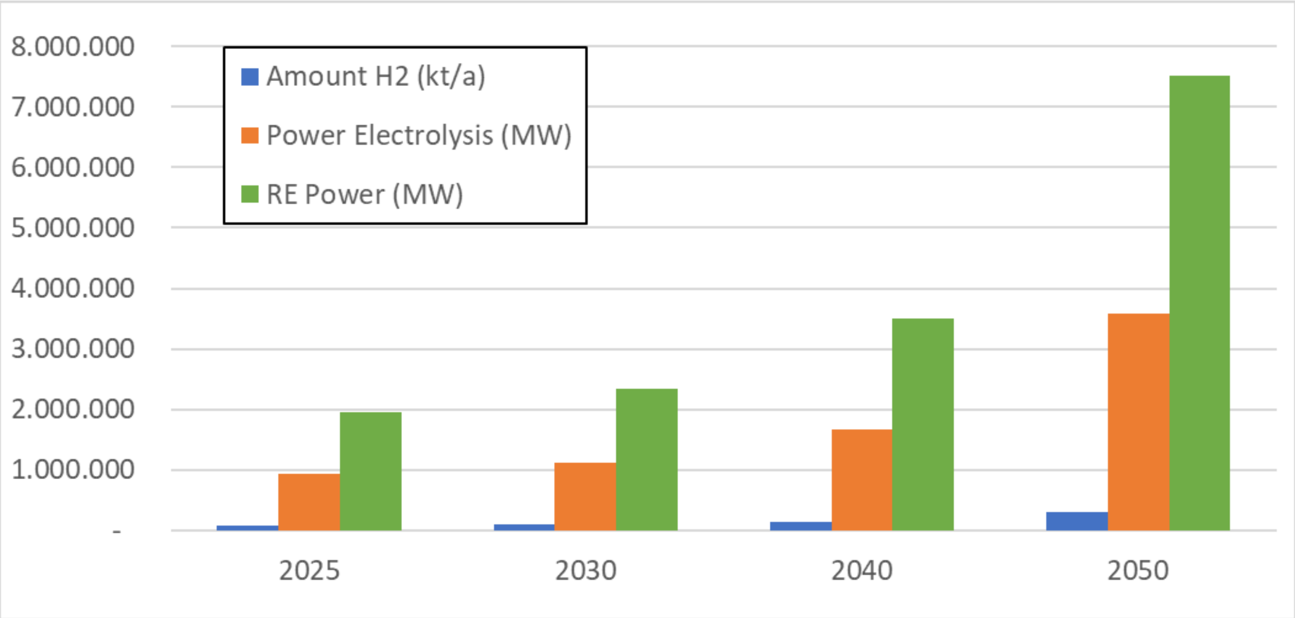
STRONG GROWTH FOR GREEN HYDROGEN

MEETING THE EXPECTED DEMAND REQUIRES VERY LARGE RENEWABLE SOURCES

Challenge

- *Hydrogen demand will rise*
- *Global hydrogen market*
- *Production of green hydrogen needs enormous amounts of renewable energy*

Global hydrogen demand in the Sustainable Scenario (~50% of Net Zero)



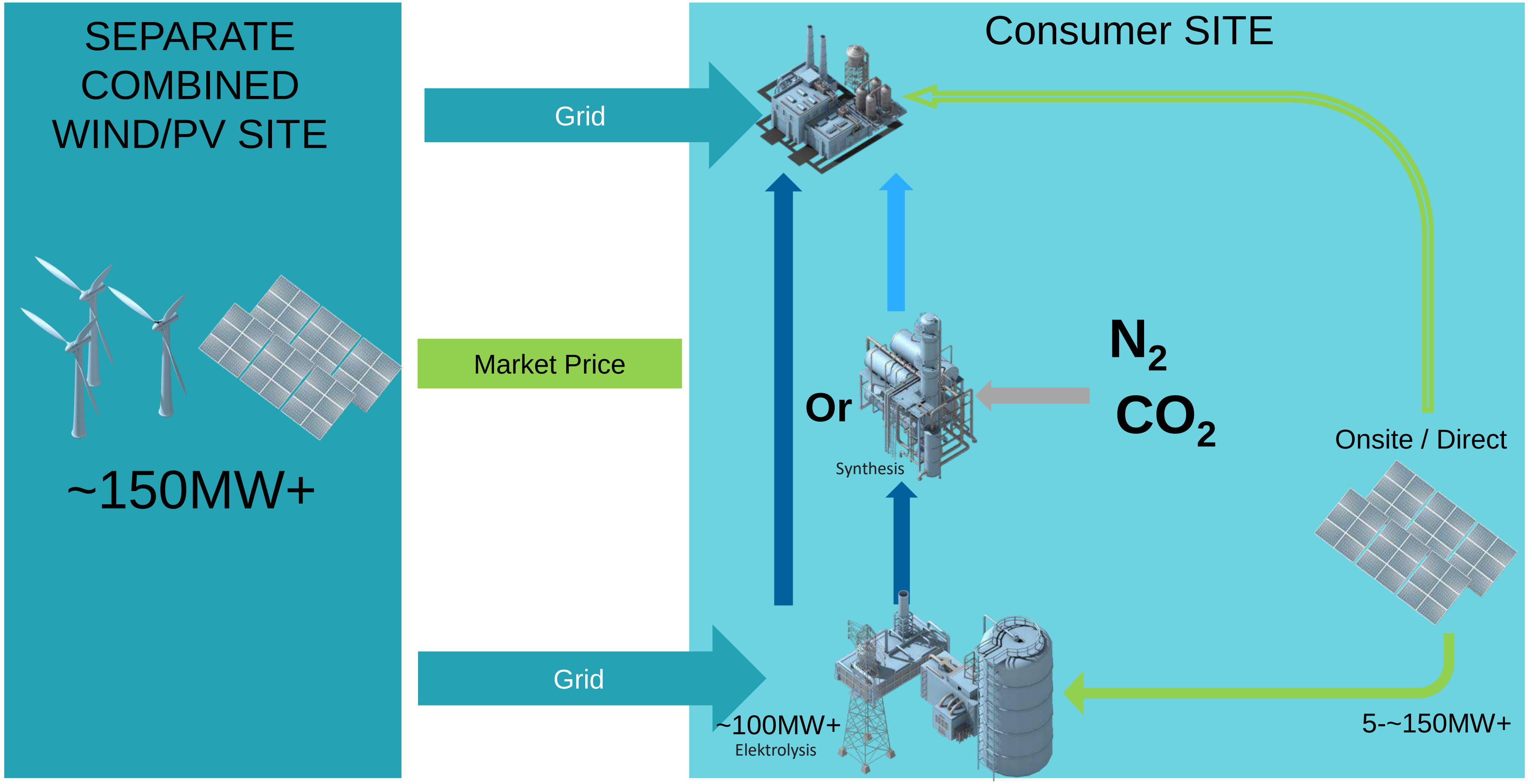
Drivers

- *Regulatory framework and quotas for use of green Hydrogen and Derivatives*
- *E.g. RED II in the EU with quotas for fuels*
- *E.g. RED III extending quotas to chemical products & steel*
- *Decarbonisation objectives & ESG of corporates*
- *Supply independence and security*
- *Cost of CO2*
- *Low cost production of Hydrogen*

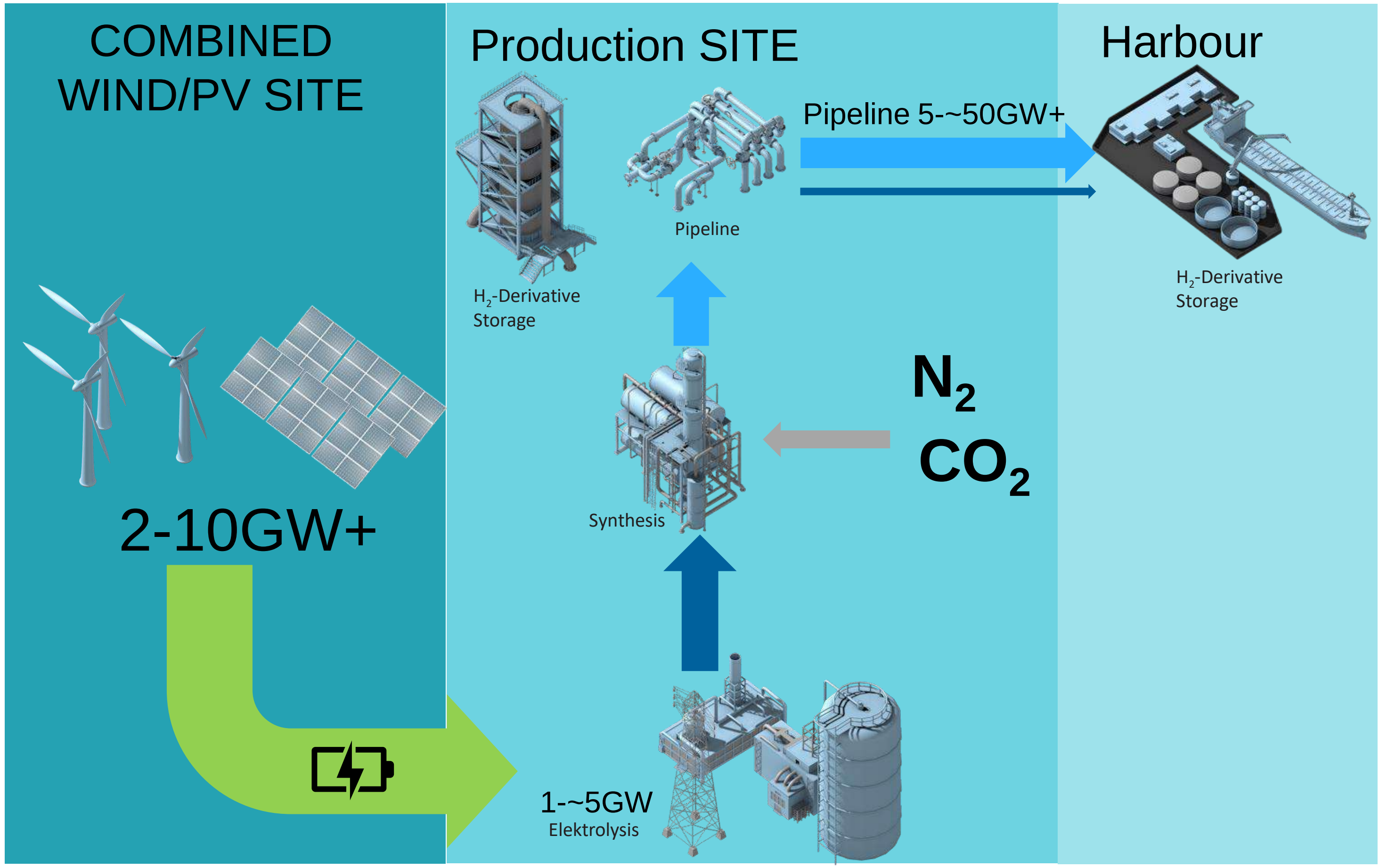
„Hard to abate Sectors“ = Potential Markets

Steel Industry | Chemical Industry | Shipping | Heavy loads | Aviation

PROJECT DESIGN REGIONAL



PROJECT DESIGN INTERNATIONAL / EXPORT

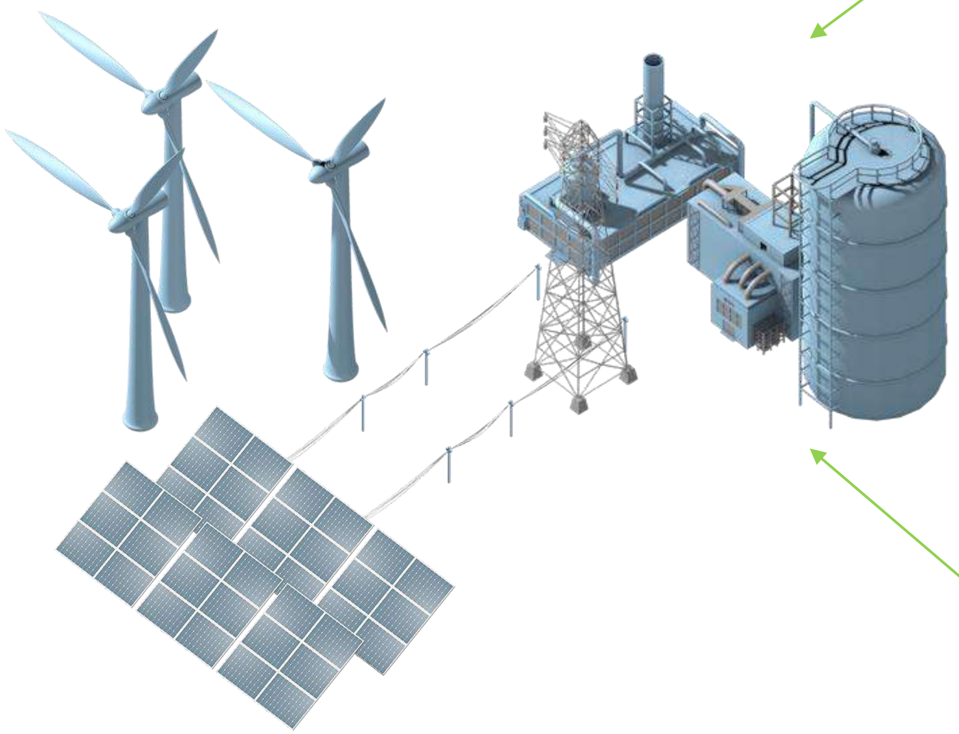


ENABLING HYDROGEN PRODUCTION AND USAGE

REQUIREMENTS FOR RENEWABLES AT SCALE

Sites
- Availability of sufficient area
- Prioritization of for combined plants
- Support of infrastructure measures in supply countries

Financing
- HPA Market
- Political stability and support
- Offtake warranties
- Framework for green products



Route to Market
- Security of supply
- Reliable market framework
- Support for Offtake
- Clear and pragmatic certification - internationally

Permitting
- Efficient
- High quality
- Pragmatic
- Green field

Infrastructure
- Pipelines
- Ports
- Railways

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E-Mail carsten.buehrer@pne-ag.com

“Water Issues related to Hydrogen Production in Pecém Harbor”

Prof. Dr. José Araruna
PUC - Rio de Janeiro

Brazil

Water Issues Related to Hydrogen Production in Pecém Harbor

JOSÉ ARARUNA

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

CO_2 footprint for H_2 production

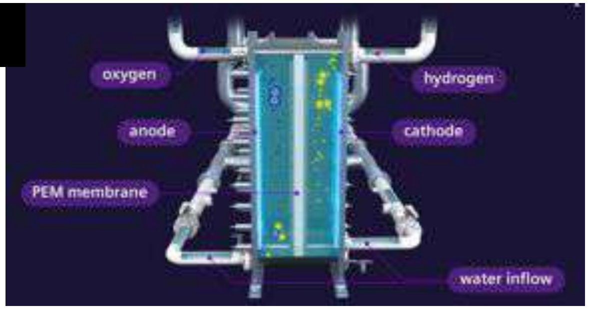
Technology	CO_2 footprint $kg\ CO_2e\ kg^{-1}\ H_2$
Steam methane reforming	10.1–17.2[b)]
Coal gasification	14.7–26.1[b)]
CH_4 pyrolysis	4.2–9.1[b)]
Biomass	0.3–8.6[b)]
Electrolysis, electricity supply from natural gas combined cycle turbine[a)]	23.0[b)]
Electrolysis, wind electricity[a)]	0.5–1.1[b)]
Electrolysis, solar electricity[a)]	1.3–2.5[b)]
Electrolysis, nuclear electricity[a)]	0.5–1.0[b)]

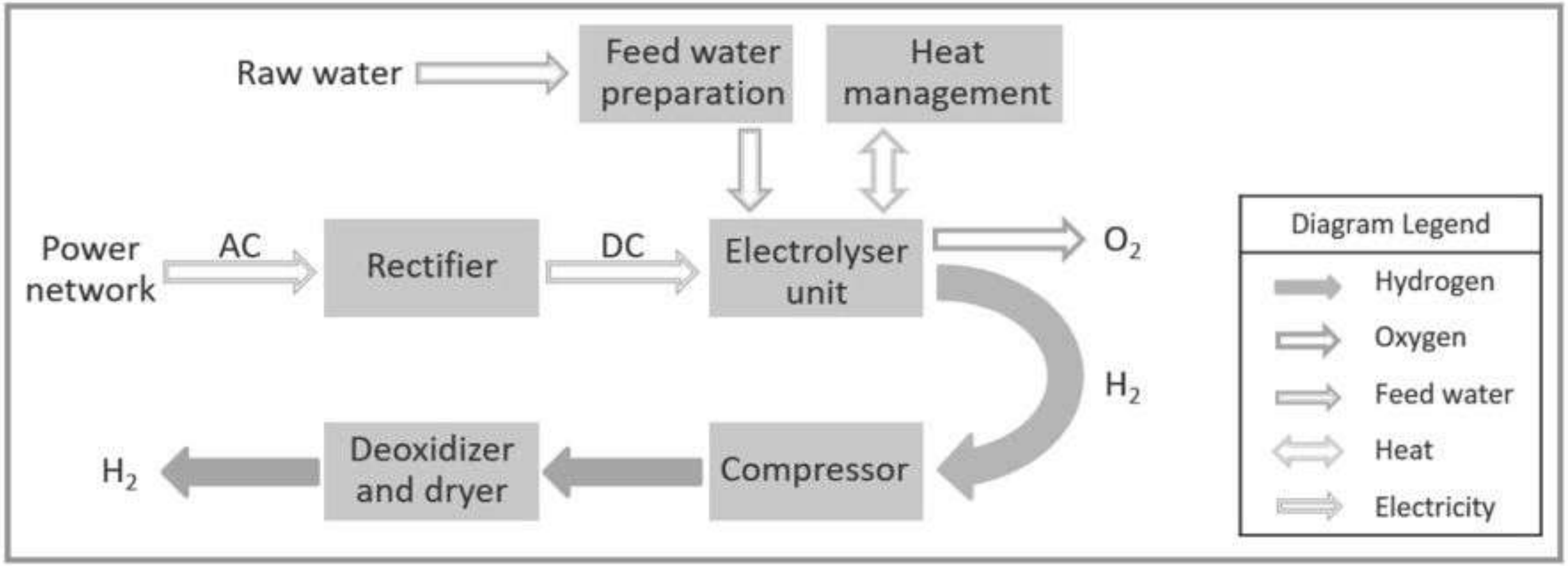
a) Specific energy consumption of water electrolysis: 51.2 $kWh\ kg^{-1}\ H_2$; average life-cycle CO_2 emissions: 467 $kg\ CO_2\ MWh^{-1}$ (electricity supply from natural gas combined cycle turbine), 9.4–21.4 $kg\ CO_2\ MWh^{-1}$ (wind electricity), 25.0–48.0 $kg\ CO_2\ MWh^{-1}$ (solar electricity), 8.4–18.0 $kg\ CO_2\ MWh^{-1}$ (nuclear electricity); b) Parkinson et al. [6].


Ecological and Economic Evaluation of Hydrogen Production by Different Water Electrolysis Technologies

simplified layout of water electrolysis system

Siemens PEM system






Ecological and Economic Evaluation of Hydrogen Production by Different Water Electrolysis Technologies

water electrolysis parameters

Technology	AEL	PEM	SOEC
Electrolyte	20–40 wt % KOH	water	steam
Operating temperature [°C]	60–90	50–80	700–900
Typical operating pressure [bar]	10–30	20–50	1–15
Current density [$A\,cm^{-2}$]	0.2–0.4 / 1.2[b)]	0.6–2.0	0.3–2.0
Cell area [m^2]	<4	<0.3	<0.01
Specific energy consumption (stack) [$kWh_{el}\,Nm^{-3}\,H_2$]	4.2–4.8	4.4–5.0	>3.0
Specific energy consumption (system) [$kWh_{el}\,Nm^{-3}\,H_2$]	5.0–5.9	5.0–6.5	3.7–3.9 (4.7 $kWh\,Nm^{-3}\,H_2$)
Lower dynamic range [%][a)]	10–40 / <10[c)]	0–10	>30
Gas purity [%]	> 99.5 / > 99.95[b)]	99.99	99.90
System response	seconds	milliseconds	seconds
Cold time start [min]	<60 / <1–50 %[b)]	<20	<60
Stack lifetime [h]	60 000–90 000	20 000–60 000	<10 000
Maturity	mature	commercial	demonstration
Investments costs [€ kW^{-1}]	800–1500	1400–2100	>2000

a) Minimum operable hydrogen production rate relative to maximum specified production rate; b) thyssenkrupp system installed at Carbon2Chem®; c) Lüke and Zschocke [14].


Research Article

Ecological and Economic Evaluation of Hydrogen Production by Different Water Electrolysis Technologies

total energy demand

	AEL	PEM	SOEC I	SOEC II	SOEC III	SOEC IV	SOEC V	Integrated C2C-SOEC
Operating pressure [bar]	20[a)]	30[a)]	n.s.	5[a)]	10[c)]	n.s.	n.s.	10[c)]
Energy demand								
Electrical energy [kWh Nm^{-3} H_2]	4.64[a)]	4.83[a)]	3.70[a)]	3.70[a)]	3.70[f)]	3.25[h,i)]	2.95[j)]	3.70[f)]
Thermal energy demand [kWh Nm^{-3} H_2]			n.s.	0.70[c)]	0.70[c)]	1.27[h,i)]	1.37[j)]	0.26 kWh_{el}[k)]
H_2 compression to 30 bar [kWh Nm^{-3} H_2]	0.02[b)]			0.10[d)]	0.06[g)]	0.10[g)]	0.10[g)]	0.06[g)]
Total energy demand [kWh Nm^{-3} H_2]	4.66	4.83	4.70[e)]	4.50	4.46	4.62	4.42	4.02

n.s. = not specified. a) Smolinka et al. [23]; b) calculated energy demand for compression of hydrogen from 20 to 30 bar; c) calculated thermal energy demand for steam generation (150 °C, 3 bar); d) calculated energy demand for compression of hydrogen from 5 to 30 bar; e) Schmidt et al. [16]; f) Sunfire-HyLink FactSheet [22]; g) calculated energy demand for compression of hydrogen from 10 to 30 bar; h) Mehmeti et al. [21]; i) Dai et al. [18]; j) Harvego et al. [20]; k) additional electricity demand as compensation for steam generation in power plant.

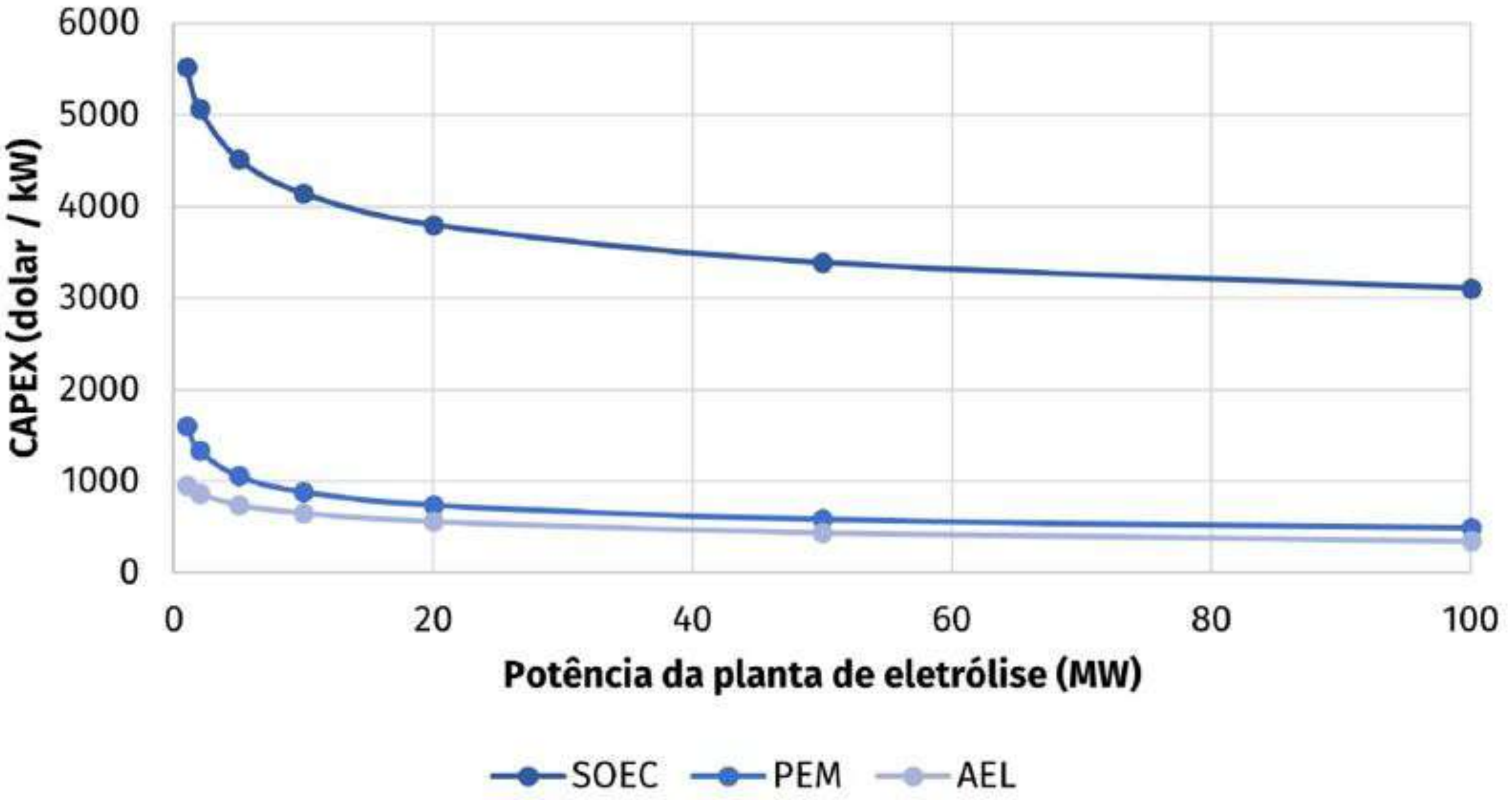

Research Article

Ecological and Economic Evaluation of Hydrogen Production by Different Water Electrolysis Technologies

Nils Tenhumberg and Karsten Büker

1 Introduction

CAPEX

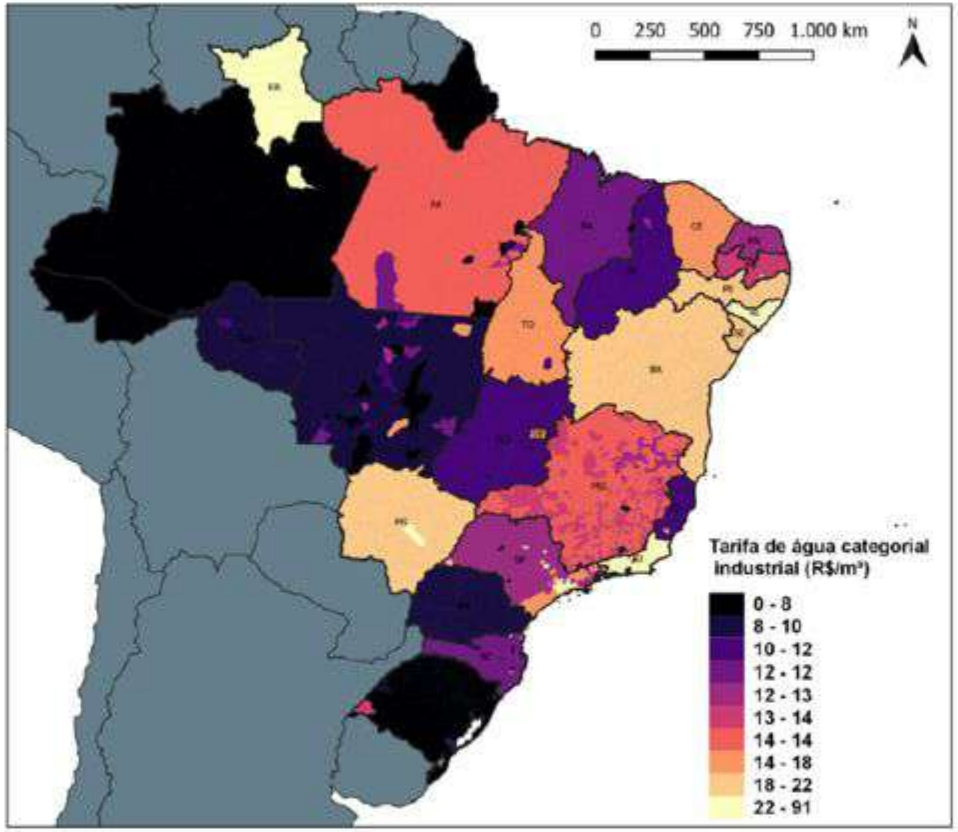

6000
5000
4000
3000
2000
1000
0
CAPEX (dolar / kW)
0
20
40
60
80
100
Potência da planta de eletrólise (MW)
SOEC
PEM
AEL


A Economia do Hidrogênio
Transição, descarbonização e oportunidades para o Brasil
GESEL
ANEEL

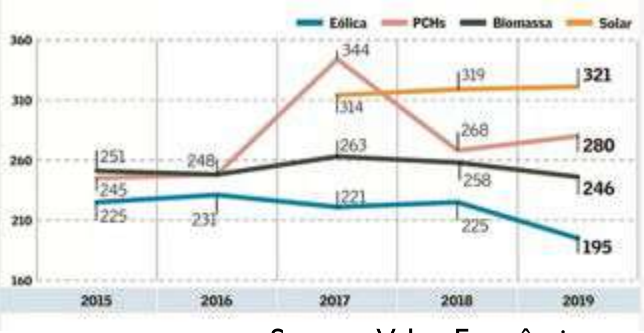
OPEX

industrial water costs (2021)

- O&M (including effluent treatment): 3% CAPEX/year
- Water costs
- Energy costs

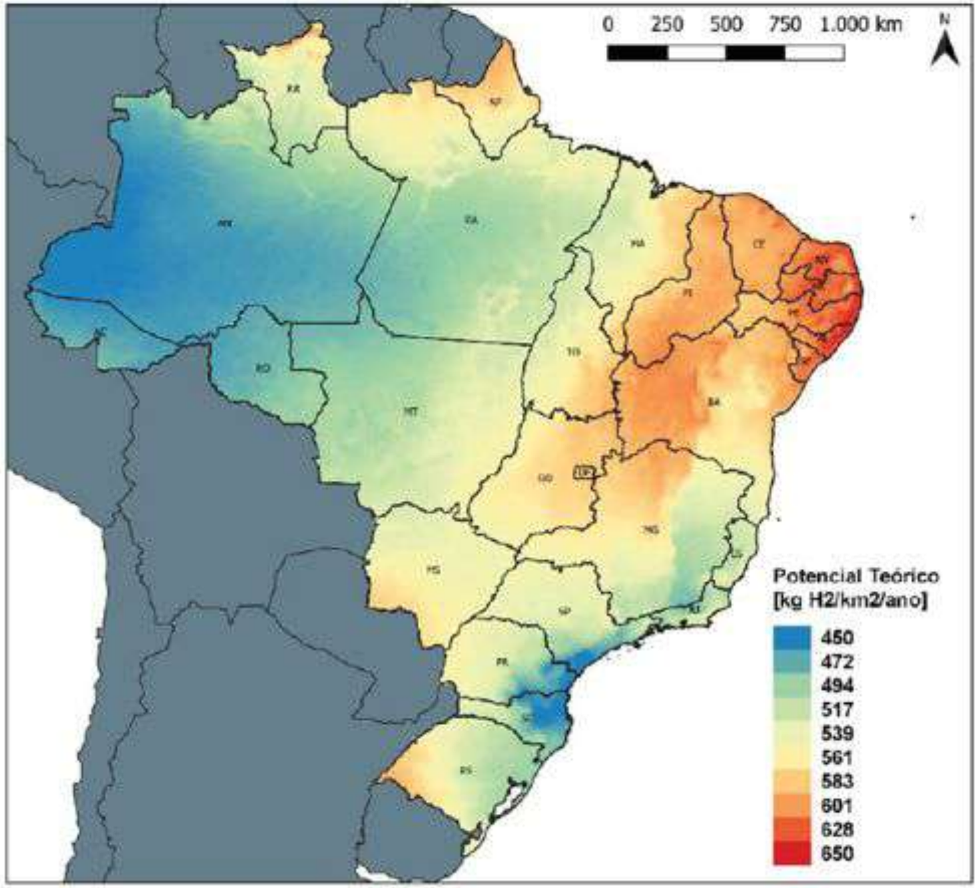


OPEX

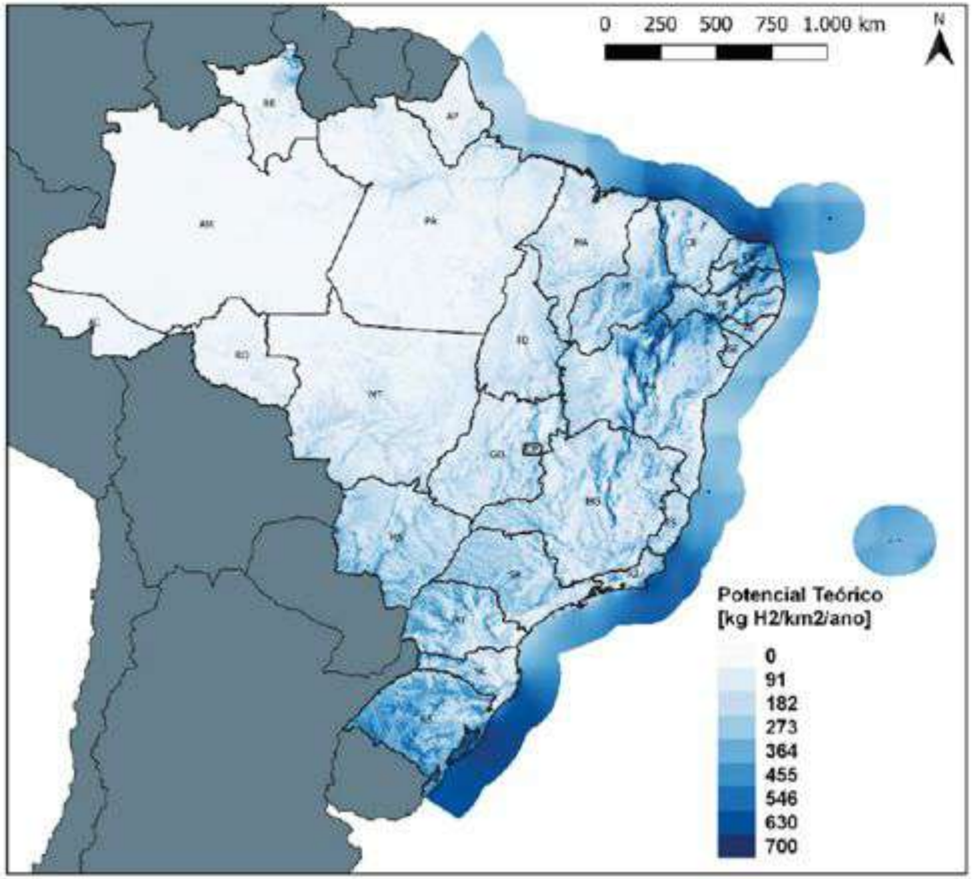


Source: Valor Econômico

solar energy



wind energy



motivation for H_2 production in Pecém Harbor

POTENTIAL FOR POWER GENERATION IN CEARÁ AND EXPECTED H2 COSTS

SOLAR GENERATION POTENTIAL

643 GW

WIND GENERATION POTENTIAL

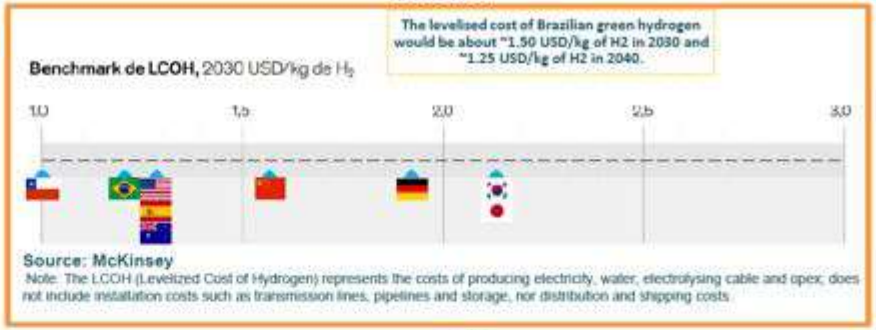
ONSHORE 94 GW

OFFSHORE 117 GW

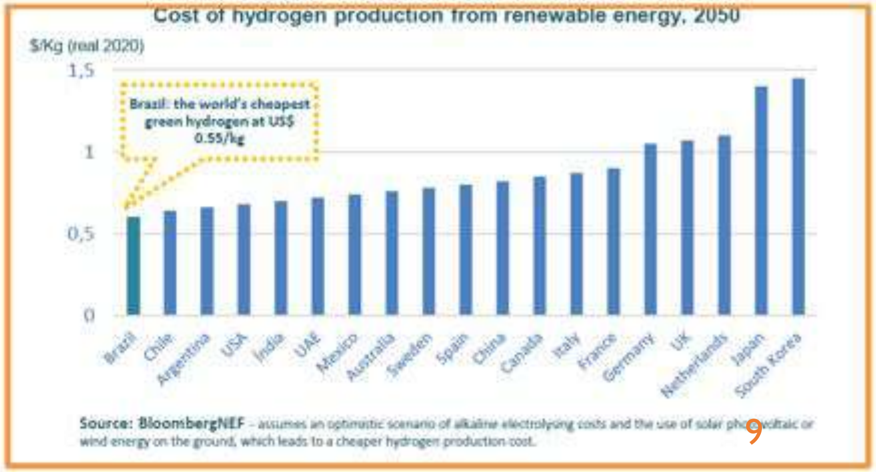
HYBRID POTENTIAL

137GW

Cost 2030

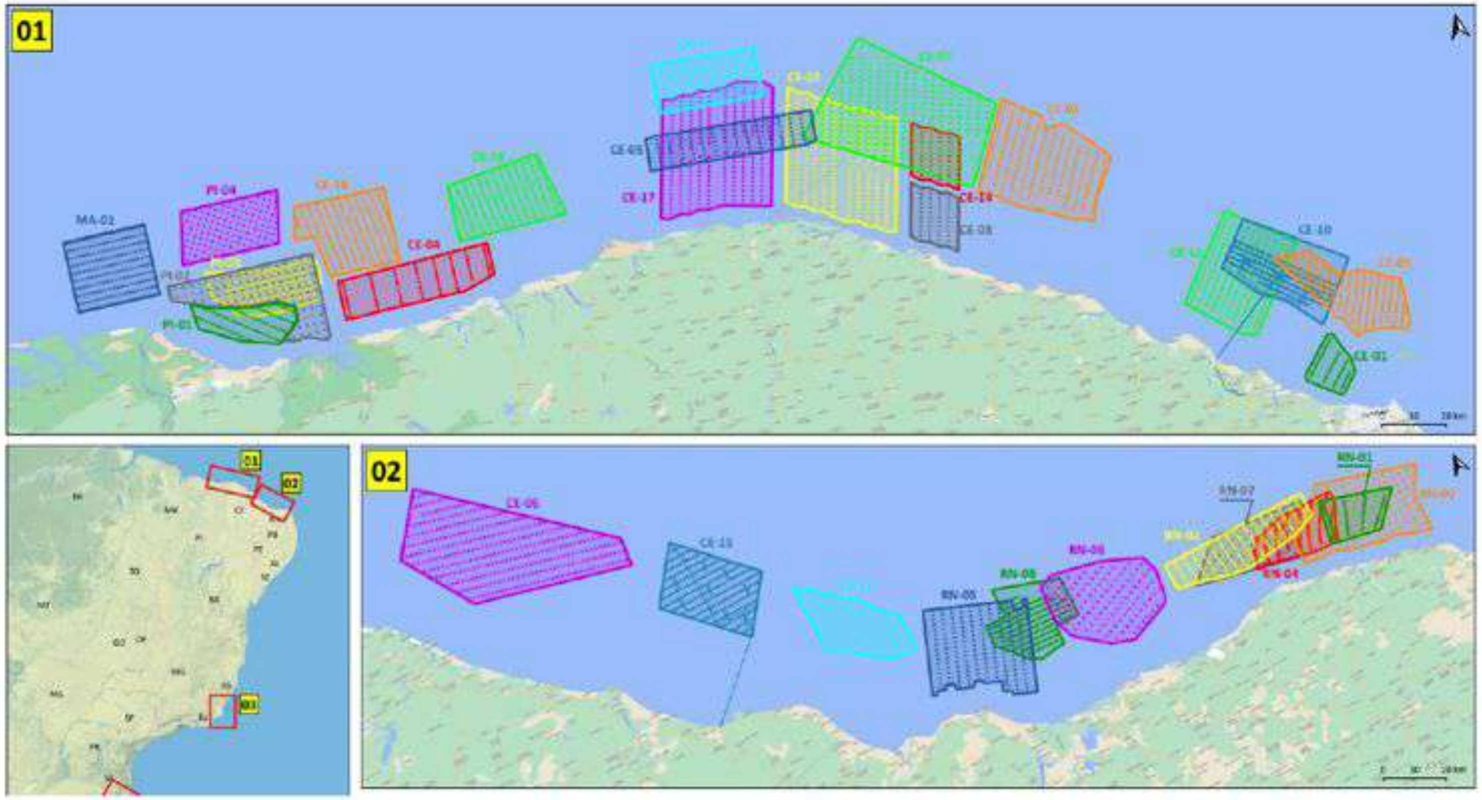


2050



Source: GOVERNMENT OF THE STATE OF CEARÁ, McKinsey, BloombergNEF

motivation for H2 production in Pecém Harbor



69 projects under licensing in Brazil, totalizing 169,4 GW (August 2nd, 2022)

Ceará State has 21 projects (48,4 GW)

Rio Grande do Norte State has 8 projects (15,8 GW)

Piauí State has 4 projects (6.9) GW

Source: GOVERNMENT OF THE STATE OF CEARÁ

motivation H_2 production

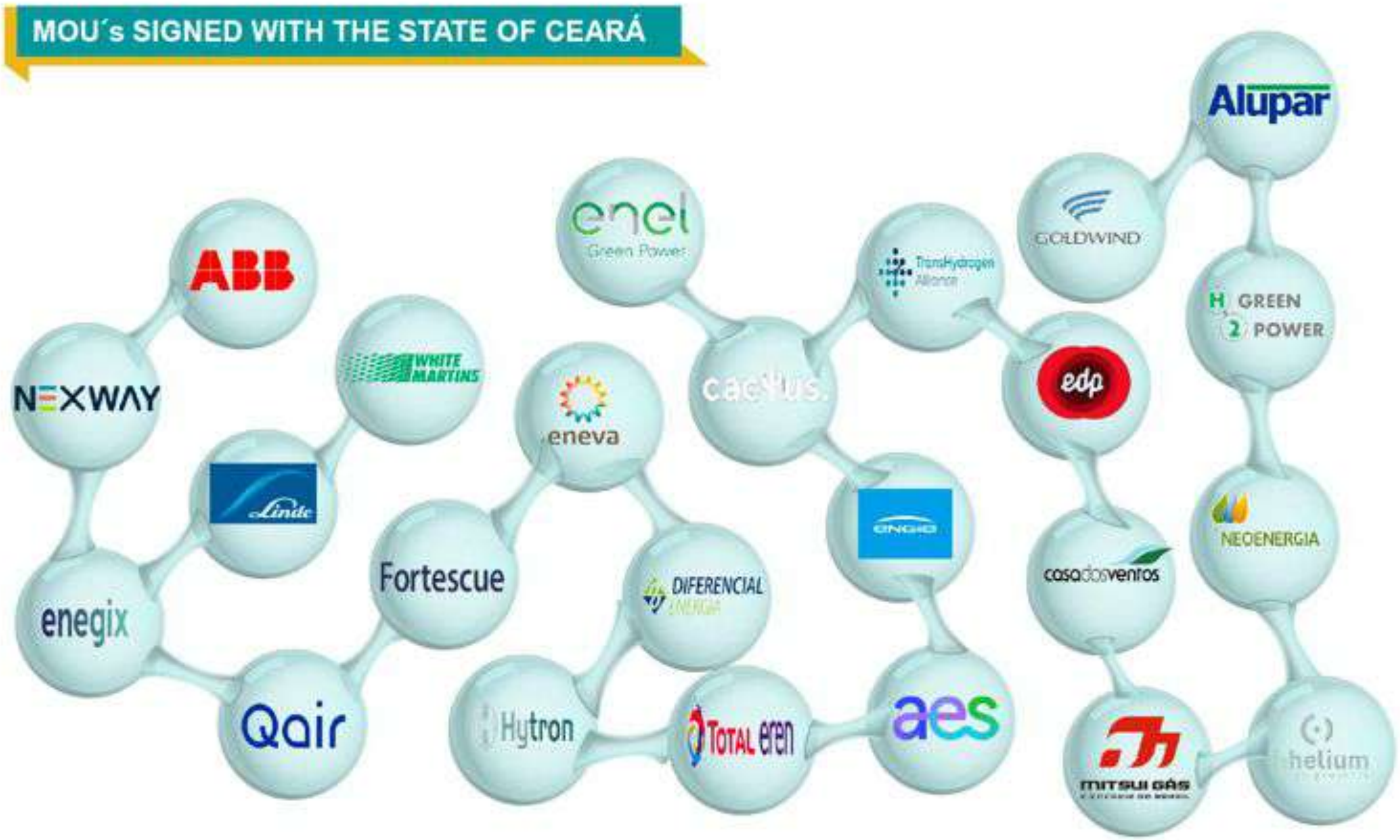
Source: GOVERNMENT OF THE STATE OF CEARÁ

Pecém Port can serve 71.1 GW of OW (3 states. 30 Farms) within 200 nm radius

Pecém Port can serve for 42% of all OW in Brazil

4.935 wind turbines sets

motivation for H2 production in Pecém Harbor



Source: GOVERNMENT OF THE STATE OF CEARÁ

water consumption

Manufacturer	Model	Technology	Water consumption (L/kg H_2)
Cummins	HyLYZER® 4.000-30	PEM	16.9
Cummins	HyLYZER® 1.000-30	PEM	16.9
Cummins	HyLYZER® 500-30	PEM	16.9
Siemens	SiLYZER® 200	PEM	12.1
Siemens	SiLYZER® 300	PEM	10
Cummins	HySTAT® 100	ALK	15
Green Hydrogen	HyProvide A90	ALK	10.9
Nel Hydrogen	Nel A3880	ALK	10.9
Nel Hydrogen	Nel M4000	PEM	10.9

water consumption

Economia

Pecém projeta aporte de R$ 2,2 bi em infraestrutura para H2V

| Em 5 anos | Obras incluem gasodutos, subestações de energia e mudanças no Porto. Montante deve ser aplicado parte pelo Complexo, parte pelas empresas do setor instaladas na área industrial

Início » Jornal

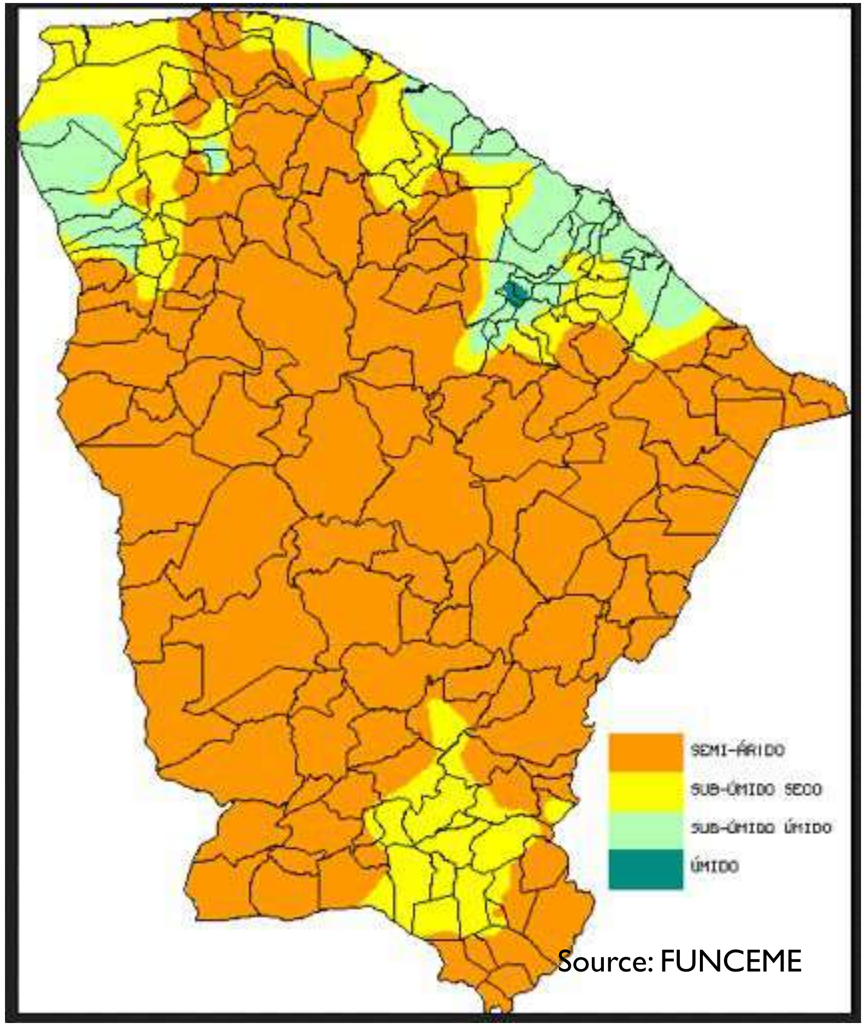
Publicado 01:15 | fev. 24, 2023 Tipo Notícia Por Armando De Oliveira Lima

Compartilhar Salvar notícia Comentar

O investimento necessário para dotar o porto do Pecém de infraestrutura capaz de operar a exportação de **1 milhão de toneladas de hidrogênio verde** (H2V) anualmente até 2030 deve somar **R$ 2,2 bilhões**. A projeção a ser executada em cinco anos foi revelada com exclusividade ao O POVO por **Hugo Figueiredo**, presidente do Complexo do Pecém, e inclui aplicações do Estado e das empresas.

- expected production 2030: 10^6 t of H_2 per year
  - 10^7 m^3 H_2O per year
  - 0.32 m^3/s

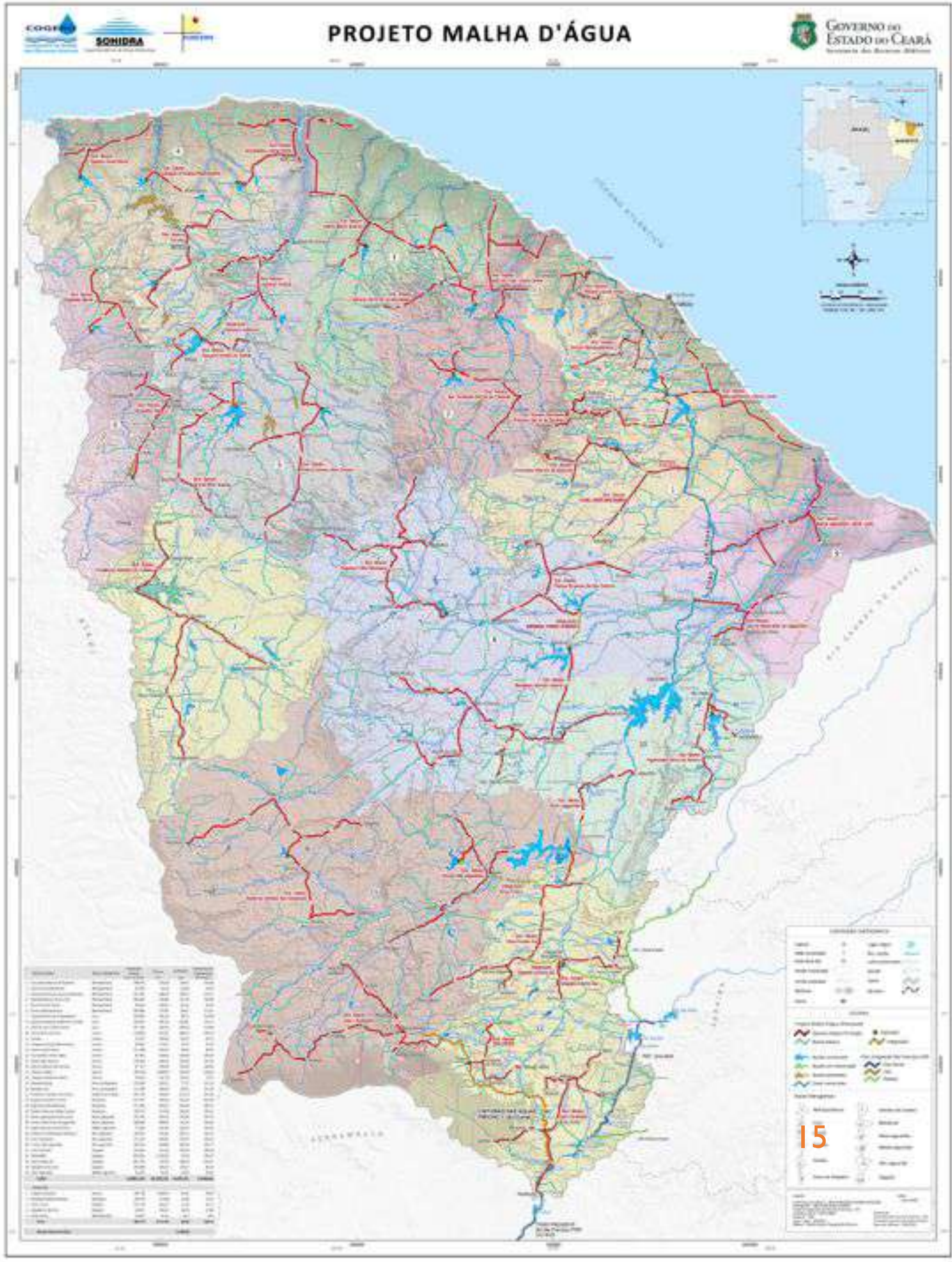
water issues in the State of Ceará



Source: FUNCEME

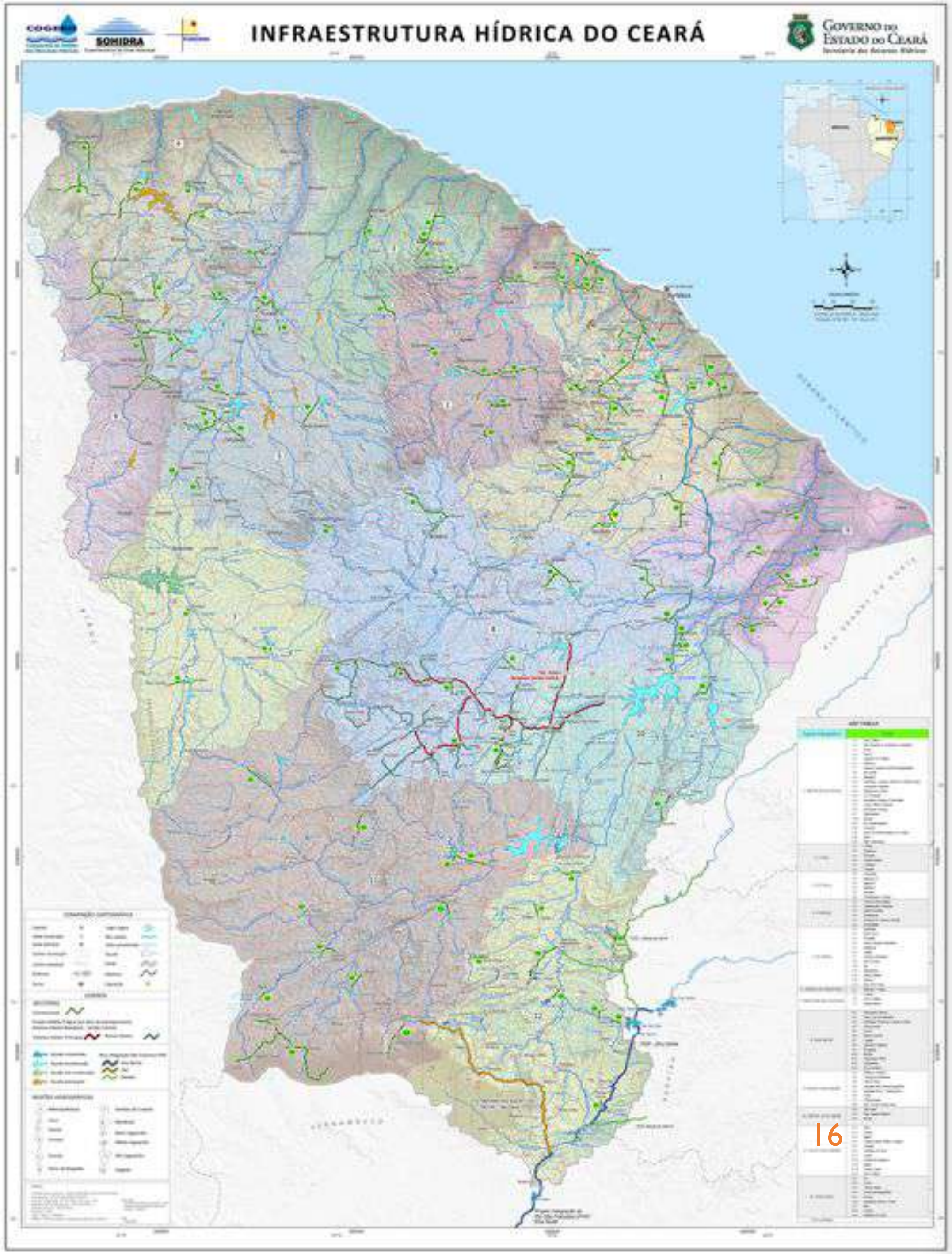
$$AI_U = \frac{P}{PET}$$

Classification	Aridity Index
Hyperarid	AI < 0.05
Arid	0.05 < AI < 0.20
Semi-arid	0.20 < AI < 0.50
Dry subhumid	0.50 < AI < 0.65



water issues in the State of Ceará

Source: CAGECE



water availability

- main reservoirs: 8.65 m^3/s;
- transboundary waters: 27 m^3/s
- groundwater: 2.91 m^3/s

Source: CAGECE

Source: COGERH

water reuse

contact

- José Araruna Jr.
- Department of Civil and Environmental Engineering
- Pontifical Catholic University of Rio de Janeiro
- http://www.civ.puc-rio.br//civil/
- araruna@puc-rio.br

“Wind Energy Potential for Green Hydrogen Production: Morocco”

Prof. Dr. Chouaib Benqlilou & Abir Dahani
Ecole Nationale Supérieure des Mines de Rabat

Morocco

Wind Energy Potential for Green Hydrogen Production: Morocco

23-05-2023

GERMAN-AFRICAN GREEN HYDROGEN FORUM

Chouaib Benqlilou & Abir Dahani

Ecole Nationale Supérieure des Mines de Rabat

HOCHSCHULE ANHALT University of Applied Sciences

Green Hydrogen – Challenge

Morocco **NDC** aim to reach **GHG** reduction of **45,5%** **including all economics' sectors** (2030)

Industrial decarbonisation *(Green new deal)*

- **Ammonia (NH_3)** importation for **fertilizer** production is about **2 Millions tons / year**
- 2sd international **phosphate** producer (**40 Millions tons in 2022**)
- 4th international exporter of Phosphate **fertilizer**
- **Morocco holds 75% of the world's phosphate rock reserves**

National energy strategy (2030)

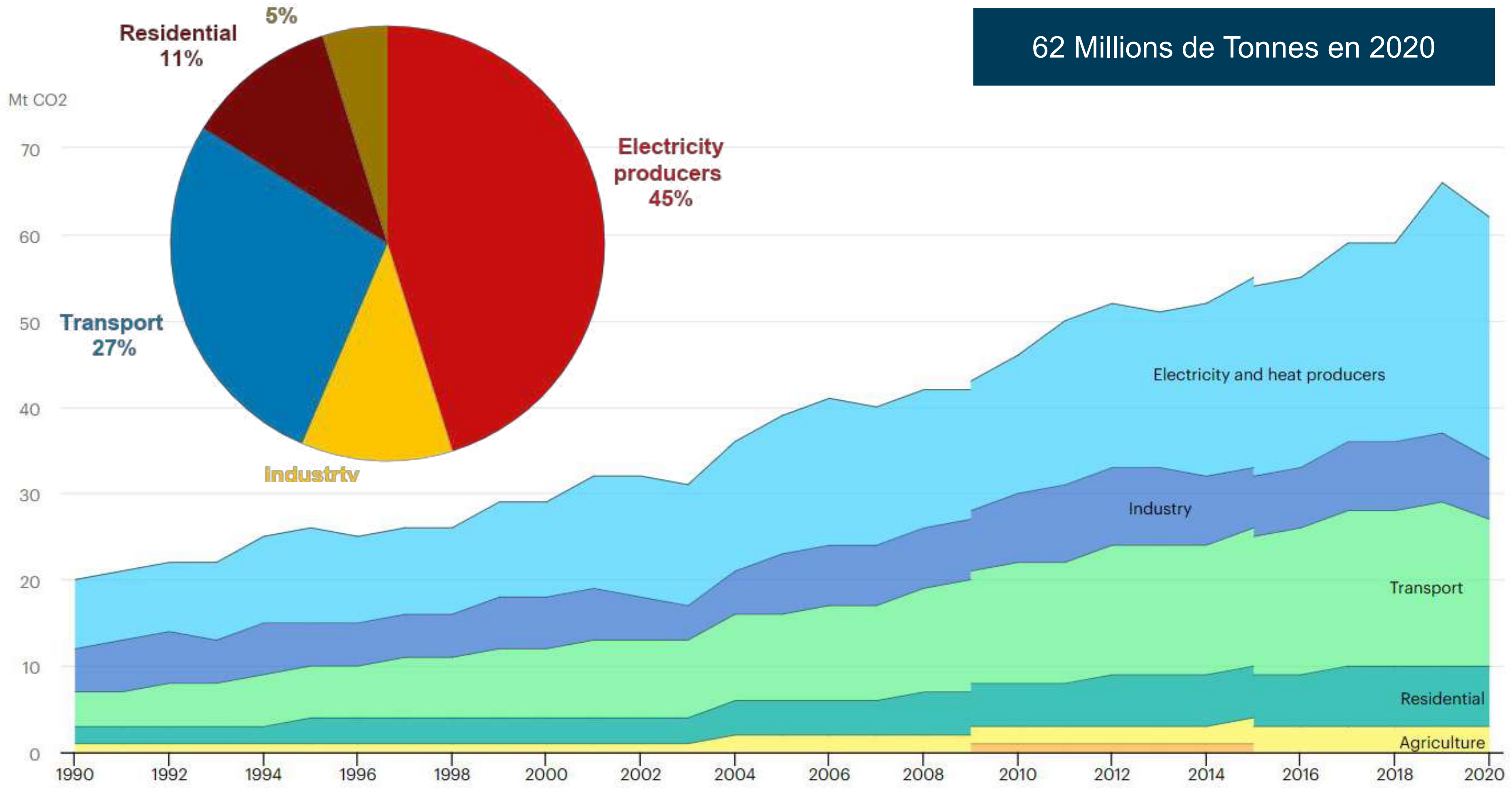
- aim at responding to **52%** of Moroccan electricity demand on **renewable energy** - **12 GW**
- Challenging energy storage
  - **Molten Salt Energy Storage** System
  - Vanadium-flow battery (under study)

Connectivity & **pipeline network**

- An **operational gas pipeline (** ***Gazoduc Maghreb – Europe*** **)** is deployed **(13,5 Bm^3)**
- **Under study Nigeria – Morocco gaz pipeline**

Decarbonisation based Hydrogen

62 Millions de Tonnes en 2020



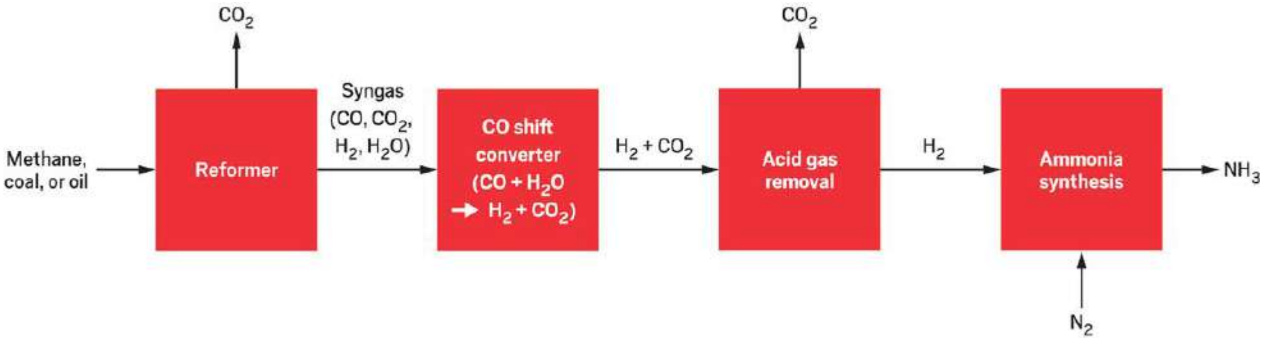
Green Hydrogen – Challenge

Office Chérifien des Phosphates

- Morocco imports ~2 Millions tons of ammonia
- Life cycle analysis global warming potential

Carbon tax

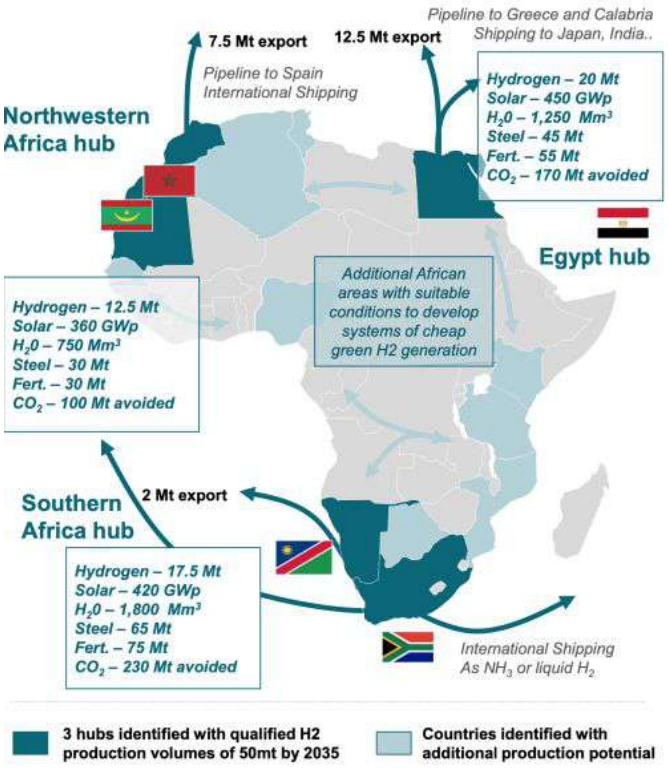
	Grey	Green
Ammonia	6 -10 tCO_2 /tNH_3	No emission
H_2		



Green Hydrogen – Réponse : H2 roadmap

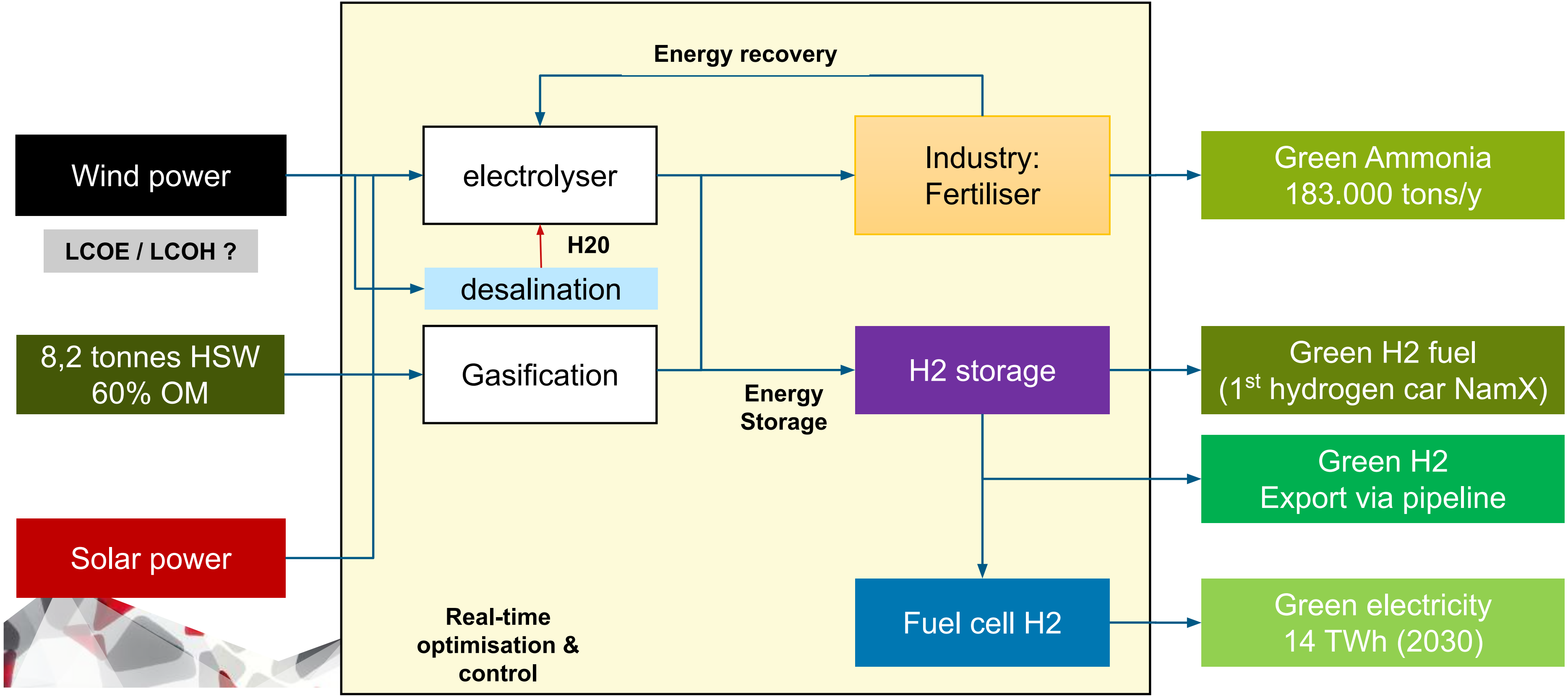
Moroccan Green Hydrogen Road Map 14 TWh (4 TWh local & 10 TWh international market) 2030

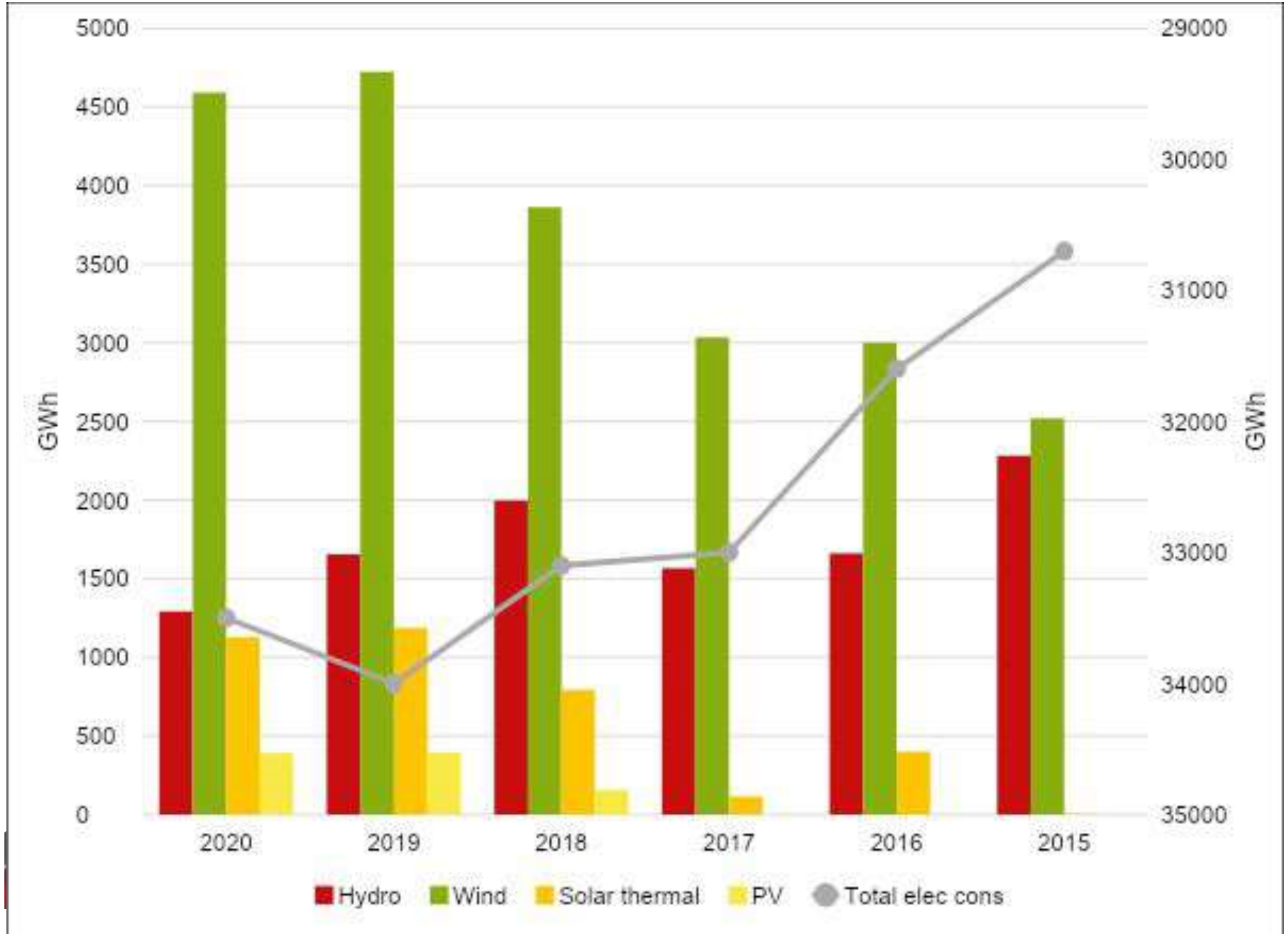
- 6 GW RENEWABLE ENERGY
- 420.000 tons GREEN H2
- 15.000 direct / indirect JOB CREATION

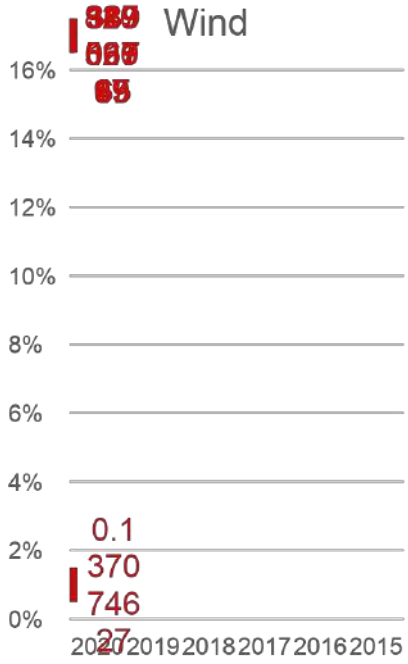


Courtesy: European Investment Bank (EIB),

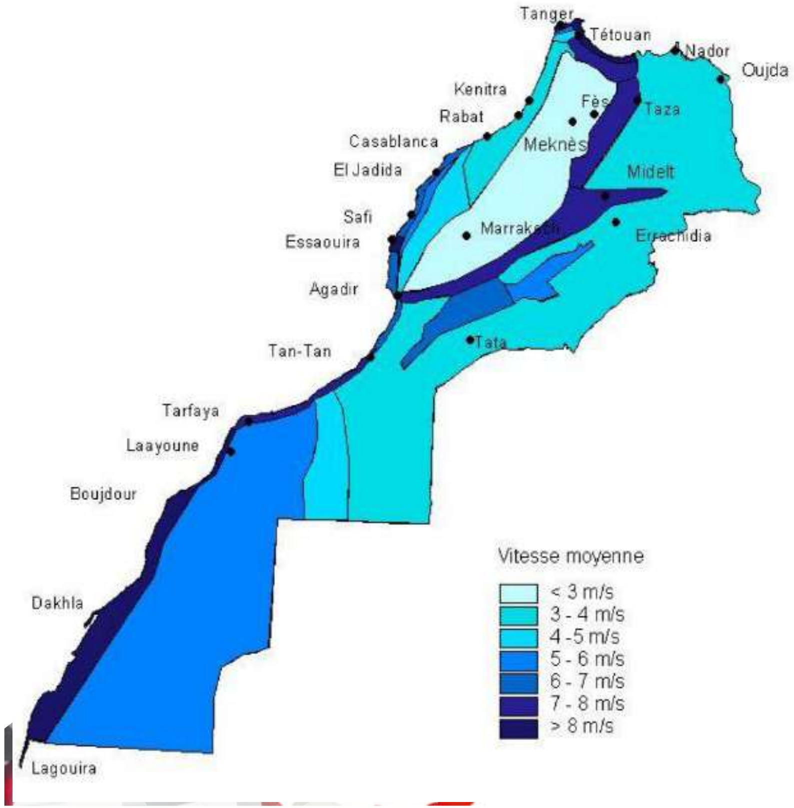
Green Hydrogen – Réponse : value Chain




5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
GWh
29000
30000
31000
32000
33000
34000
35000
GWh
2020
2019
2018
2017
2016
2015
Hydro
Wind
Solar thermal
PV
Total elec cons


Wind
16%
14%
12%
10%
8%
6%
4%
2%
0%
0.1
370
746
2019
2018
2017
2016
2015

Green Hydrogen – Wind to H_2



Moroccan wind map (source: ONEE)

Technical potential	Wind Onshore	Wind offshore
TWh/y	11.500	2.250
GW	6.000	500

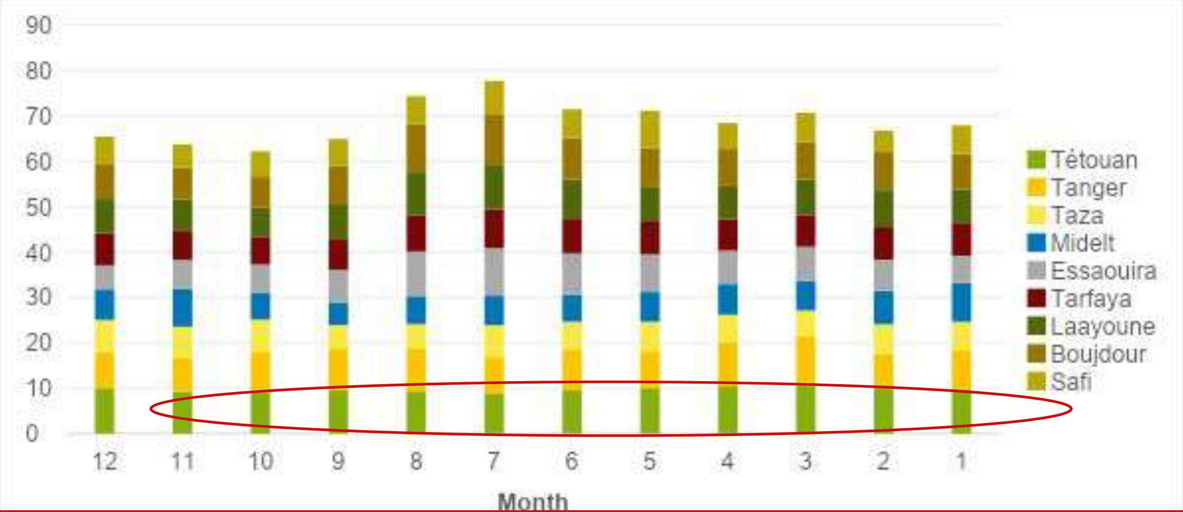
Technical potential for wind energy (source: IRESEN)

		GW
2022	Installed	1,86
2025	Under construction	1,6
Roadmap	Potential for H2 purpose	6

Green Hydrogen – Wind Power

Existing sites
Mean Wind speed

Existing sites
Monthly average wind speed variation



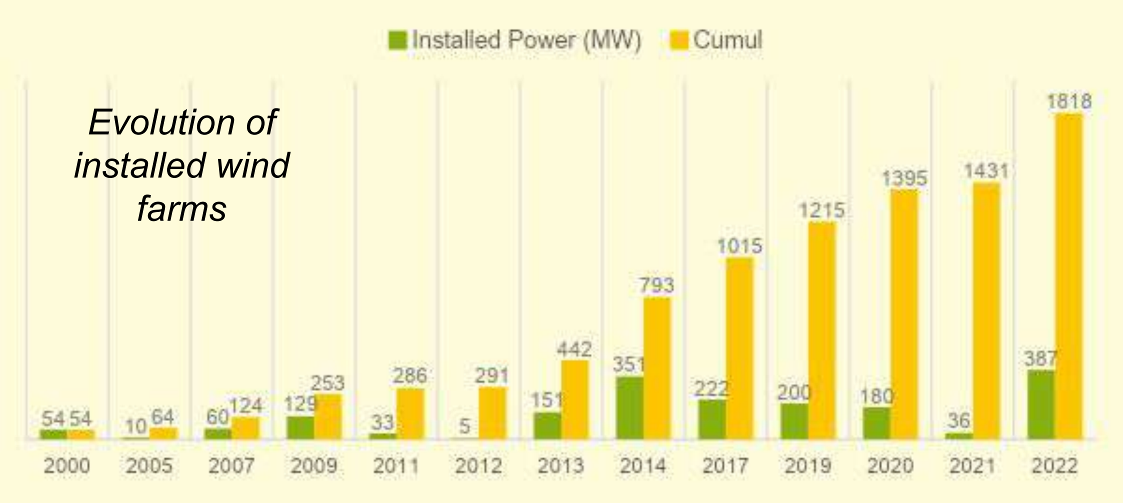
The average wind speed curve in Tetouan is the most regular. Therefore, the management of intermittency will be reduced.

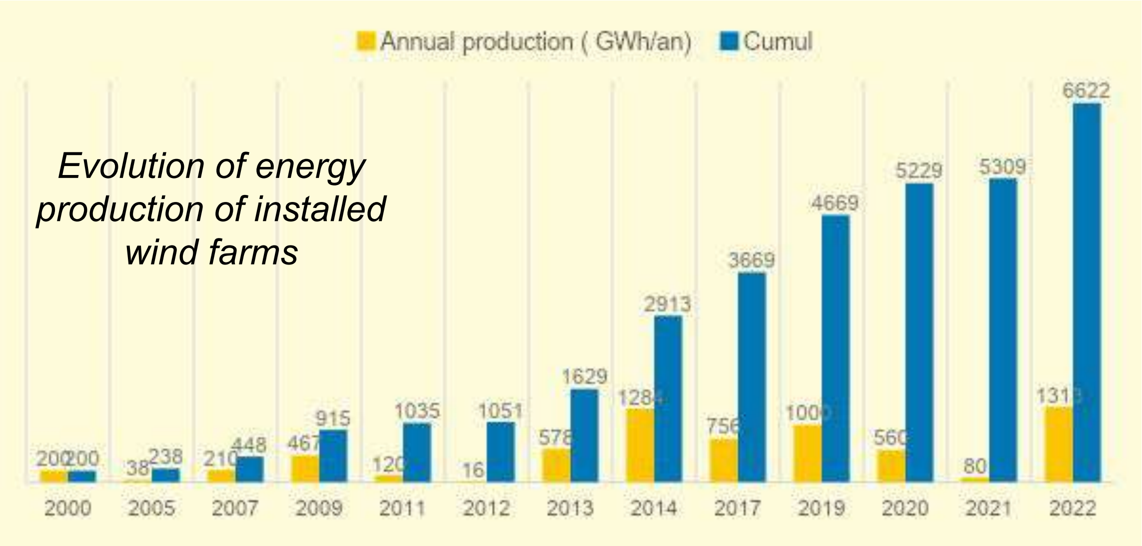
Green Hydrogen – *Specifications of operational wind farms in Morocco*

	Site	Year of commissioning	Installed (MW)	Technology	Turbine unit power	Energy (GWh/an)	Avoided $teqCO_2$/an	Investment in MDH	Cf (%)
Tetouan	Koudia Baida	2000	54	Vestas, Enercon	0.6/0.5	200	147 000.00	526.76	42%
	Lafarge	2000	10	Siemens Gamesa	0.85	38	27 930.00	101.3	43%
	Lafarge +	2005	22	Siemens Gamesa	2	77	56 595.00	405.2	40%
Tanger	Haouma	2009	50	Siemens Gamesa	2.3	200	147 000.00	810.4	46%
	DahrSaadane	2013	107	Siemens Gamesa	0.85	390	286 650.00	2127.3	42%
	Bni majmel	2009	33	Siemens Gamesa	0.85	120	88 200.00	658.45	42%
	Tanger II	2011	70	Siemens Gamesa	2.3	253	185 955.00	972.48	41%
	Jbel khelladi	2017	120	Vestas	3	378	277 830.00	1722.1	36%
Taza	Taza- Phase I	2022	87	GE Energy	3.2	313	230 055.00	1468.85	41%
Midelt	Midelt	2020	180	Siemens Gamesa	4.3	560	411 600.00	2329.9	36%
Essaouira	Amougdoul	2007	60	Siemens Gamesa	0.85	210	154 350.00	810.4	40%
Tarfaya	Akhefennir 1	2013	101	Ecotecnia	1.67	378	277 830.00	1418.2	43%
	Akhefennir 2	2017	102	Ecotecnia	1.67	378	277 830.00	1823.4	42%
	Tarfaya	2014	301	Siemens Gamesa	2.3	1084	796 740.00	5672.8	41%
Laâyoune	Cimar	2012	5	Siemens Gamesa	1	16	11 760.00	101.3	37%
	Foum El aoued	2014	50	Siemens Gamesa	2.3	200	147 000.00	810.4	46%
Boujdour	Aftissat	2019	200	Siemens Gamesa	3	1000	735 000.00	4052	57%
	Boujdour	2022	300	Siemens Gamesa	-	1000	735 000.00	4193.82	38%
Safi	Oualidia	2021	36	Winwind WWD	3	80	58 800.00	500	25%

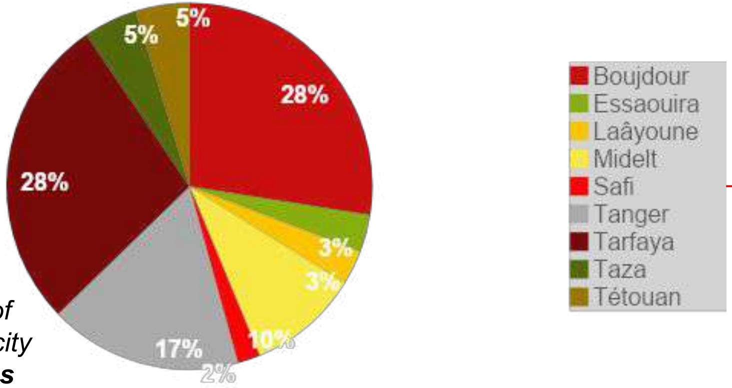
ARIMA model
Trend analysis

Year	Installed (MW)
2022	1,818
2023	2,310
2024	2,934
2025	3,728
2026	4,736
2027	6,017
2028	7,644
2029	9,711
2030	12,338

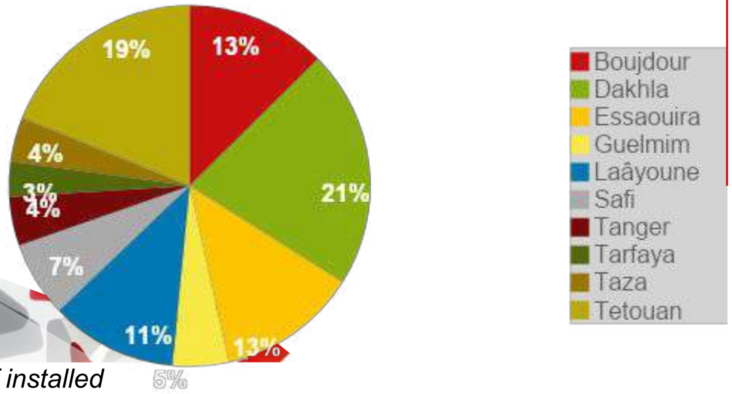




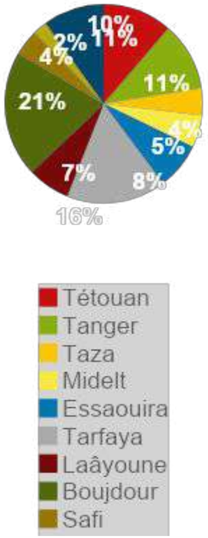
Green Hydrogen – *diagnosis of wind farms in Morocco*



Distribution of installed capacity ***existing sites***

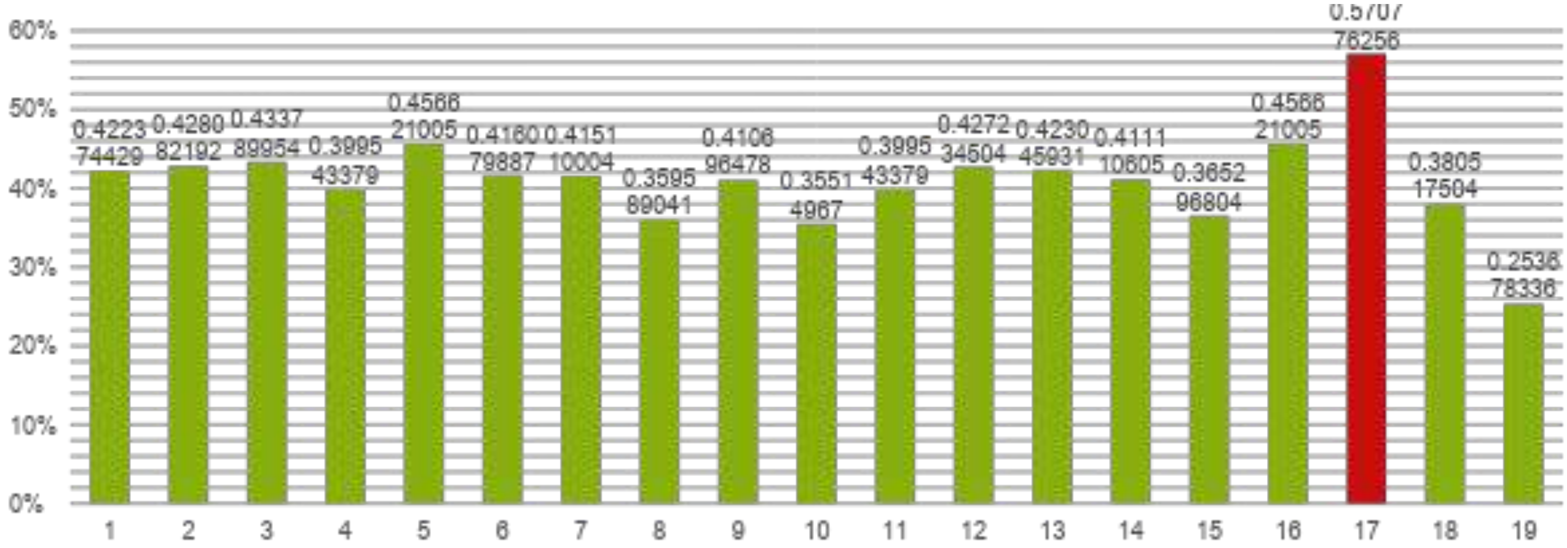


Distribution of installed capacity ***sites under construction***



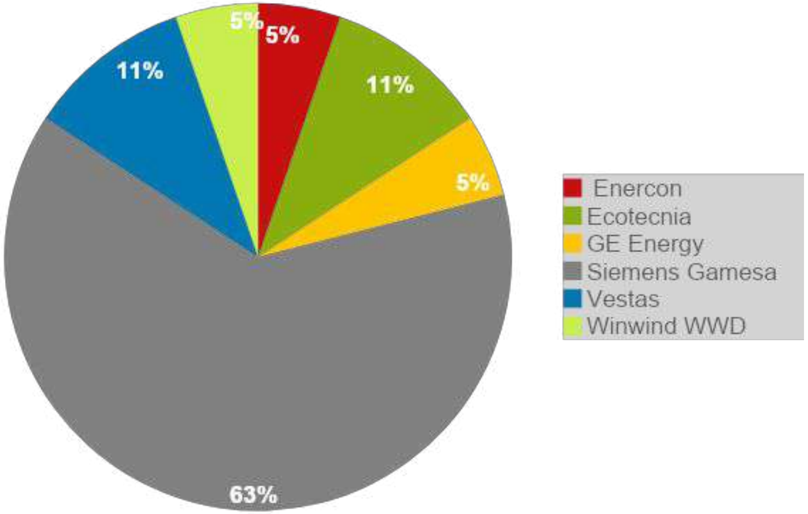
- **southern regions -** **fertilizer industry / energy storage**
- **northern regions -** **H2 Hub**

Green Hydrogen – *Representation of capacity factor (Cf) : existing sites*



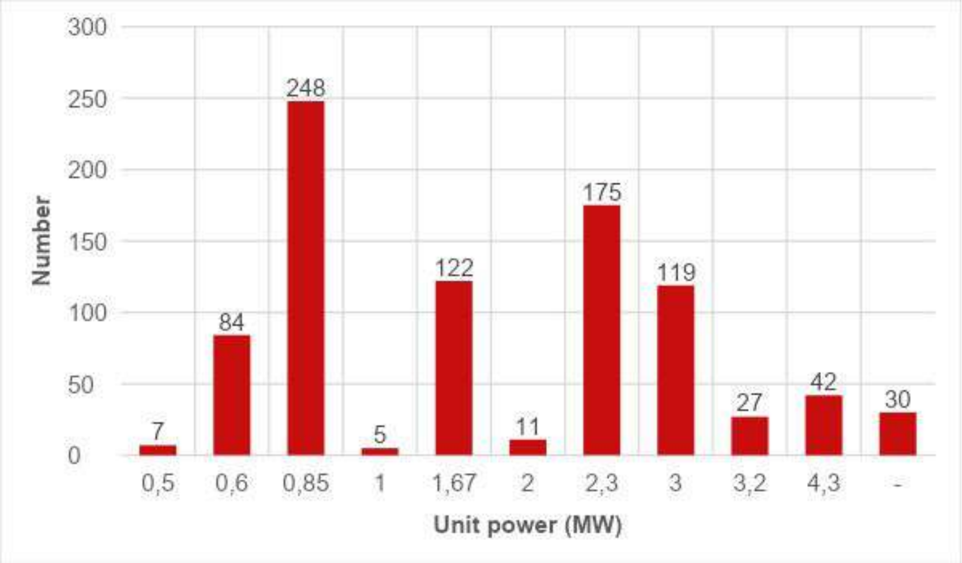
The capacity factor fluctuates between 25% and 57% which highly depends on the **site specification** (wind speed, roughness, wind regularity), **the technology deployed** (type, power, efficiency), **the blades's specification** (height and diameter)

Green Hydrogen – *diagnosis existing sites*



Distribution of technology deployed - existing sites

Siemens Gamesa technology is one of the major emerging technologies for existing onshore wind farms



Distribution of unit powers deployed - existing sites

The distribution of unit powers of wind turbines deployed in existing sites shows that power of 2MW is deployed for onshore wind farms

Green Hydrogen – Analysis of green hydrogen production potential

APPROACH & ASSUMPTIONS

- Technical potential of energy produced by Wind power **14 TWh/year**
  - **Favorable site** ?
  - (which provides the **best capacity factor Cf and maximum annual energy production - AEP**)

  - **Turbine technology should be selected** ? (e.g.Siemens Gamesa, Vestas, Enercon)

  - **Cost analysis**?
  - Determination of the LCOE and LCOH for green hydrogen production

Diagnosis of existing Farms

Clustring Based K-means

The **optimal hub height is about 100 m.** It provides a reduction of the intermittence variability and ensures a regular operation of wind farms

The distribution of unit powers of wind turbines deployed in existing sites shows that an **approximate power of 2MW** is deployed for onshore wind farms

Systemic search

For different technologies

For different sites characteristics

[Cf, AEP] = Simulation based Wind Pro

End

End

Energy target 14 TWh/an

Losses

Installed power

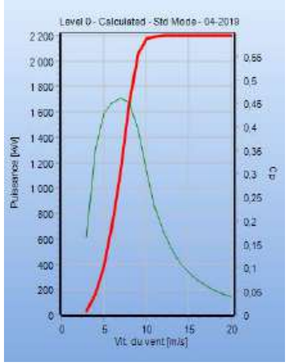
Wind turbine number

Site selection Cf

Best Cf

Max AEP

Priority based CF / AEP



Power curve

Wind speed data
Weibull distribution

Green Hydrogen – *cost analysis*

Technical specifications of SG 2.2-122

Height	*h*	m	108
Diameter	*D*	m	122
Swept area	*A*	m^2	11690
Cut-in wind speed	*Vc*	$m.s^{-1}$	3
Cut-out wind speed	*Vd*	$m.s^{-1}$	20
Rated wind speed	*Vr*	$m.s^{-1}$	13
Rated power	P_r	MW	2.2

Siemens Gamesa technology is one of the major emerging technologies for existing onshore wind farms

Calcul of the LCOE (USD/kWh)

- CAPEX, OPEX, FCR

Calcul of the LCOH (USD/Kg)

- Amount of hydrogen produced $M(H_2)$
- Electrolyser cost $C_{electro}$
- Electricity cost $C_{electricity}$
- Operation life of the electrolyser-T

Green Hydrogen – *cost analysis*

1- Site selection: The analysis of the results shows that the **site of Tetouan** offers a significant wind energy potential, which is more favourable to the exploitation of this type of energy for electricity production. It is the most suitable site, whereas Safi is the least qualified.

Site	AEP (kWh)	AEP_{net} (kWh)	Cf (%)	Pinst (MW)	N
Tetouan	14 138 252	10 628 431	55.1%	15.4	7
Tanger	13 119 891	9 862 878	51.2%	16.6	8
Taza	8 849 401	6 652 537	34.5%	24.6	11
Midelt	8 317 416	6 252 617	32.4%	26.2	12
Essaouira	10 819 916	8 133 872	42.2%	20.1	9
Tarfaya	10 727 723	8 064 566	41.8%	20.3	9
Laayoune	12 295 247	9 242 952	48.0%	17.7	8
Boujdour	13 698 773	10 298 052	53.4%	15.9	7
Safi	8 152 293	6 128 486	31.8%	26.7	12

Green Hydrogen – *cost analysis*

Referring to TETOUAN site as the exemplary site, the energy saving potential (*ESP*) fluctuates between 2% and 32%. Therefore, the annual emissions avoided are up to 3.307 $teqCO_2$ / year.

Site	AEP_{net}(kWh)	AEP_s(kWh)	ESP (%)	AE ($teqCO_2$)
Tetouan	10 628 431	-	-	-
Tanger	9 862 878	765 553	5%	562.68
Taza	6 652 537	3 975 893	28%	2 922.28
Midelt	6 252 617	4 375 813	31%	3 216.22
Essaouira	8 133 872	2 494 559	18%	1 833.50
Tarfaya	8 064 566	2 563 865	18%	1 884.44
Laayoune	9 242 952	1 385 479	10%	1 018.33
Boujdour	10 298 052	330 378	2%	242.83
Safi	6 128 486	4 499 944	32%	3 307.46

Green Hydrogen – *cost analysis*

2- Wind turbine technology selection: The simulation established with the aforementioned tech present a similar power 2.2 MW, and similar diameter (≈122m) for the “exemplary” site (TETOUAN), reveals a relative similarity in terms of Cf and AEP.

Technology		AEP (kWh)	AEP_{net} (kWh)	Cf (%)
Siemens Gamesa	SG 2.2-122	14 138 252	10 628 431	55.1%
Vestas	V-120 2.2	14 091 648	10 593 397	55.0%
Enercon	E-103 2350	13 363 161	10 045 756	48.8%

Green Hydrogen – *cost analysis*

3. Estimated amount of hydrogen produced

Wind energy – technical potential: **27 TWh/year**

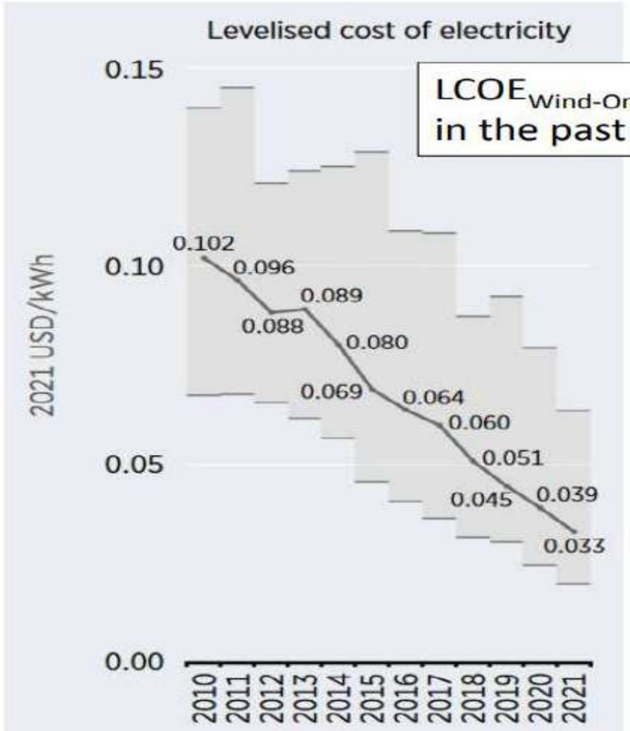
Electrolyser efficiency : **80% - 95%**

Electrolyser energy consumption : **55 - 60 kWh/kg**

420.000 tons H_2/year

14 TWh/year

4. Economic model – determination of the **LCOE** *tendency for onshore wind*



$LCOE_{Wind-Onshore}$ fell by ca. 70 % in the past 10 years

Kaltschmitt, M., F. Carels, « Renewable Energies as the Base for Hydrogen Production », 2023.

4. Economic model- determination of the LCOE

Site	AEP_{net} (kWh)	Cf (%)	P_{inst} (GW)	CapEX (USD/kW)	AEP_{net}(kWh/kW/an)	FCR (%)	OpEX (USD/kW.an)	LCOE (USD/kWh)
Tétouan	**10 628 430,65**	**55,1%**	**2 380,41**	**1 300,00**	**4 831,10**	**7%**	**46**	**0,029**
Tanger	9 862 878	51,2%	2 565,17	1 300,00	4 483,13	7%	46	0,031
Taza	6 652 537	34,5%	3 803,06	1 300,00	3 023,88	7%	46	0,046
Midelt	6 252 617	32,4%	4 046,31	1 300,00	2 842,10	7%	46	0,049
Essaouira	8 133 872	42,2%	3 110,45	1 300,00	3 697,21	7%	46	0,037
Tarfaya	8 064 566	41,8%	3 137,18	1 300,00	3 665,71	7%	46	0,038
Laayoune	9 242 952	48,0%	2 737,22	1 300,00	4 201,34	7%	46	0,033
Boujdour	10 298 052	53,4%	2 456,78	1 300,00	4 680,92	7%	46	0,030
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The resulting LCOE fluctuates between **0,029 - 0,05 USD/kWh**

Green Hydrogen – *cost analysis*

5. Economic model – determination of the LCOH

Site	AEP_{net} (kWh)	Cf (%)	LCOE (USD/kWh)	$C_{electricity}$ (MUSD)	$C_{electro}$ (USD)	LCOH (USD/kg)
Tétouan	**10 628 430,65**	**55,1%**	**0,029**	329 063	4,89967E+12	1,95
Tanger	9 862 878	51,2%	0,031	354 605	5,27998E+12	2,10
Taza	6 652 537	34,5%	0,046	525 728	7,82797E+12	3,11
Midelt	6 252 617	32,4%	0,049	559 353	8,32865E+12	3,31
Essaouira	8 133 872	42,2%	0,037	429 982	6,40234E+12	2,54
Tarfaya	8 064 566	41,8%	0,038	433 678	6,45736E+12	2,57
Laayoune	9 242 952	48,0%	0,033	378 388	5,63411E+12	2,24
Boujdour	10 298 052	53,4%	0,030	339 620	5,05686E+12	2,01
Safi	6 128 486	31,8%	0,050	570 683	8,49734E+12	3,38

The LCOH fluctuates between **1,95 – 3,38 USD/kWh**

Green Hydrogen – *Conslusion*

1. Based on wind speed data recorded over a period of ten years for the 9 sites and adopting SG 2.2-122 technology, the sites analysis shows that **Tetouan** provides a high wind potential compared to other sites with **a capacity factor of 55%**

2. The simulation conducted using three technologies (Siemens Gamesa, Vestas and Enercon) of similar power, diameter and hub height, reveals that **Siemens Gamesa technology is the most advantageous and appropriate,** offering the best capacity factor and maximum energy production

3. The amount of hydrogen produced to satisfy moroccan Hydrigen strategy (**14TWh – 0,42 Mt/an**) is about **27TWhe/year (772 M$/year)**

4. The economic evaluation revealed a significant **LCOE of 0,0286 $/kWh** and an **LCOH of 1,946 $/kg** for wind-$H_2$ production in TETOUAN site

5. **Investment purpose** : Northern region – Hydrogen Hub and Southern region Industry

Wind Energy Potential for Green Hydrogen Production: Morocco

23-05-2023

Chouaib Benqlilou & Abir Dahani
Ecole Nationale Supérieure des Mines de Rabat

GERMAN-AFRICAN GREEN HYDROGEN FORUM

HOCHSCHULE ANHALT University of Applied Sciences

“H2Global meets Africa”

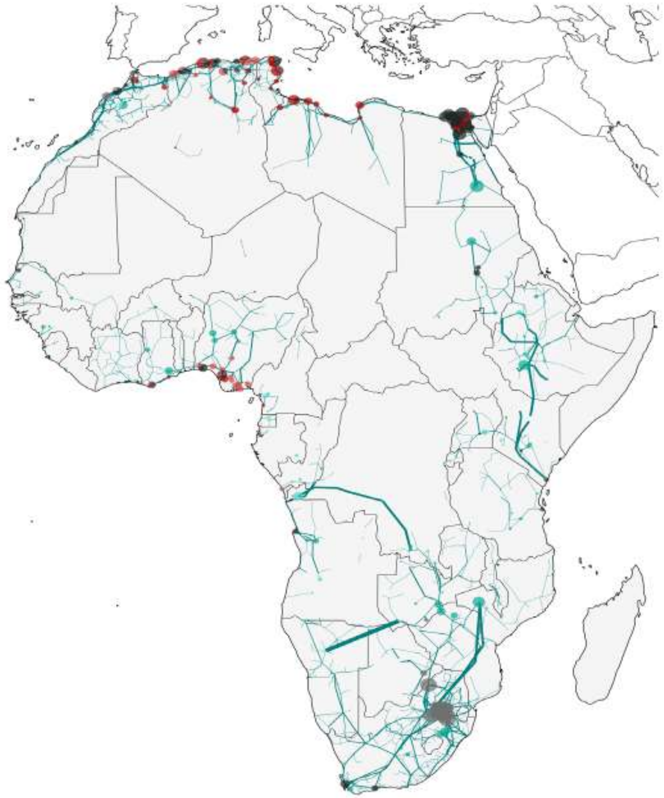
Prof. Dr.-Ing. Michael Sterner & Leon Schumm
OTH Regensburg

Germany

H2Global meets Africa

Prof. Dr.-Ing. Michael Sterner & Leon Schumm

German-African Green Hydrogen Forum
23.05.2023 Bernburg (Saale)



Created using PyPSA-Earth and https://github.com/pypsa-meets-earth/documentation/blob/main/notebooks/viz/regional_transm_system_viz.ipynb

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

H2Global meets Africa

Agenda

- Project overview
- H2Global
- Robust transformation pathways
- Capacity validation
- Demand modelling in Germany/EU
- Coupled energy systems EU/Africa
- Techno-economic analysis of integrated value chains in Africa and Germany
- Site assessment

H2Global meets Africa

Key facts

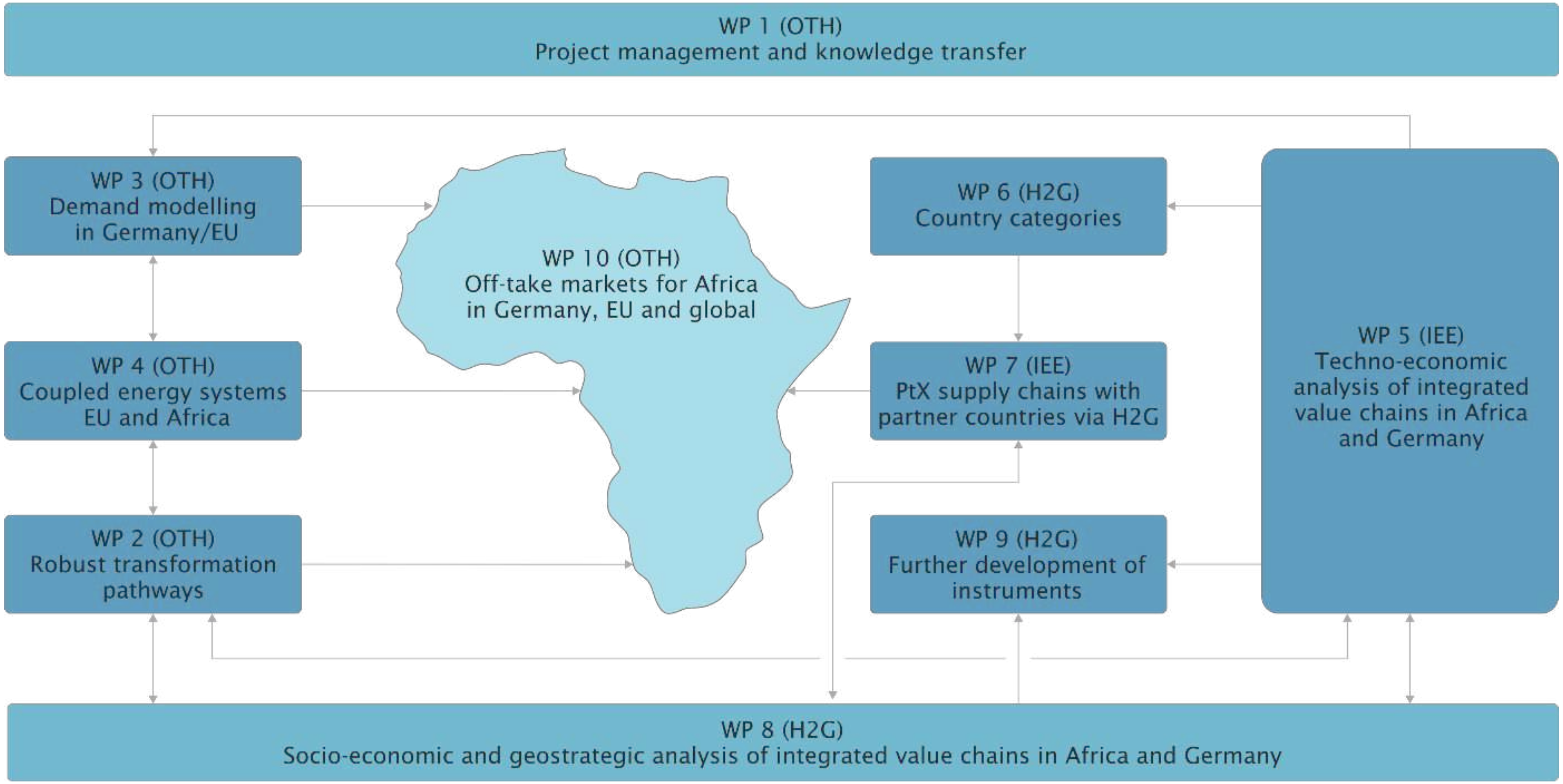
- Title: Potentials and policies for sustainable hydrogen and PtX ramp-up in Africa
- Period: 01.01.2023 – 31.12.2025
- Budget: 4.2 million €
- Funded by the German Federal Ministry of Education and Research
- PyPSA-Earth-(Sec) as main model

Project partners

- OTH Regensburg
  University of Edinburgh, University of Pisa
- H2Global Foundation
- Fraunhofer IEE
- Associated Partners: ADB, WASCAL, SASSCAL

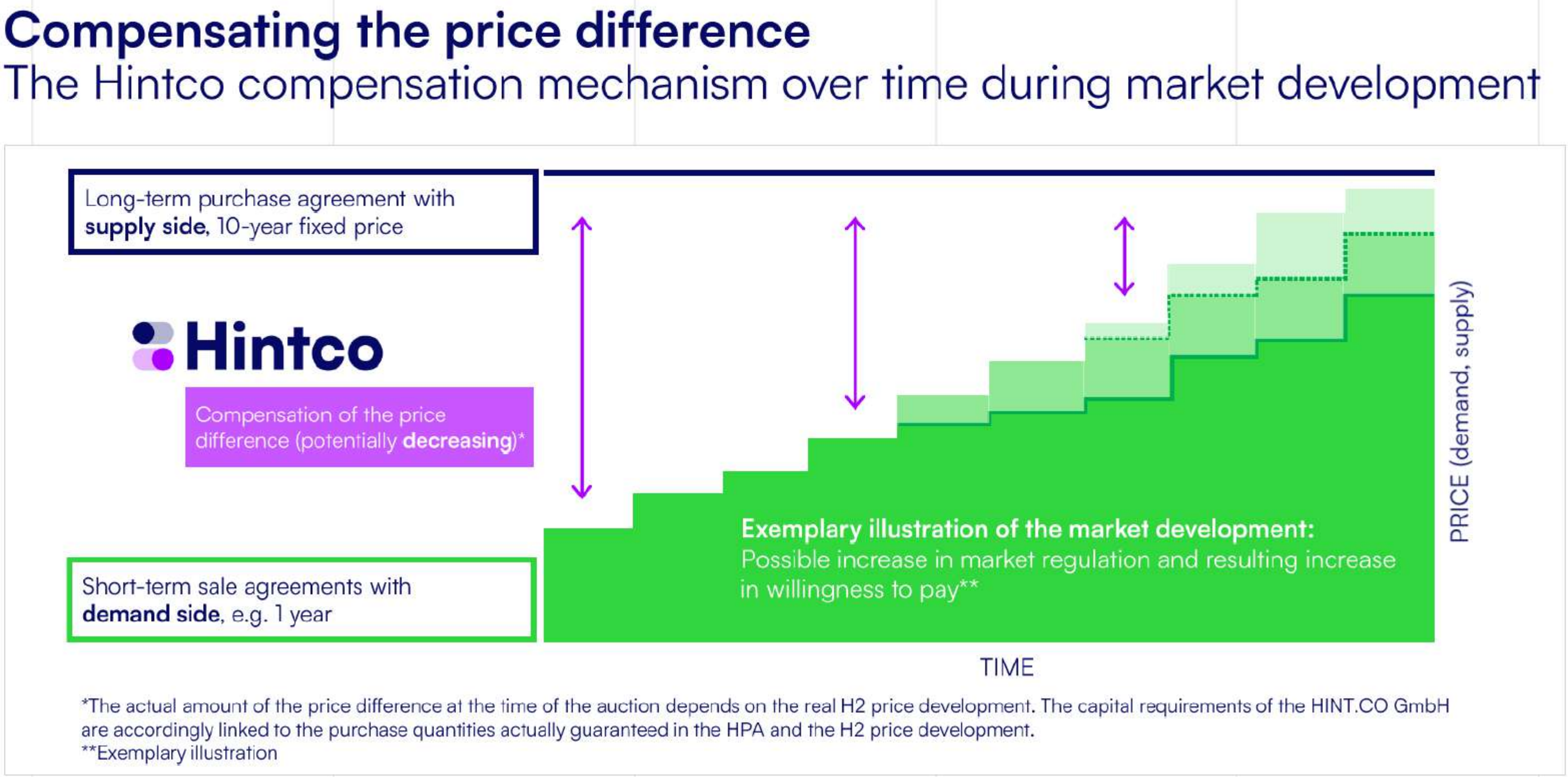
H2Global meets Africa

Overview



H2Global meets Africa

H2Global



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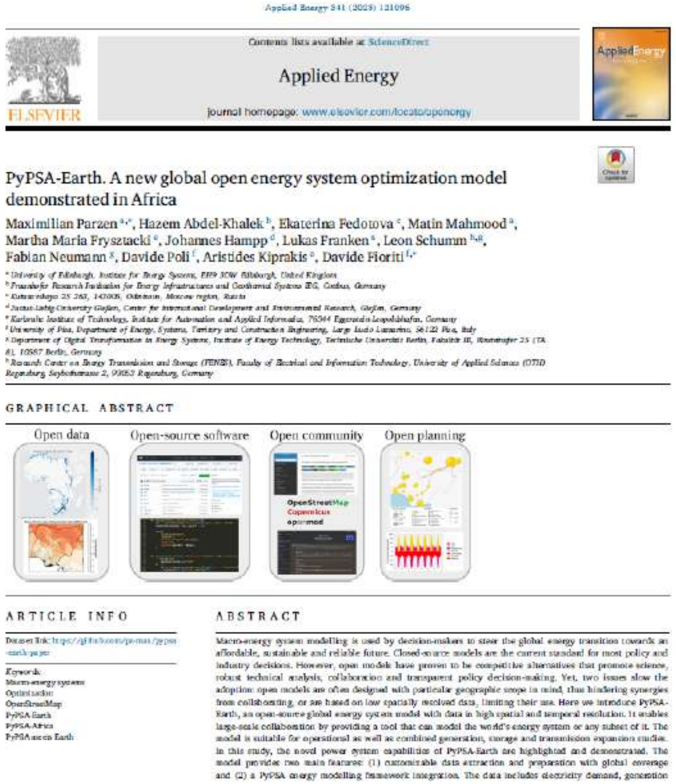
Robust Transformation Pathways

Main Models:

- PyPSA-Earth
- PyPSA-Earth-Sec
- EMPRISE


Applied Energy 341 (2023) 121096

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/apenergy

PyPSA-Earth. A new global open energy system optimization model demonstrated in Africa

Maximilian Parzen [a,*], Hazem Abdel-Khalek [b], Ekaterina Fedotova [c], Matin Mahmood [a], Martha Maria Frysztacki [e], Johannes Hampp [d], Lukas Franken [a], Leon Schumm [h,g], Fabian Neumann [g], Davide Poli [f], Aristides Kiprakis [a], Davide Fioriti [f,*]

GRAPHICAL ABSTRACT

Open data | Open-source software | Open community | Open planning

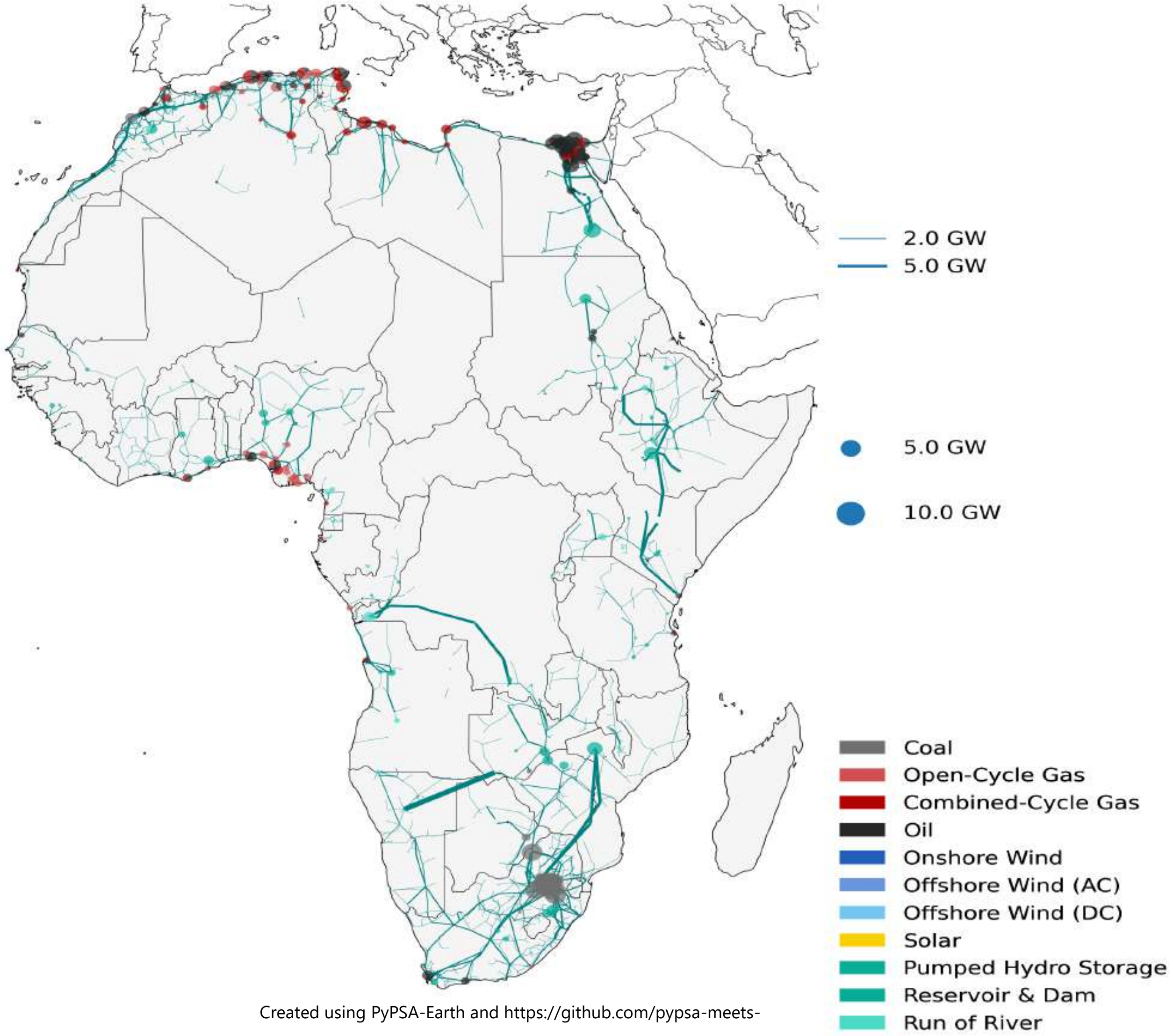
ARTICLE INFO

Keywords:
Macro-energy systems
Optimization
OpenStreetMap
PyPSA-Earth
PyPSA-Africa
PyPSA meets Earth

ABSTRACT

Macro-energy system modelling is used by decision-makers to steer the global energy transition towards an affordable, sustainable and reliable future. Closed-source models are the current standard for most policy and industry decisions. However, open models have proven to be competitive alternatives that promote science, robust technical analysis, collaboration and transparent policy decision-making. Yet, two issues slow the adoption: open models are often designed with particular geographic scope in mind, thus hindering synergies from collaborating, or are based on low spatially resolved data, limiting their use. Here we introduce PyPSA-Earth, an open-source global energy system model with data in high spatial and temporal resolution. It enables large-scale collaboration by providing a tool that can model the world's energy system or any subset of it. The model is suitable for operational as well as combined generation, storage and transmission expansion studies. In this study, the novel power system capabilities of PyPSA-Earth are highlighted and demonstrated. The model provides two main features: (1) customizable data extraction and preparation with global coverage and (2) a PyPSA energy modelling framework integration. The data includes electricity demand, generation

Check out
PyPSA-Earth here:

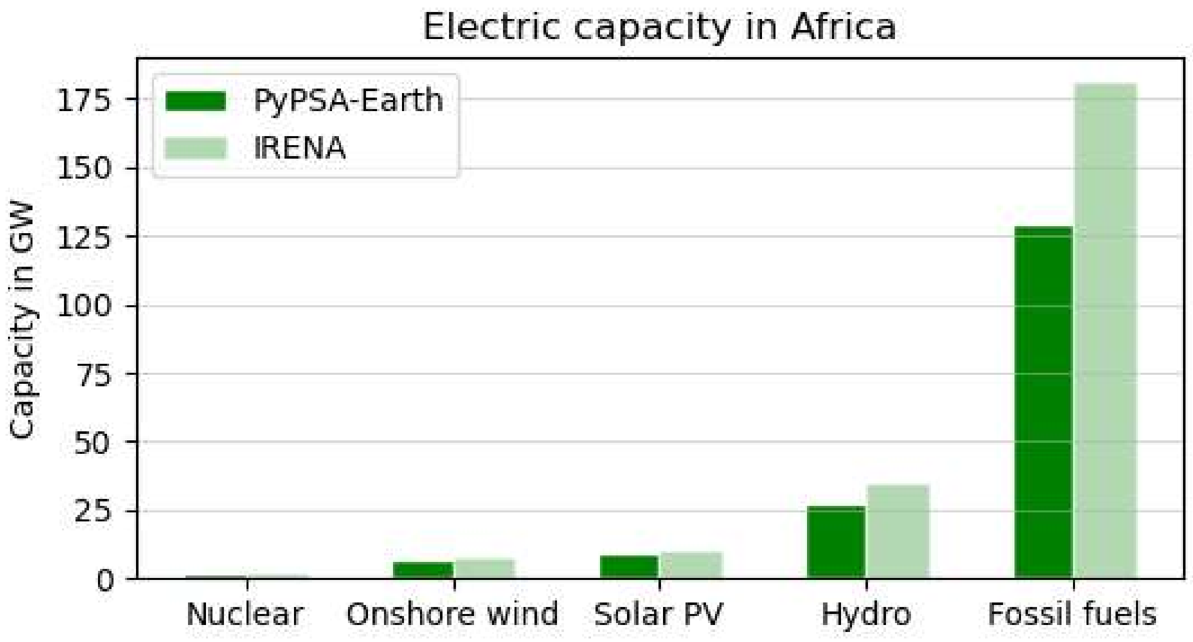


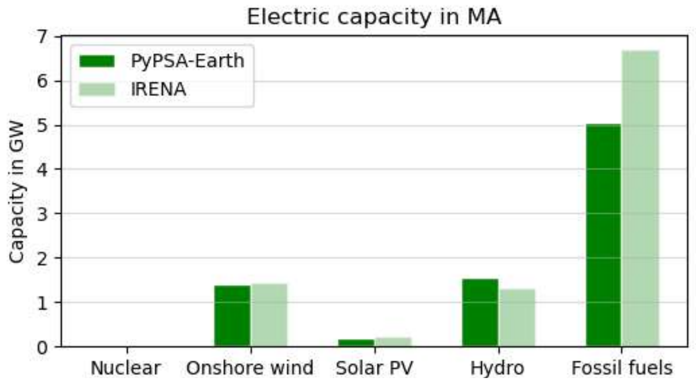
Created using PyPSA-Earth and https://github.com/pypsa-meets-earth/documentation/blob/main/notebooks/viz/regional_transm_system_viz.ipynb

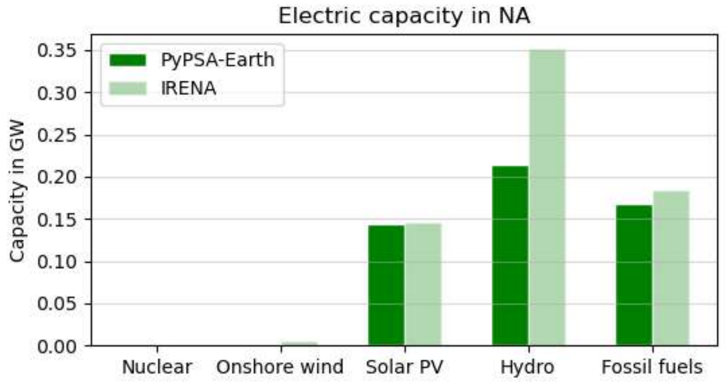
H2Global meets Africa

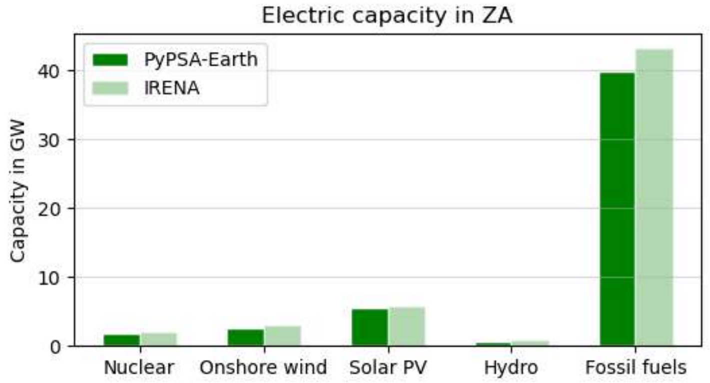
Capacity validation

Validating geo-referenced electric capacities of **PyPSA-Earth** against country-wise **IRENA data**









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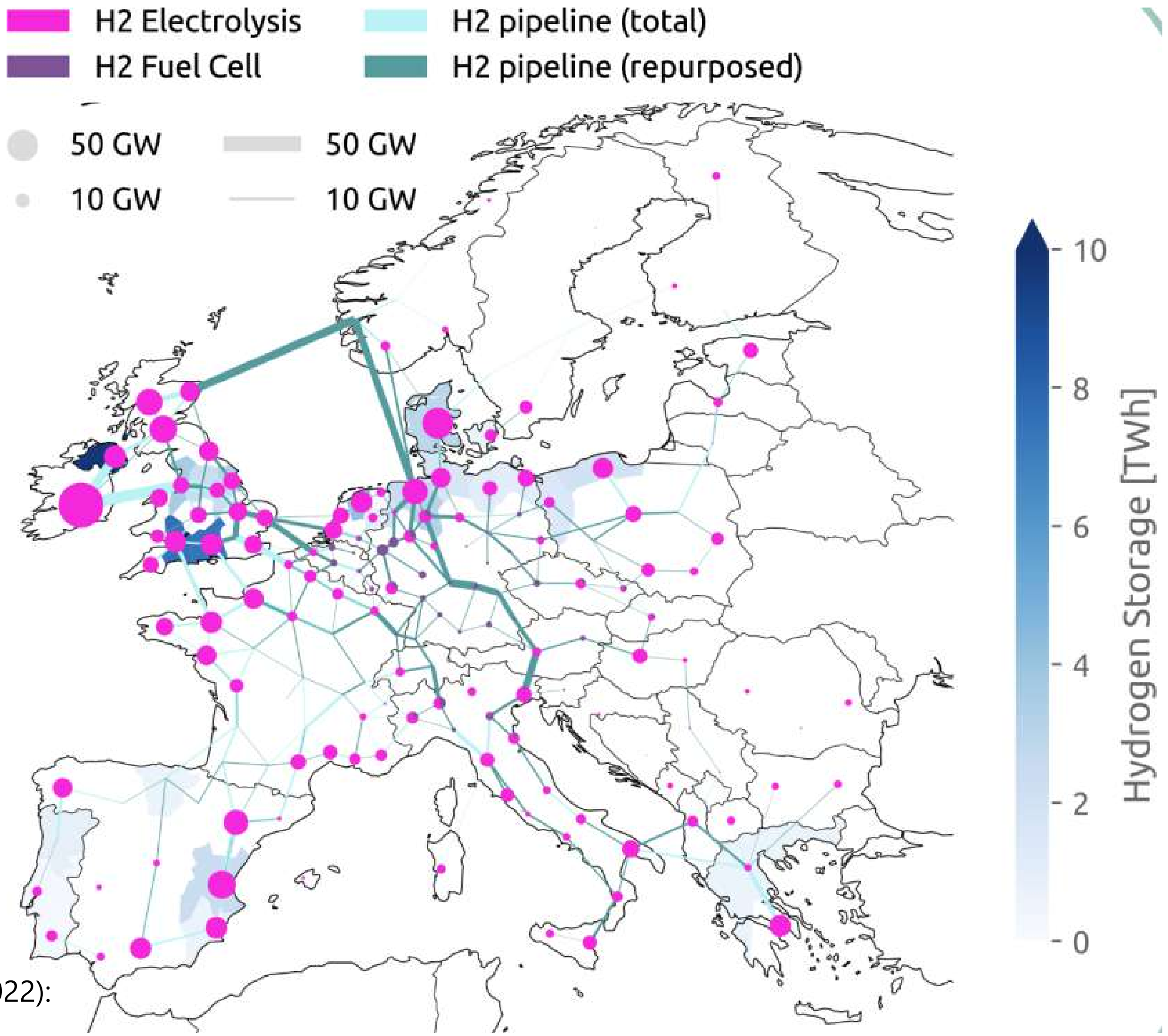
Hydrogen demand in Germany/EU

PyPSA-Eur



Neumann, Fabian; Zeyen, Elisabeth; Victoria, Marta; Brown, Tom (2022): Benefits of a Hydrogen Network in Europe

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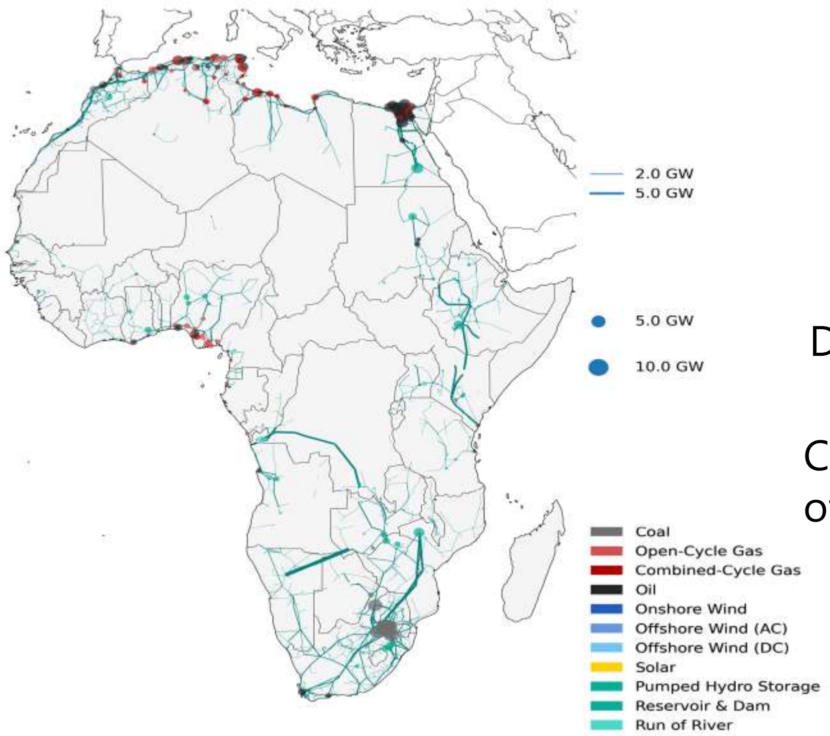
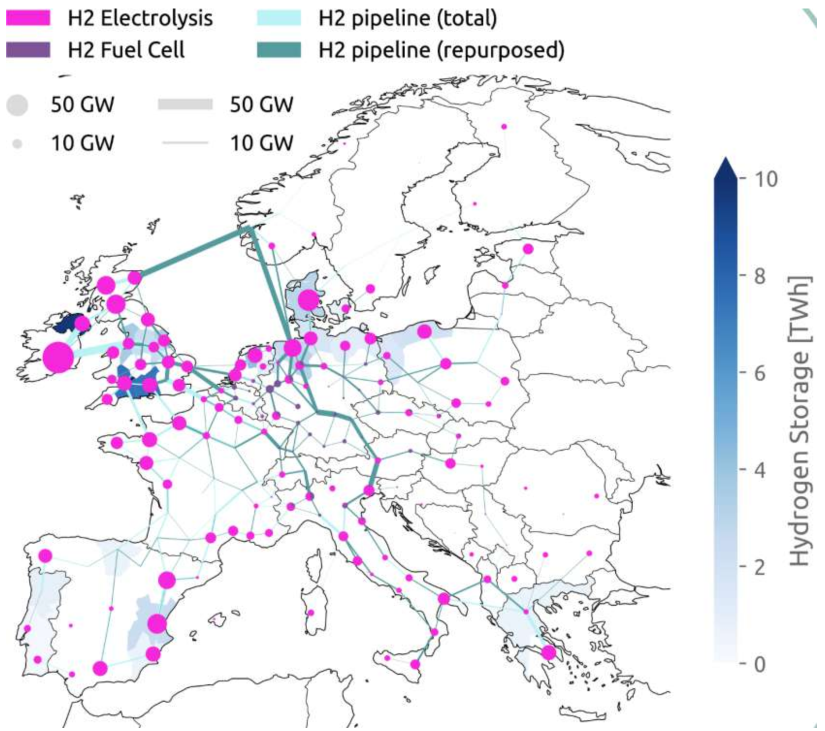
Coupled Energy Systems EU/Africa



Direct model coupling

Common optimization of selected countries



Created using PyPSA-Earth and https://github.com/pypsa-meets-earth/documentation/blob/main/notebooks/viz/regional_transm_system_viz.ipynb

Neumann, Fabian; Zeyen, Elisabeth; Victoria, Marta; Brown, Tom (2022): Benefits of a Hydrogen Network in Europe

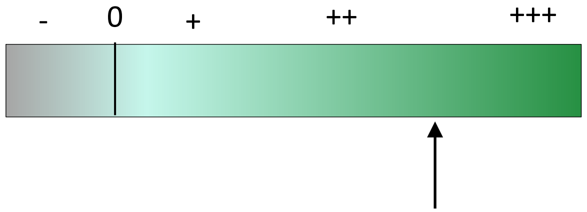
H2Global meets Africa

Techno-economic analysis of integrated value chains in Africa and Germany

Production costs and technical feasibility

Socio-economic analysis

Multi-criteria evaluation of the environmental performance of PtX products, "Green Rating"



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Site Assessment

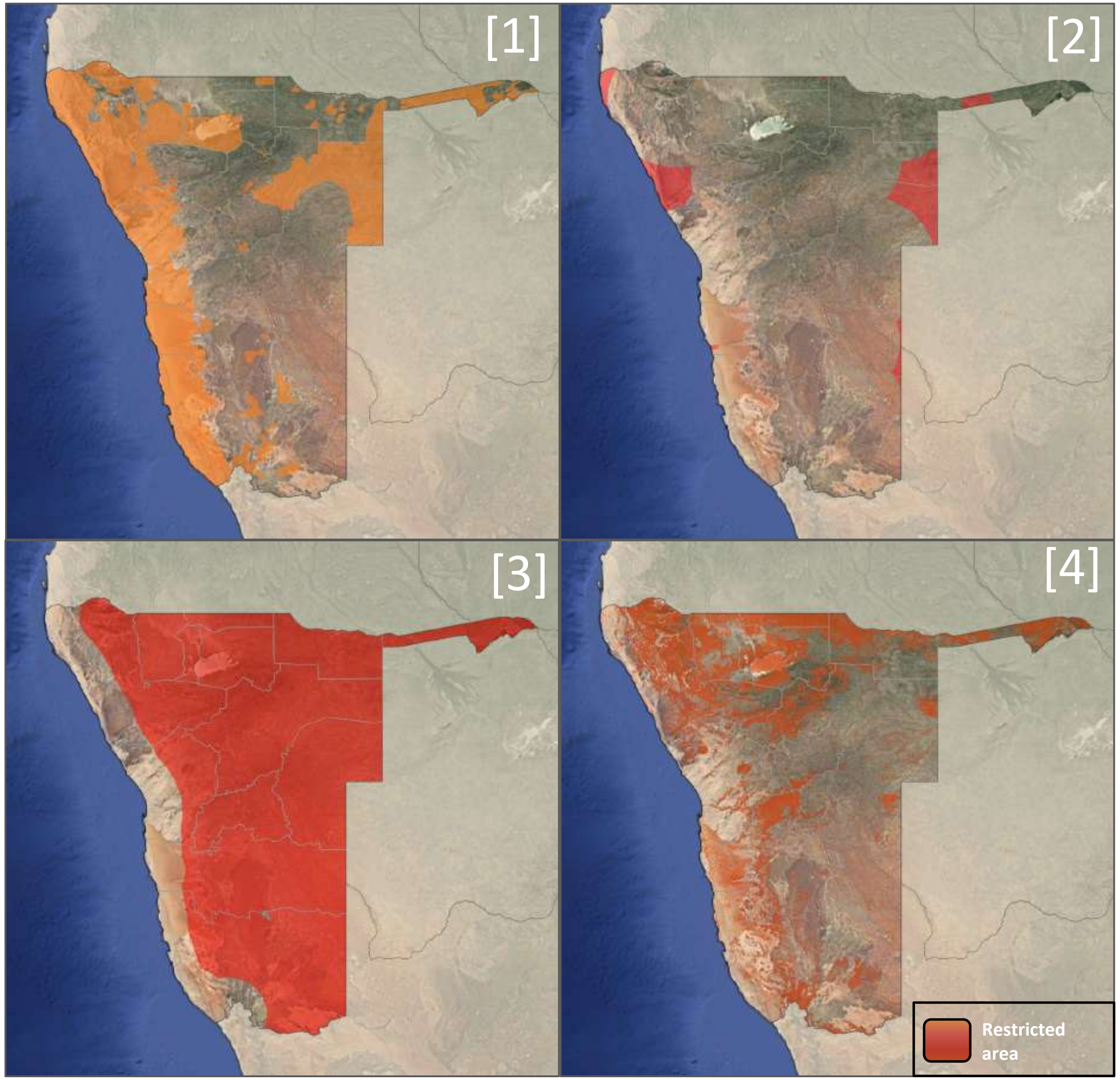
Excluded areas

1. Nature conservation
   Protected areas, critical habitats

2. Poor infrastructure
   City proximity > 150 km

3. Limited water availability
   Country coasts proximity > 50 km
   No use of surface waters with high water risk level

4. Unsuitable areas
   Croplands, forests, residentials, waterbodies
   Population density > 50 habitants per km²
   Slope > 5 %



[1] map source: Google Maps

H2Global meets Africa

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“The role of capacity building, certification and technology developments for a green hydrogen market in Africa”

Dr. Klemens Ilse
Fraunhofer IMWS

Germany

The role of capacity building, certification and technology developments for a green hydrogen market in Africa

German African Green Hydrogen Forum

2023/05/24

Dr. Klemens Ilse
Deputy Director FIP-H2ENERGY@KENTECH
Head of Group – Materials Diagnostics for H2 Technologies, Fraunhofer IMWS

Fraunhofer Innovation Platform for Hydrogen Energy

KENTECH Korea Institute of Energy Technology

in cooperation with Fraunhofer

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Introduction to the Fraunhofer Gesellschaft

The leading applied research organization

Fraunhofer at a Glance

The leading applied research organization

Joseph von Fraunhofer
(1787-1826)

Applied research is the foundation of our organization. We **partner** with **companies** to transform original ideas into **innovations** that **benefit society** and **strengthen** both the German and the European **economy**.

€2.9 billion

total business volume

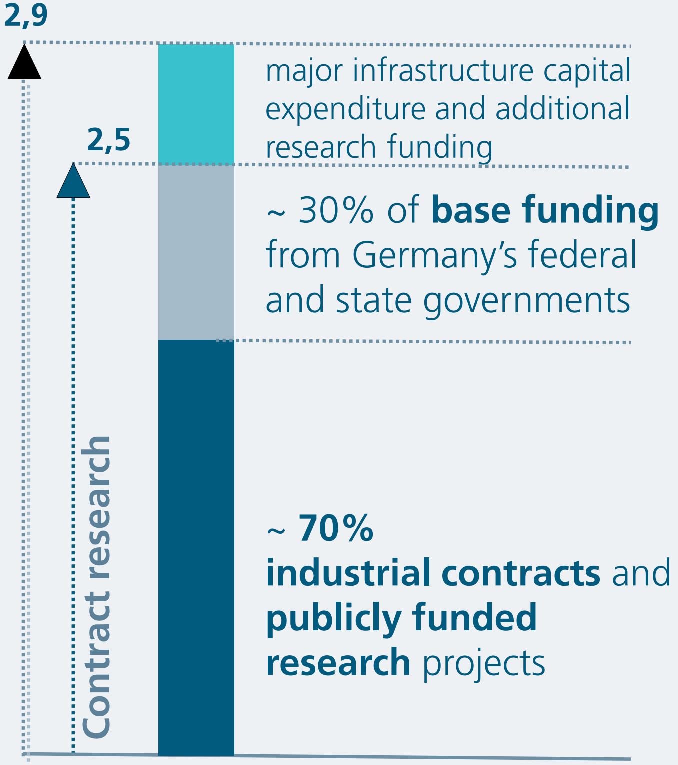
30,000

employees

76

institutes and research institutions

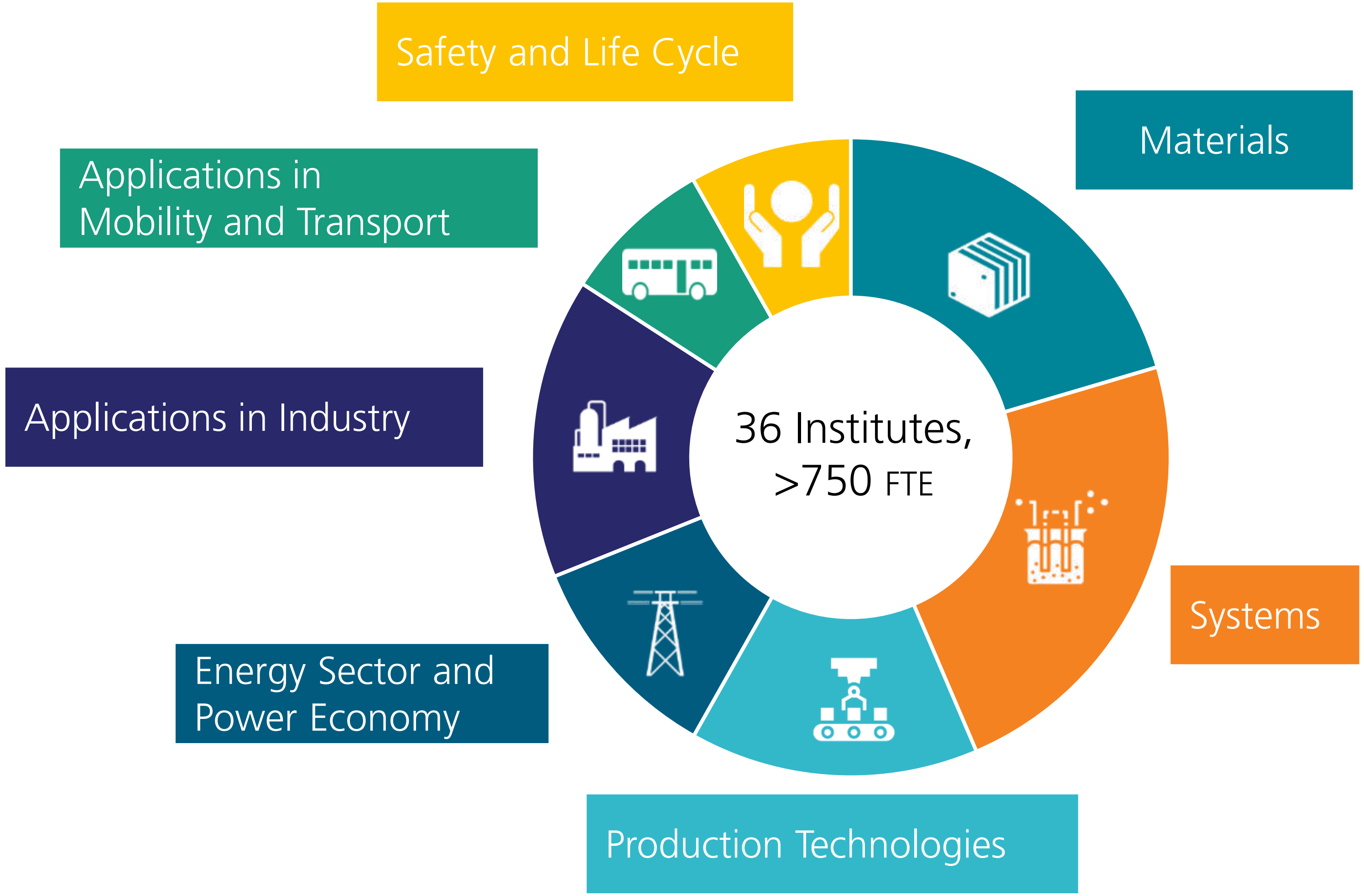
Total business volume 2021
in billion EUR

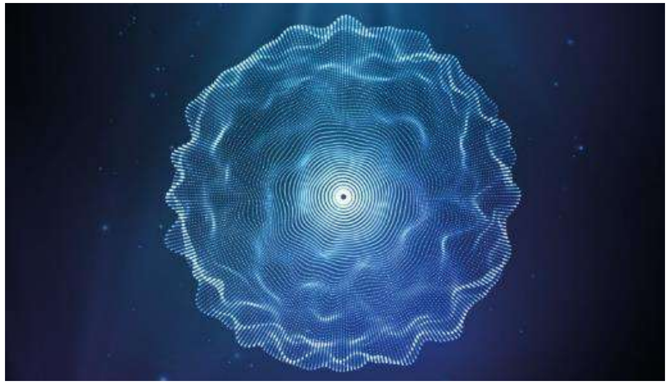


Fraunhofer

Hydrogen R&D at Fraunhofer

The Fraunhofer Hydrogen Network





Fraunhofer Core Competencies

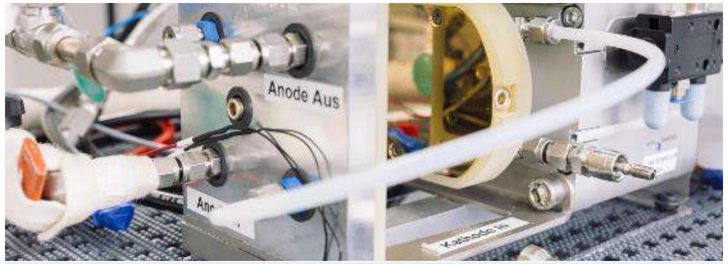
- **Security, reliability and standardization**
- **Upscaling of plants**
- **Production technologies**
- **Digitization**
- **Analysis of potential, infrastructure and system modelling**
- **Living labs / model regions**

Fraunhofer IMWS

Fraunhofer Institute for Microstructure of Materials and Systems IMWS

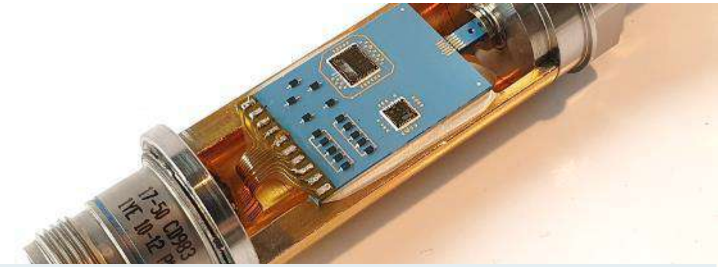
Hydrogen Research at Fraunhofer IMWS

Fields of Competence



Electrolysis and Fuel Cells

Hydrogen Tanks



Hydrogen Sensors

Photoelectrochemical Cells PEC

Green H_2 Systems

Power electronics for H_2 applications

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Green Hydrogen Production

PtX global ATLAS

Major flows of hydrogen and derivates in 2050

There is a mismatch between the best locations for hydrogen production and demand centers

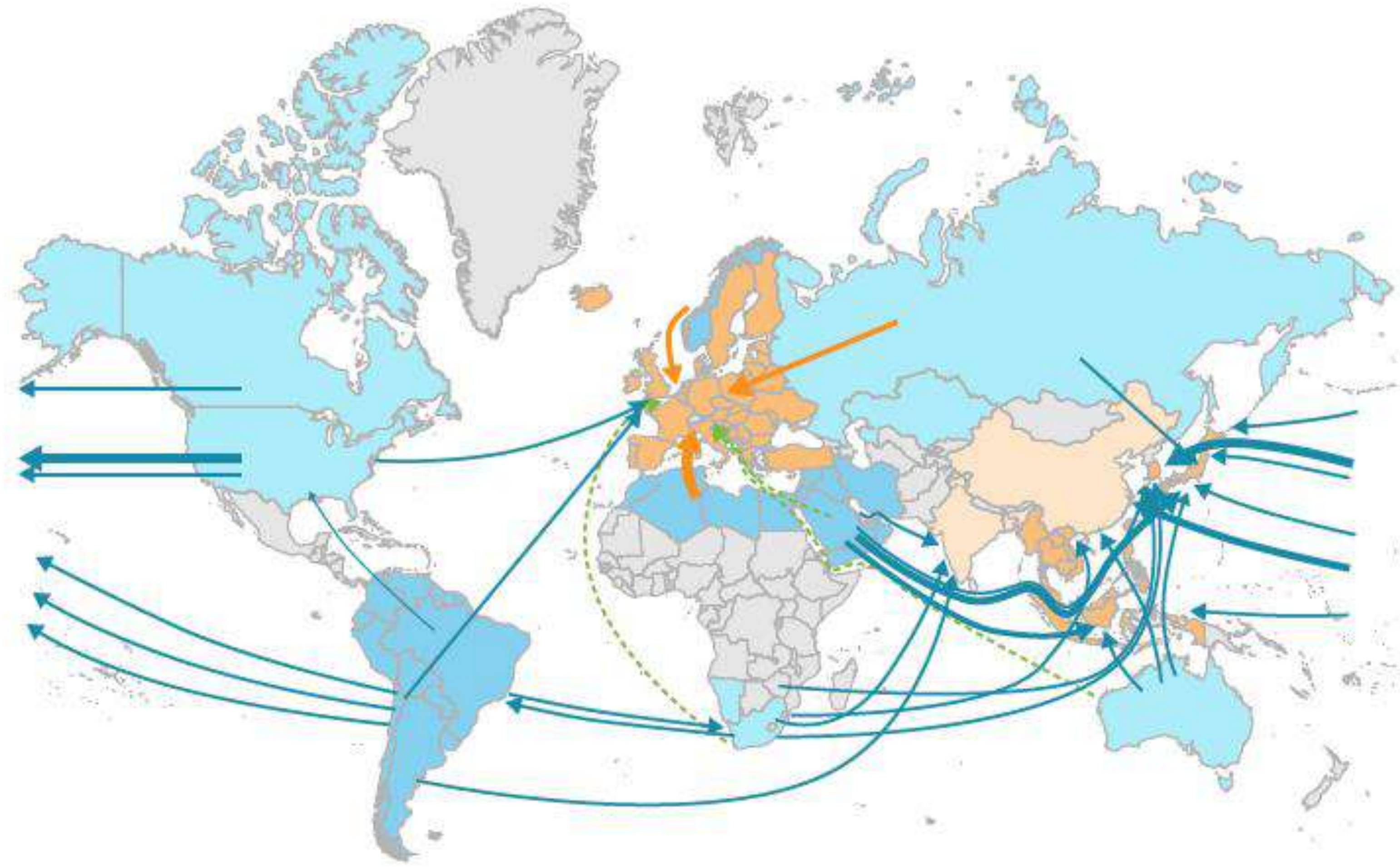
Region consumes more than it produces

Neutral

Region produces more than it consumes

Net trade flows, million tons hydrogen per annum

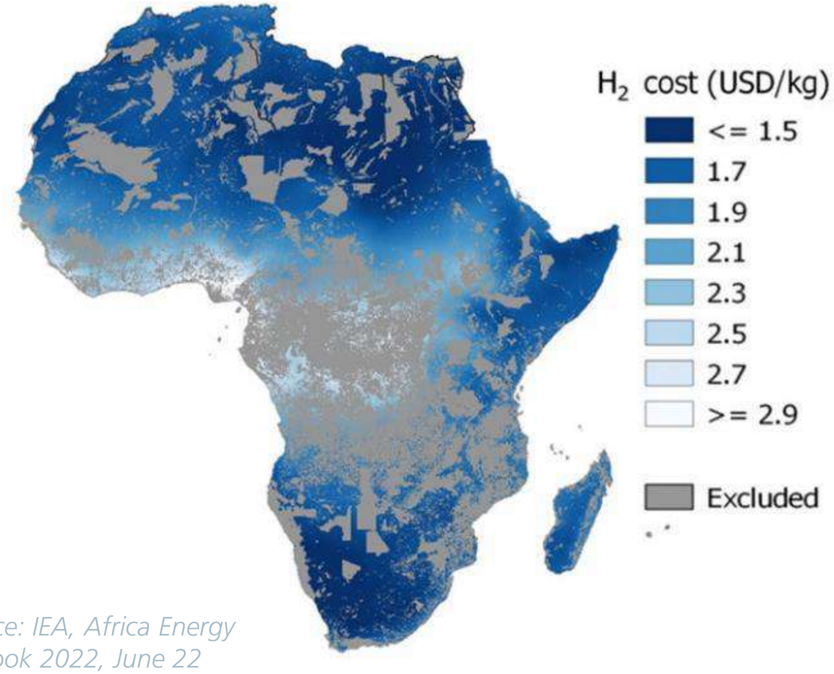
- > 20
- 10–20
- 5–10
- 1–5
- Mostly shipped
- Mostly piped
- Alternative potential flows if optimal sources constrained



Hydrogen Council, McKinsey & Company; "Global Hydrogen Flows: Hydrogen trade as a key enabler for efficient decarbonization", Oct 2022

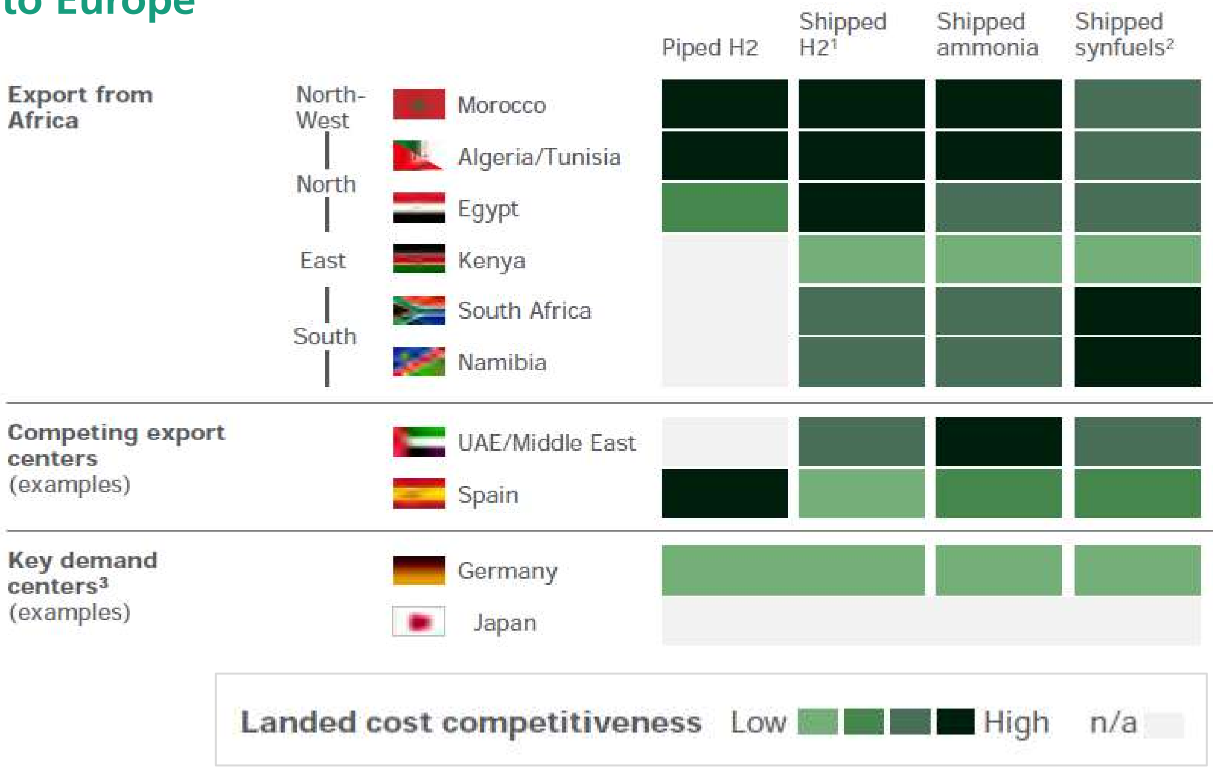
Africa has a great potential for cost-competitive hydrogen production for export

Hydrogen production potential in Africa 2030



Source: IEA, Africa Energy Outlook 2022, June 22

Competitiveness of landing costs of hydrogen and derivatives to Europe



Source: Masdar and ADSW, Africa's green energy revolution Hydrogen's role in unlocking Africa's untapped renewables, Nov 2022

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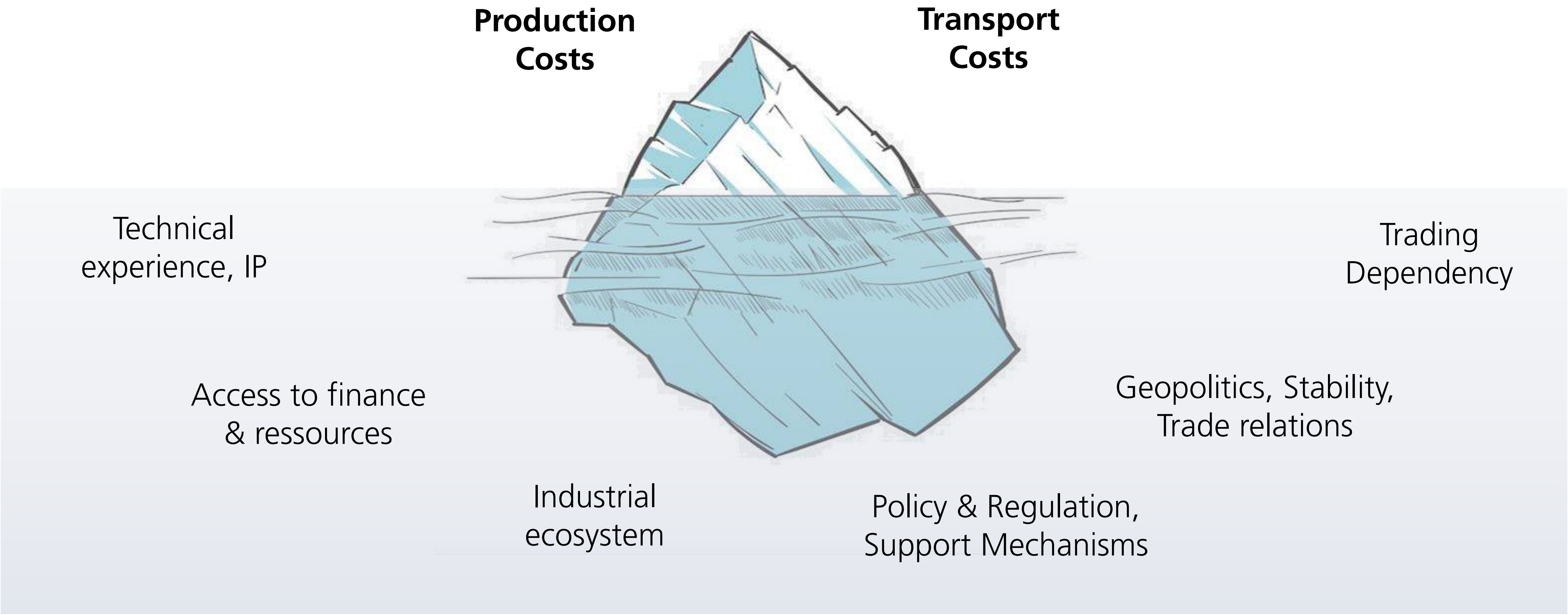
Various Impact Factors for the Future Hydrogen Trade

Hydrogen Production and Transport Costs are only the Tip of the Iceberg

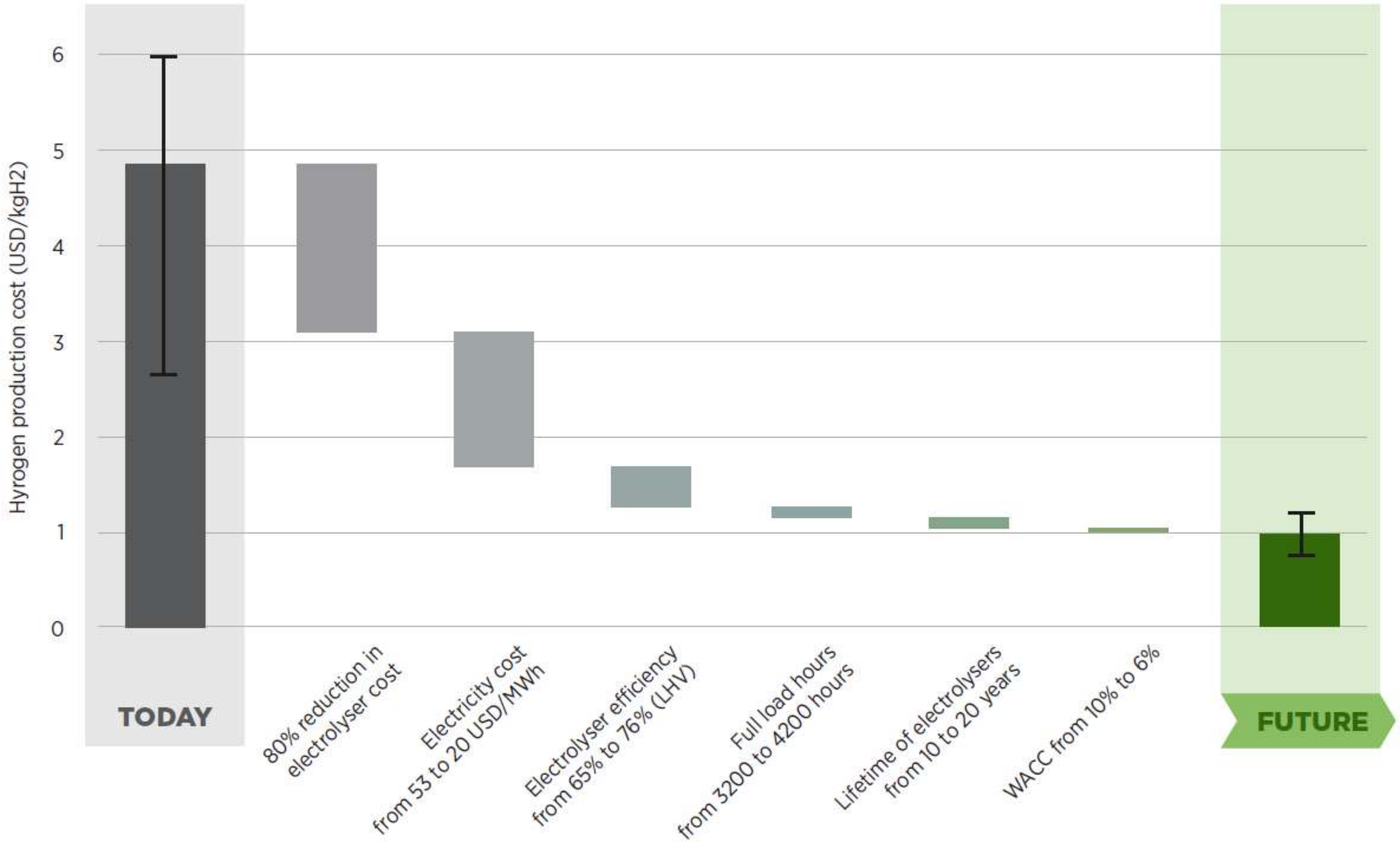


Adapted from: IRENA (2022), Global hydrogen trade to meet the 1.5°C climate goal: Part I – Trade outlook for 2050 and way forward, Internalalational Renewable Energy Agency, Abu Dhabi.

The role of technology developments to enable green hydrogen production at scale

Green Hydrogen: Production Cost Reduction

Overview



Major cost reductions expected to come from:

- Electrolyser CAPEX reduction
- Electricity costs reductions

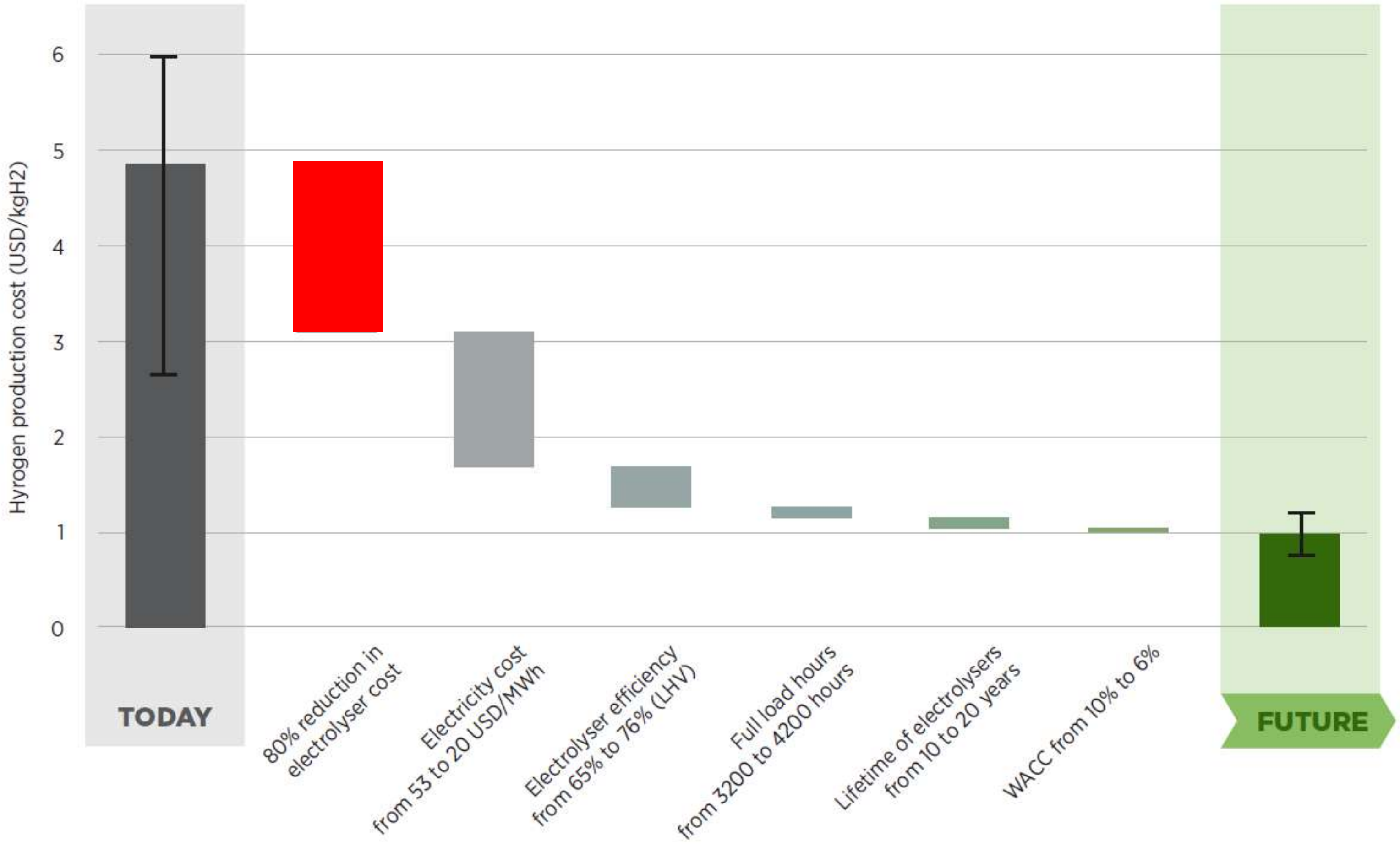
And further benefits from:

- Electrolyser efficiency increase
- More full load hours
- Longer lifetime of electrolysers
- Lower weighted average cost of capital

Source: IRENA 2020, Green Hydrogen Cost Reduction

Green Hydrogen: Production Cost Reduction

Overview



Major cost reductions expected to come from:

- **Electrolyser CAPEX reduction**
- Electricity costs reductions

And further benefits from:

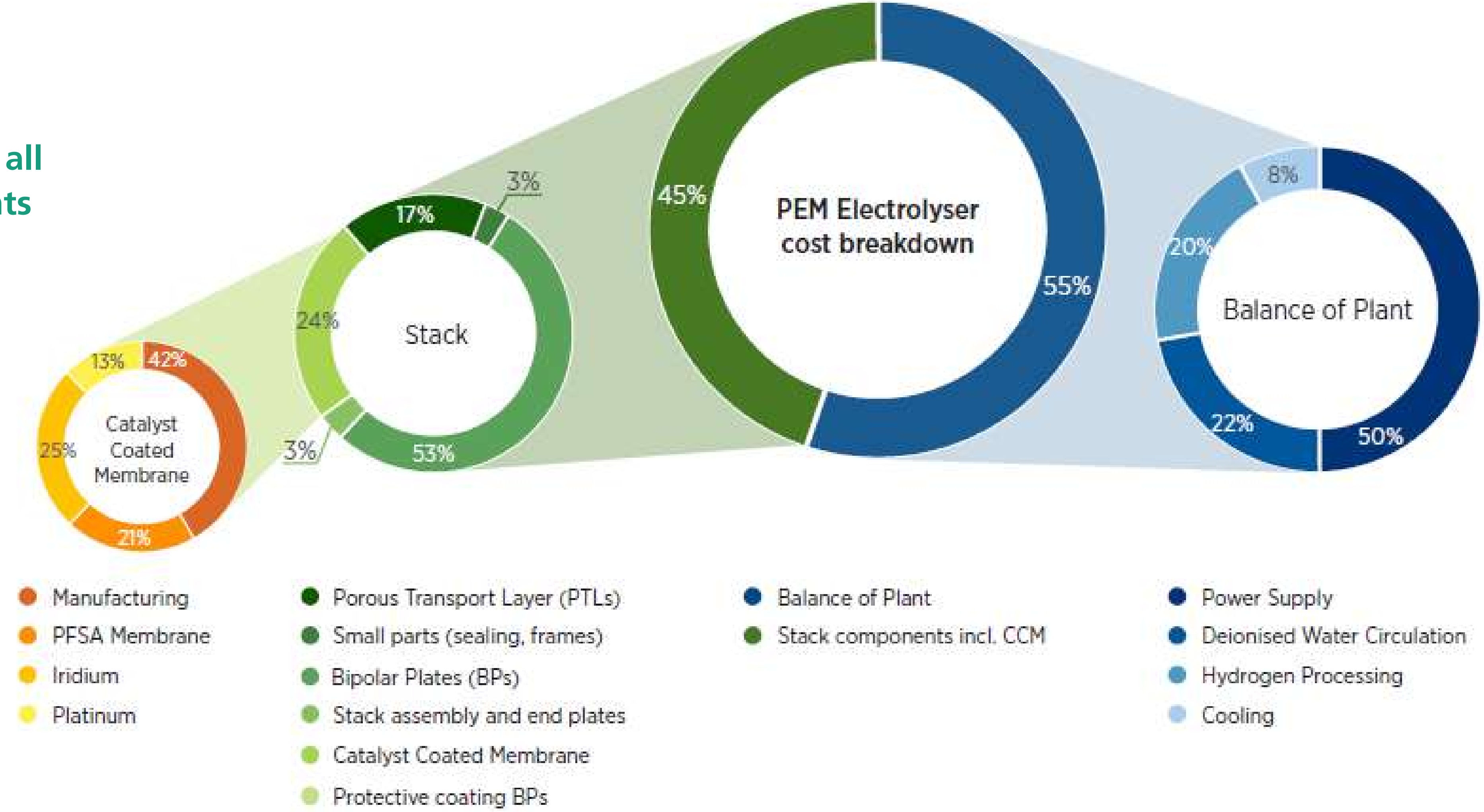
- Electrolyser efficiency increase
- More full load hours
- Longer lifetime of electrolysers
- Lower weighted average cost of capital

Source: IRENA 2020, Green Hydrogen Cost Reduction

Green Hydrogen: Production Cost Reduction

Cost breakdown of a 1MW PEM electrolyser

Fraunhofer works on technical advances for all electrolyzer components

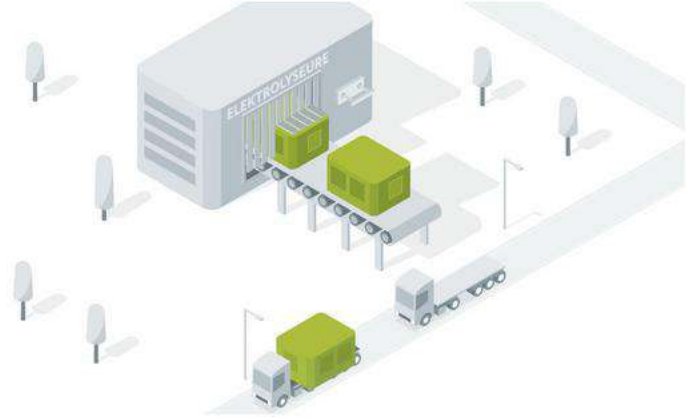


Source: IRENA 2020, Green Hydrogen Cost Reduction

Hydrogen Lead Projects
Overview

SPONSORED BY THE Federal Ministry of Education and Research

Wasserstoff Leitprojekte Grün. Groß. Global.



H2-Giga

Supports the scale-up process for electrolyzers

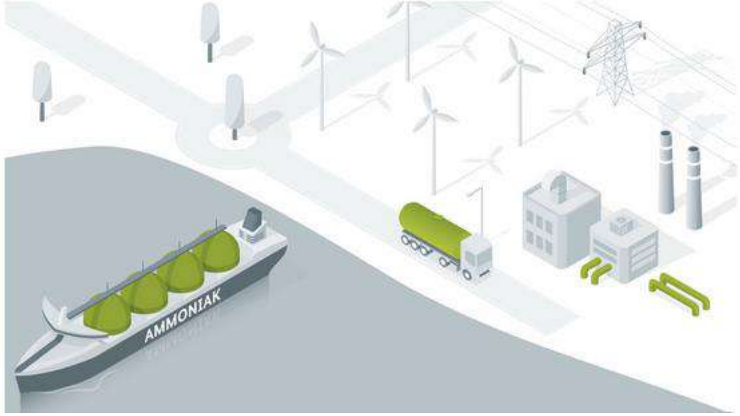
→ StacIE

→ FRHY

H2-Mare

Supports the production of hydrogen off-shore

→ H2Wind



Transhyde

Supports the transport infrastructure for hydrogen

https://www.wasserstoff-leitprojekte.de

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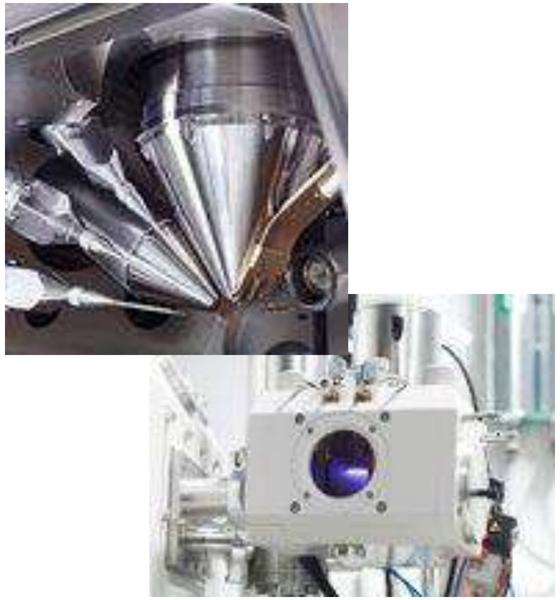
Project example: StacIE

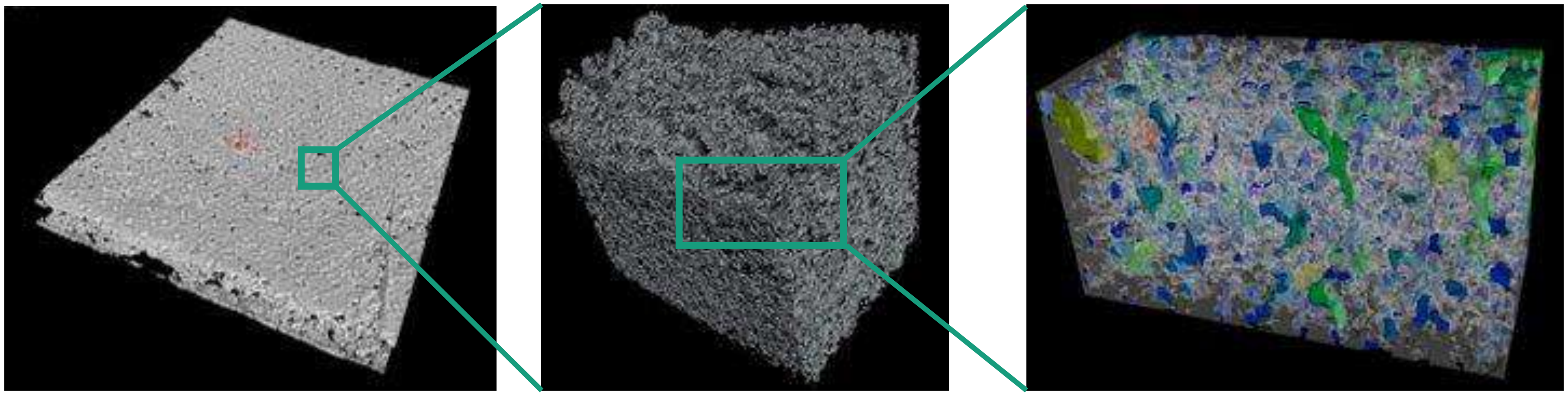
Cross-scale three-dimensional investigations of catalyst coated membranes



Industrializing the stack production of electrolyzers on the level of cell components and stables

Role of Fraunhofer IMWS:

- Support of the development of new industrial processes
- Focus: active materials and catalyst coated membranes
- Two- and three-dimensional microstructural characterization and evaluation across scales



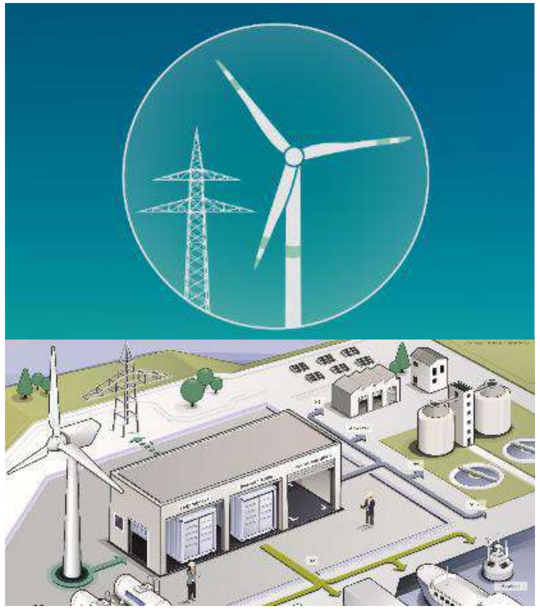
SPONSORED BY THE Federal Ministry of Education and Research

Leitprojekt H_2Giga

Fraunhofer IMWS

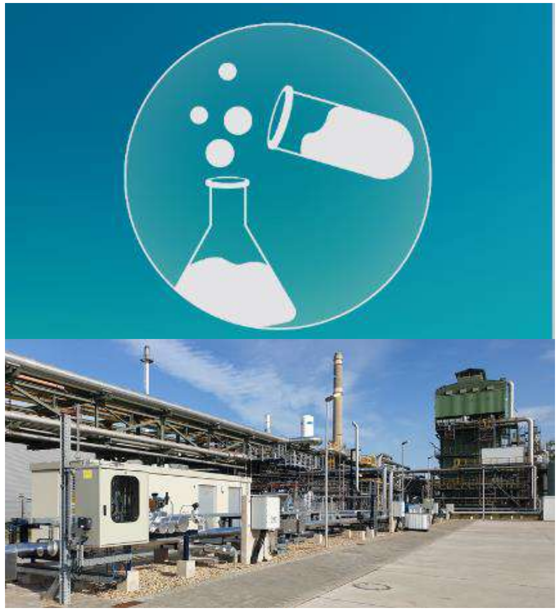
Fraunhofer Hydrogen Labs

Test infrastructure for technology validation at an industrial scale



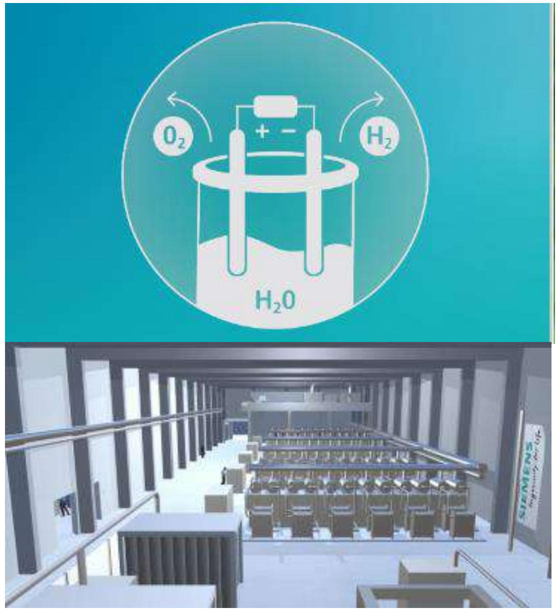
Hydrogen Lab Bremerhaven

Focus: Coupling wind power and electrolysis



Hydrogen Lab Leuna

Focus: Green H2 for the chemical industry



Hydrogen Lab Görlitz

Focus: Decarbonisation of industrial production

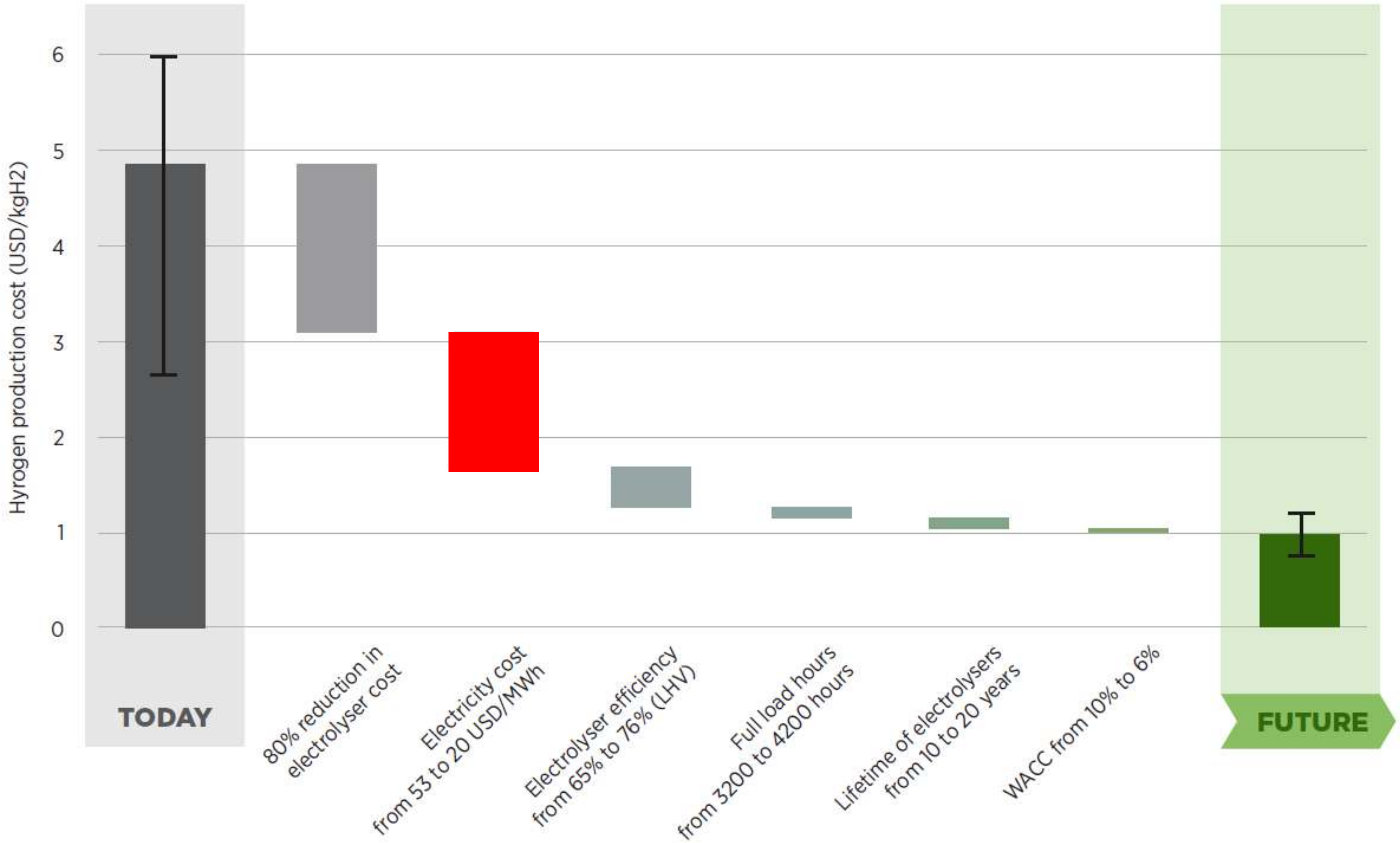
Key Features:

- Tests of electrolysers, components and systems up to the multi-MW range
- Direct coupling with 8MW wind turbine
- Grid simulation with grid emulator
- Connection to hydrogen pipeline
- H2 use in PtL pilots

Fraunhofer IWES Fraunhofer IWU Fraunhofer CBP Fraunhofer IMWS

Green Hydrogen: Production Cost Reduction

Overview



Major cost reductions expected to come from:

- Electrolyser CAPEX reduction
- **Electricity costs reductions**

And further benefits from:

- Electrolyser efficiency increase
- More full load hours
- Longer lifetime of electrolysers
- Lower weighted average cost of capital

Source: IRENA 2020, Green Hydrogen Cost Reduction

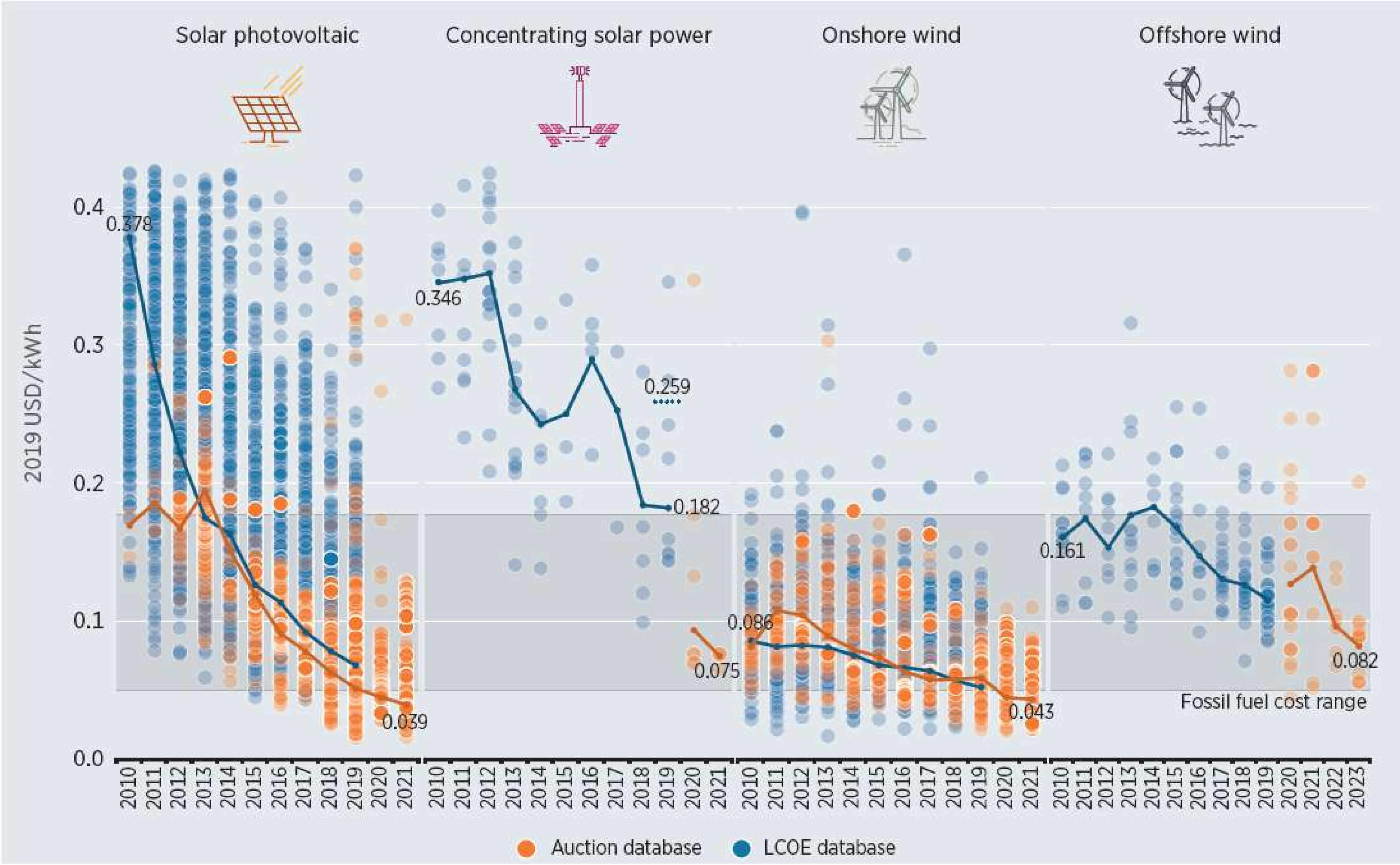
Fraunhofer IMWS

Green Hydrogen: Production Cost Reduction

Levelized Costs of Electricity (LCOE)

Average LCOE and PPA/Auction price development in the period between 2010 and 2021

- Solar PV: -90%
- Onshore wind: -78%
- Offshore wind: -50%
- CSP: -49%

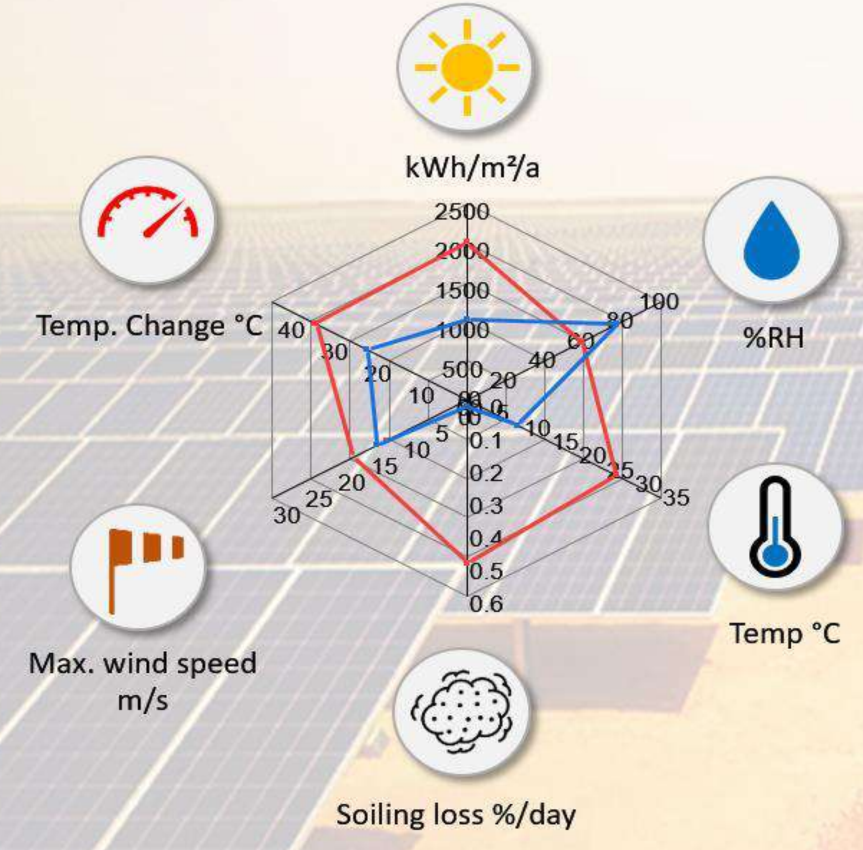


Source: IRENA 2020, Renewable Power Generation Costs in 2019

Fraunhofer IMWS

Derisking large scale PV deployment in desert environments

Developing PV modules, materials, standards and new technologies for the harsh desert climate



Desert
Moderate

DESERT CHALLENGE

- 2x Irradiance Dose
- 2x Temperature change
- 3.5x Max. wind speed
- 50x Soiling rate
- +20 °C Ambient Temp.

HOCHSCHULE ANHALT University of Applied Sciences · Fraunhofer CSP · Fraunhofer IMWS

Certification and standards for green hydrogen production

Ensuring sustainability of H_2 projects
Role of standards and certification

- Sustainable hydrogen projects must fulfil several criteria, including
  - technical
  - environmental and
  - social aspects
- Regulations, standards and certification schemes for green hydrogen have strong impact on plant design, used technologies and costs

Example: *Delegated Act REDII 28(5)* on CO_2 source for RFNBO production: industrial points sources should not be considered as "avoided emissions" after 2040, until then only if subject to an "effective carbon pricing scheme" e.g. EU-ETS

Main environmental criteria include:
- Air emissions
- GHG emissions
- Water Conservation
- Water quality
- Biodiversity conservation
- Land use
- Hazardous material management

Main technical criteria include:
- Renewability
- Geographical correlation
- Temporal correlation
- Additionality
- Simultaneity

Main social criteria include:
- Community health and safety
- Land acquisition and involuntary resettlement
- Labor conditions
- Indigenous people
- Cultural heritage

Regulatory & Standards for Green or Clean Hydrogen Production

Overview: Standards under constant changes and updates, some still under development

General
- Environment health and safety guideline (World Bank)
- Environmental Impact and Social Assessment, Performance Standards (IFC)
- Sustainable Development Goals (SDG)

Legal Framework
- RED II (EU)
- EU Taxonomy
- US Clean Hydrogen Production Standard (CHPS)
- US/California Low Carbon Fuel Standard (LCFS)
- UK Low Carbon Hydrogen Standard (LCHS)
- UK Renewable Transport Fuel Obligation (RTFO)

Voluntary certification
- China Hydrogen Alliance's Standard (CHAS)
- Certifhy (FCH JU)
- TÜV Süd CMS 70
- The Green Hydrogen Standard (GHS)
- Climate Bonds (CB)

Funding tool
- H2 Global / Hintco

Specific to green H_2 and derivatives (Legal Framework, Voluntary certification, Funding tool)

H2Global Stiftung

Fraunhofer IEE Fraunhofer IMWS

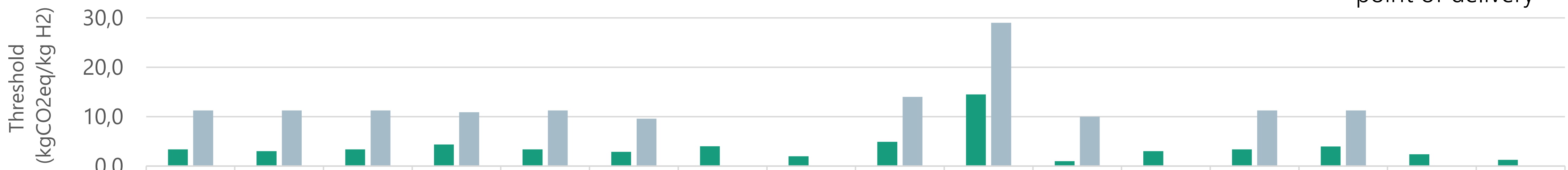
GHG emissions

Thresholds, baselines, system boundaries, production pathways, sectors

Well-to-wheel

Well-to-gate

Well-to-gate + point of delivery



	RED II	EU Taxonomy (hydrogen)	EU Taxonomy (hydrogen-based synthetic fuels)	Certifhy	TÜV Süd CMS 70	TÜV Süd CMS 70	US DOE Clean Hydrogen Production (IRA)	US DOE Clean Hydrogen Production (BIL)	China Hydrogen Alliance's Standard	China Hydrogen Alliance's Standard	Green hydrogen standard	Climate Bonds	H2Global	UK Renewable Transport Fuel Obligation (RTFO)	UK Low Carbon Hydrogen Standard	US/CA Low Carbon Fuel Standard (LCFS)
GHG Emissions threshold	3,4	3,0	3,4	4,4	3,4	2,9	4	2	4,9	14,51	1	3 **	3,4	3,9	2,4	1,3
Reference baseline	11,28	11,28	11,28	10,92	11,28	9,60			13,99	29,02	10		11,28	11,3		

Label	RFNBO	H_2	H_2-Fuels	Low-Carbon/ Green H_2	GreenH_2/ GreenH_2+	GreenH_2/ GreenH_2+	Qualified H_2	Clean H_2	Clean/RE H_2	Low-carbon H_2	GH_2	Green/ Low-Carbon H_2	RFNBO	RFNBO	Low-Carbon H_2	Low Carbon/RE
Production Pathway	RE	RE	RE	RE (Green), non-RE low carbon (Low Carbon)	RE, Biom, SMR, pyro, CCS	RE, Biom, SMR, pyro, CCS	RE, SMR, CCS, Nuclear, Biom, Pyro	RE, SMR, CCS, Nuclear, Biom, Pyro	RE, Biom, CCS	SMR (coal), Coal Gas. CCS	RE	RE, Biom (Waste), Pyro, SR	RE	RE	RE, Biom, Nuclear, NGR, CCS (fossil)	RE, Biom (SMR)
Sector	Transport, Industry*	Not spec.	Not spec.	Not spec.	Transport, Material use, Storage medium	Steam/heat-ing, cooling	Not spec	Not spec	Not spec.	Not spec.	Not spec.	Not spec.	Transport, Industry	Transport	Not spec.	Transport
Boundary	Well-to-wheel	Well-to-wheel	Well-to-wheel	Well-to-gate	Well-to-gate (+)	Well-to-gate (+)	Well-to-gate + point of delivery	Well-to-gate + point of delivery	Well-to-gate	Well-to-gate	Well-to-gate	Well-to-gate + point of delivery	Well-to-gate + point of delivery	Well-to-gate + point of delivery	Well-to-gate	Well-to-wheel

(+) TÜV: for becoming the label "GreenHydrogen+" the system boundary is until the point of supply

* Industry will be added in RED III
** 2030: 1,5 → 2040: 0,6 → 2050: 0

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Fraunhofer IMWS

Regulatory & Standards for Hydrogen Production

Summary:

- Many initiatives, inconsistent requirements & criteria, highly dynamic
- Sustainability requirements strongly influence technical design of PtX plants

Need for international harmonization of requirements to create investment security

Fraunhofer IEE Fraunhofer IMWS

Capacity Building: preparing for a future green hydrogen ecoystem

Fraunhofer IMWS

Capacity Building

Motivation

Example TUNol project: Green Methanol plant with capacity of 0.1 Mt p.a. (PV-CSP-Hybrid Power plant + Electrolyzer + Methanol plant)

Investment

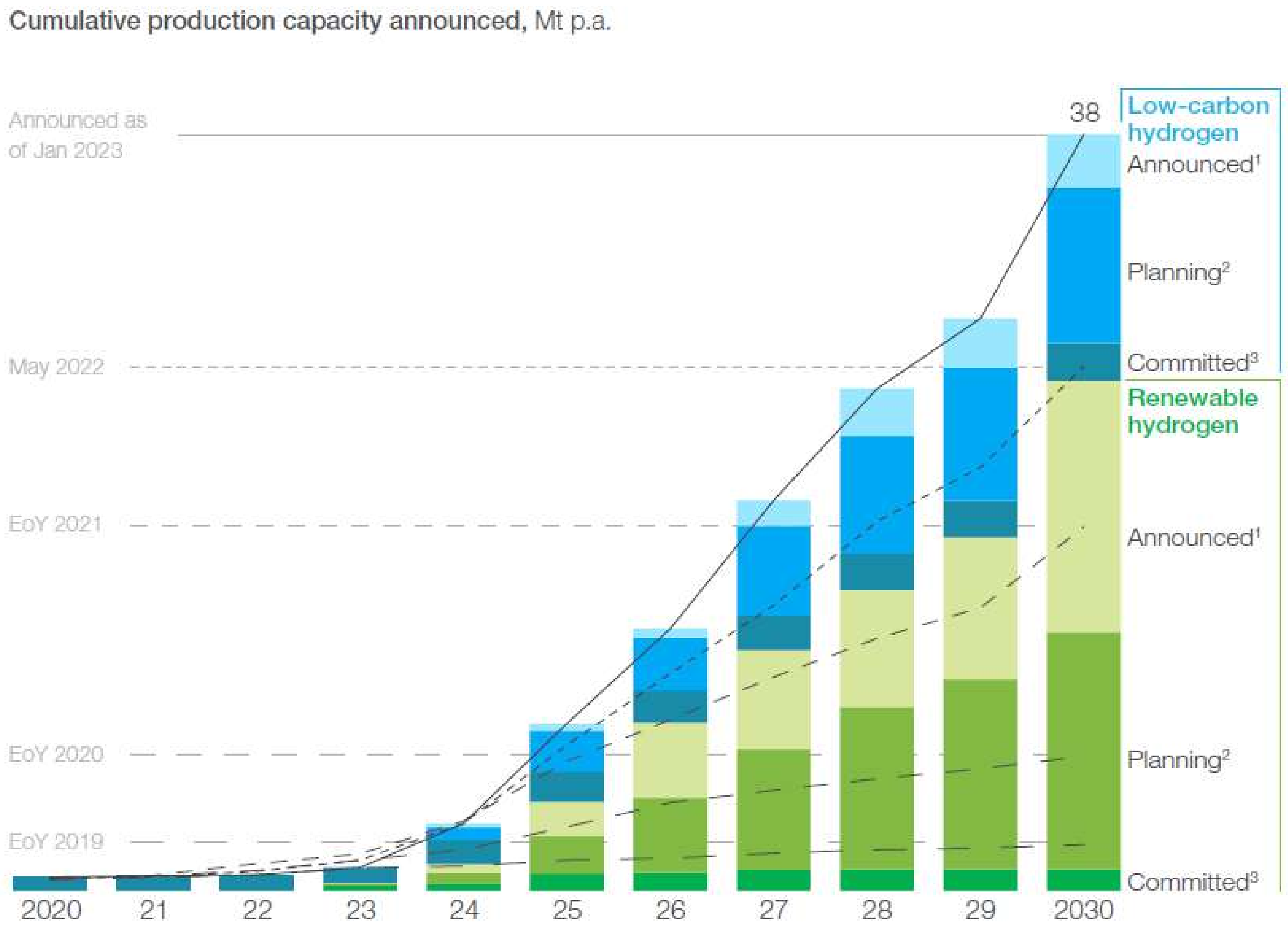
- Direct Investment (> 1.000 million EUR)
- Operation and maintenance (30 million EUR)

Job creation

- **Construction**: 1400 – 1800 staff over 18-24 months
- **Operation**: 150 direct employees, up to 500 auxiliary jobs

→ **New jobs that require new skills**

Announced hydrogen projects by 2030: 38 Mt p.a.



Source: Hydrogen Insights May 2023, Hydrogen Council, McKinsey & Company

Supported by: Federal Ministry for Economic Affairs and Climate Action

Capacity Building

The hydrogen market ramp-up needs skilled workers

Field	Topics	Skilled workers
Generation	▪ Renewable power plants ▪ Electrolysis ▪ Blue H_2 via CCS and CCU, Pyrolysis ▪ PtX (Ammonia, Methanol, Synthetic fuels, …)	• Electrical engineers • Mechanical Engineers • Planners, project planners of storage and renewable energies • Plant engineers (electrolysis) • Grid engineers • Network operators • Plant engineers (natural gas) • Specialized workers, foremen, technicians and engineers • Contract installation companies • Employees of control rooms
Infrastructures and System Integration	▪ Overall system integration ▪ Infrastructure (Grid + Non Grid) ▪ Medium and large scale storage	• Infrastructure planner / project engineer • Plant / network constructor • Employees in administrative bodies • Engineers (Electrical, Mechanical) • Grid foreman • Grid + Welding engineers • Plant technicians/mechanics for pipe system technology • Pipe fitters • Welders
Application/Use	▪ Industries (Steel, Chemical etc.) ▪ Process heat ▪ Stationary application (turbine, engines, fuel cells) ▪ Traffic (Road, Rail, Ship, Air)	• Plant engineers • Planners • Civil engineers • Installers • Plant operators
Safety, Sustainable market launch	▪ Safety issues ▪ Business models ▪ Sustainability of H_2	

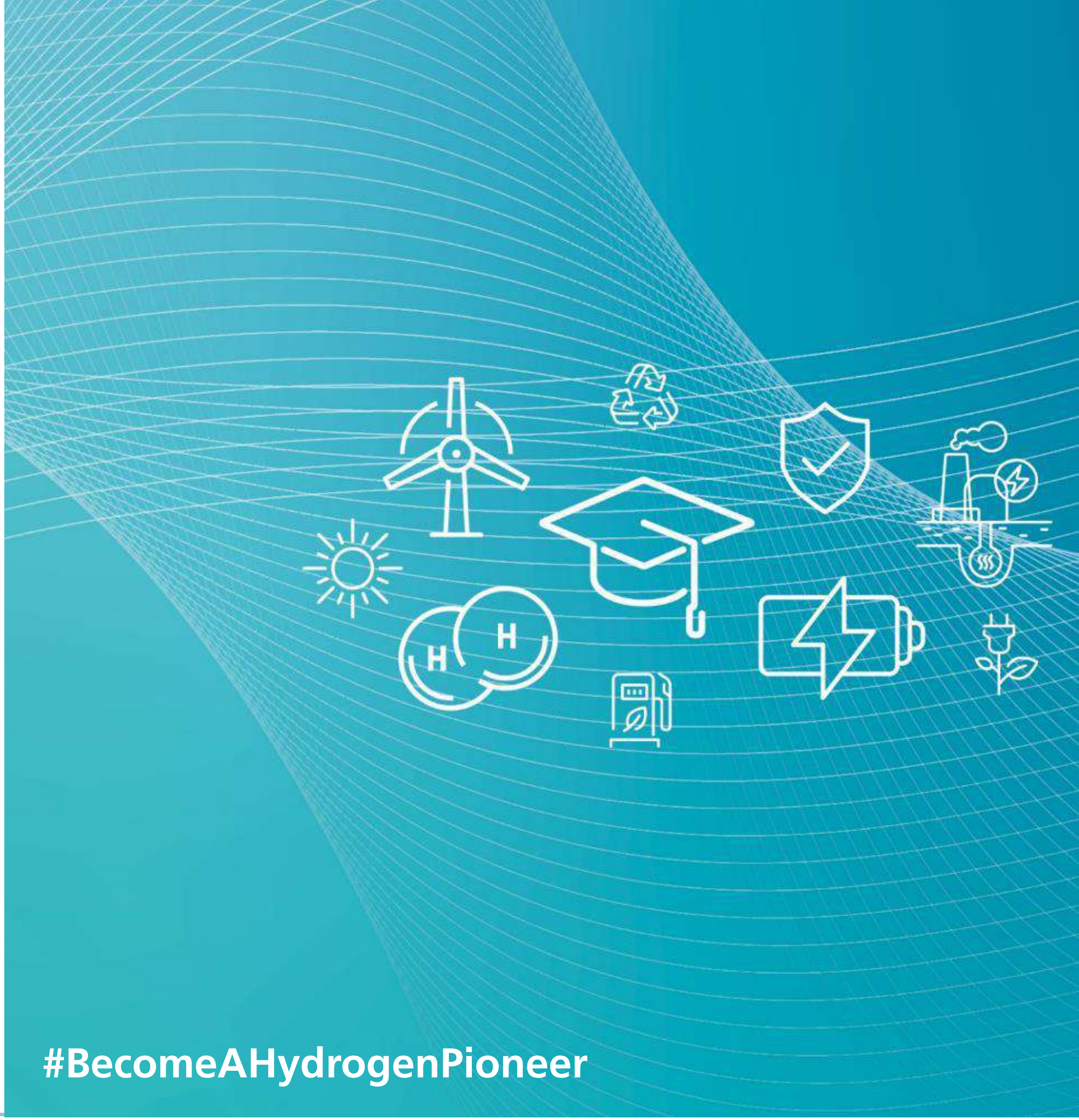
Adapted from VDE /DVGW: Impulspapier Wissensvermittlung Wasserstoff - Der Wasserstoffmarkthochlauf braucht heute Fachkräfte. February 2023

Capacity Building

The Fraunhofer Learning Community Hydrogen is offering various trainings and certified further education programs in the field of hydrogen:

Hydrogen Expertise	Production of green Hydrogen for professionals	Hydrogen applications in mobility	H2 for professionals and executives
			

Ongoing: Transfer and adoption of Fraunhofer's expertise and existing expert courses to the specific needs in African Countries



Conclusion

Technology development,
certification and
capacity building

are necessary components for the development and uptake of a green hydrogen market in Africa.

International cooperation is key to the successful and timely development of the necessary technologies

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Thank you for your attention

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06120 Halle
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“Green Hydrogen in Morocco: Which Opportunities for Germany and Morocco”

Dr-Ing. Samir Rachidi
IRESEN

Morocco

KINGDOM OF MOROCCO
Ministry of EnergyTransition and Sustainable Developmen

IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles

10 ans
au service de la recherche et de l'innovation

HOCHSCHULE ANHALT University of Applied Sciences

CLUSTER GREEN H2
RECHERCHE - INNOVATION - INDUSTRIE

GERMAN-AFRICAN GREEN HYDROGEN FORUM

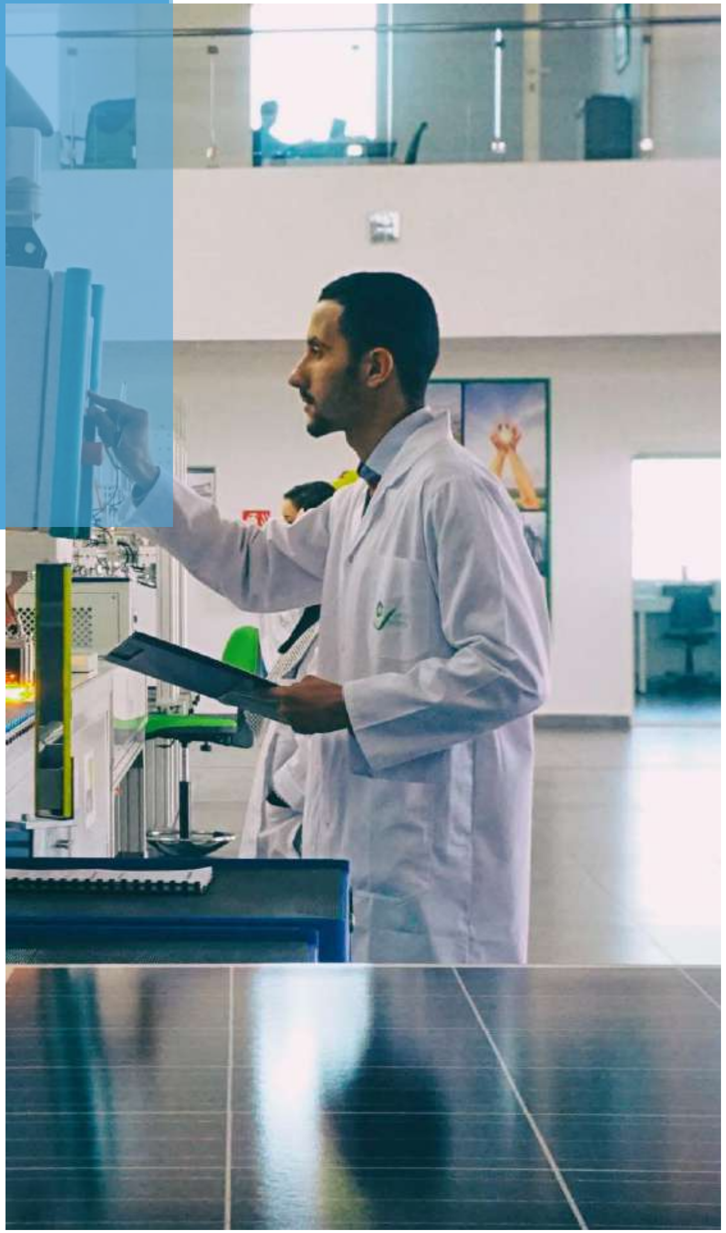
Green Hydrogen in Morocco

Which Opportunities for Germany and Morocco

Casablanca, May 24th 2023

Dr-Ing. Samir Rachidi, Acting CEO of IRESEN

IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles
10 ans au service de la recherche et de l'innovation



ABOUT THE INSTITUTE

Support and Development of Applied Research and Innovation at the service of National and Continental Energy Transition.

The Research Institute for Solar Energy and New Energies (IRESEN) was created on the sidelines of the "Assises de l'Énergie" in 2011 at the initiative of the Ministry of Energy, Mines and Environment as well as several public and private key stakeholders of the energy sector to support applied research and innovation in the field of green technologies.

IRESEN is now a major player supporting the national energy strategy and is positioned across the entire green innovation value chain, through its two instruments:

1 **INFRASTRUCTURES**

Network of research and innovation platforms in green technologies

2 **FUNDING AGENCY**

Funding of applied research and collaborative innovation projects

The Institute also contributes to the development of technological roadmaps in the clean energy sector: Solar Resources, Electric Mobility, Green Hydrogen, ...

GREEN ENERGY PARK

in partnership with

MOHAMMED VI POLYTECHNIC UNIVERSITY

and the support of

KOICA
Korea International Cooperation Agency

IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles

TOPICS COVERED

SOLAR PHOTOVOLTAIC

CONCENTRATED SOLAR POWERE

SMART GRIDS

ENERGY STORAGE

WIND POWER

BIOMASS

HYDROGEN & POWER-TO-X

ENERGY EFFICIENCY

GREEN BUILDING & SUSTAINABLE CONSTRUCTION

CITY OF THE FUTURE

SUSTAINABLE MOBILITY

WATER-ENERGY-AGRICULTURE NEXUS

RESOURCE MODELING

DIGITIZATION

IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles

GREEN H2A R&D PLATFORM
INNOVATION TO CO-LOCALIZE PTX INDUSTRY

RENEWABLE ENERGY HYBRIDIZATION

HYDROGEN PRODUCTION, TRANSPORT & STORAGE

GREEN CHEMISTRY

CARBON CAPTURE STORAGE AND APPLICATIONS

MOBILITY ON HYDROGEN

Green H2A (Hydrogen, Ammonia) — IRESEN Institut de Recherche en Energie Solaire et en Energies Nouvelles — MOHAMMED VI POLYTECHNIC UNIVERSITY

LOHC Platform

(Oxy-) Combustion Platform: Mobility & Electricity Production (Hydrogen, Ammonia, eFuels, etc.)

Hydrogen Refueling Station

Green Ammonia Platform

Green Methanol Platform

PtL Platform: Carbon Capture / Fischer Tropsh / Refining

MAIN BUILDING Indoor Laboratories & Offices

H2 Multi-Technology Electrolysers Platform (Alcalin, PEM, SOEC, etc.)


Low Temp. Electrolysis & Fuel Cell Lab. ***PEM-ALC***


Electrolysis & High Temp. Fuel Cell Lab. ***SOEC-SOFC***


Synthetic Fuels Lab. ***PtL***


Combustion Lab. ***COMB***


Water Splitting Lab. ***WATER SPLITTING***

Hydrogen Mobility Lab. ***E-H_2***


Chemistry & Materials Formulation Lab. ***CHEM***

GREEN H2A R&D PLATFORM
INNOVATION TO CO-LOCALIZE PTX INDUSTRY

Green H2A (Hydrogen, Ammonia)

TRL 1 - 3	TRL 4 - 7	TRL 8 - 9	Med-integration
Test range:	Test range:	Test range:	
1kW - 50kW	*~5MW*	*~10MW - 100MW*	*>1GW*
1g - 1kg	*~1 tpd*	*~100 tpd - 1000 tpd*	*>1000 tpd*
	2021	***mid term***	***long term***

R&D
UM6P / IRESEN
and other universities

R&D pilot projects
GreenH2A

MOHAMMED VI POLYTECHNIC UNIVERSITY · Green Energy Park · IRESEN

INDUSTRIAL
Up-Scalling

OCP · *other industries*

MOHAMMED VI POLYTECHNIC UNIVERSITY

IRESEN Institut de Recherche en Energie Solaire et en Energies Nouvelles

GREEN H2A R&D PLATFORM
INNOVATION TO CO-LOCALIZE PTX INDUSTRY

Green H2A
Hydrogen Ammonia


ÉCONOMIE

Hydrogène vert : L'installation du système Power-to-X µPilot achevée

M.T. | 14 septembre 2022 à 14:01

DERNIÈRE HEURE /

Mondial Qatar 2022 : La RAM lance 3.000 billets d'avion à...

Fonds d'équipement communal : 1,3 milliard de...

Le nouveau SUV Honda HR-V lancé sur le marché marocain

Légation américaine de Tanger : le projet de...

Le rappeur américain Coolio, auteur du succès planétaire...


challenge.ma/liresen-installe-son-1er-systeme-de-production-dhydrogene-vert-a-lechelle-micro-pilote-245306/

ECONOMIE DÉCIDEURS DOSSIER MAGAZINE AUTOMOBILE ARCHIVES CHALLENGE LIVE

L'IRESEN installe son 1er système de production d'hydrogène vert à l'échelle Micro-Pilote

ROLAND AMOUSSOU · 14 SEPTEMBRE 2022

SYMPOSIUM de L'EAU
5 OCTOBRE 2022 9h - 14h
Salle d'exposition
Anfa Park, Casablanca


pv-magazine.fr/2022/09/19/liresen-presente-un-electrolyseur-alimente-en-energie-solaire/

L'IRESEN présente un électrolyseur alimenté en énergie solaire

Dans le cadre de son projet « Power-to-X µPilot », développé avec l'Université Mohammed VI Polytechnique (UM6P) au Maroc, l'institut va tester son premier électrolyseur sous charge variable d'électricité renouvelable. Le projet pilote se veut un outil de recherche et d'innovation et un élément central dans la mise en place de formations techniques et technologiques sur l'hydrogène vert au Proche-Orient et en Afrique.

SEPTEMBRE 19, 2022 MARIE BEYER

HYDROGÈNE INNOVATION TECHNOLOGIE ET R&D FRANCE

Hi-MO 5 LONGi
Le meilleur choix pour les toitures solaires

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PtX µPilot unit: Research & Capacity Building

Institut de Recherche en Energie Solaire et en Energies Nouvelles

GREEN H2A R&D PLATFORM
INNOVATION TO CO-LOCALIZE PTX INDUSTRY

IRESEN Institut de Recherche en Energie Solaire et en Energies Nouvelles

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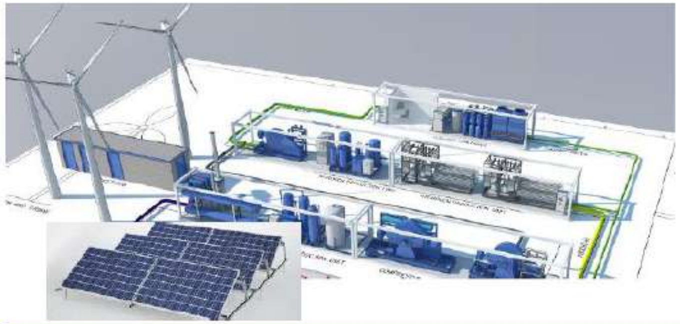
CLUSTER GREEN H2 RECHERCHE - INNOVATION - INDUSTRIE

Capacity Building & Dissemination:

GREEN H2A R&D PLATFORM
INNOVATION TO CO-LOCALIZE PTX INDUSTRY

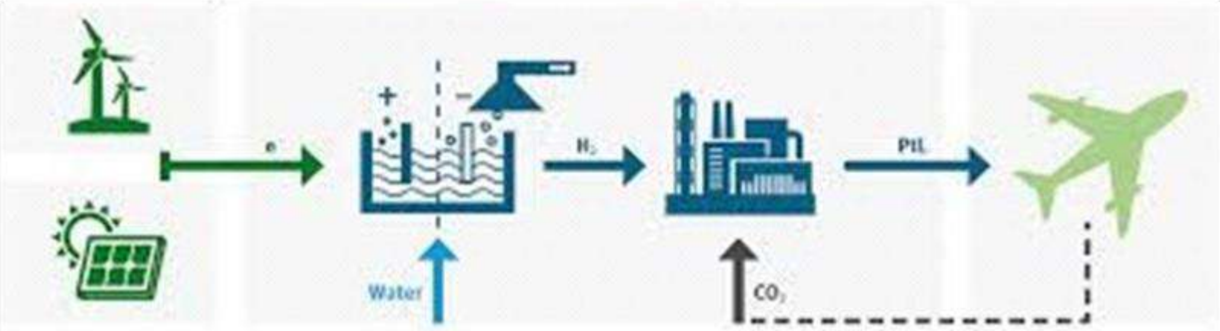


- Project « Green Ammonia Pilot Plant »
- Capacity : ~ 4 MWe || ~4Tonnes/jour
- Objectives:
  - Assessment of technologies
  - Scale-Up feasibility

GREEN H2A R&D PLATFORM
INNOVATION TO CO-LOCALIZE PTX INDUSTRY

Green H_2A (Hydrogen, Ammonia)

MOHAMMED VI POLYTECHNIC UNIVERSITY · IRESEN · Agora Energiewende · CSIR · DECHEMA · giz

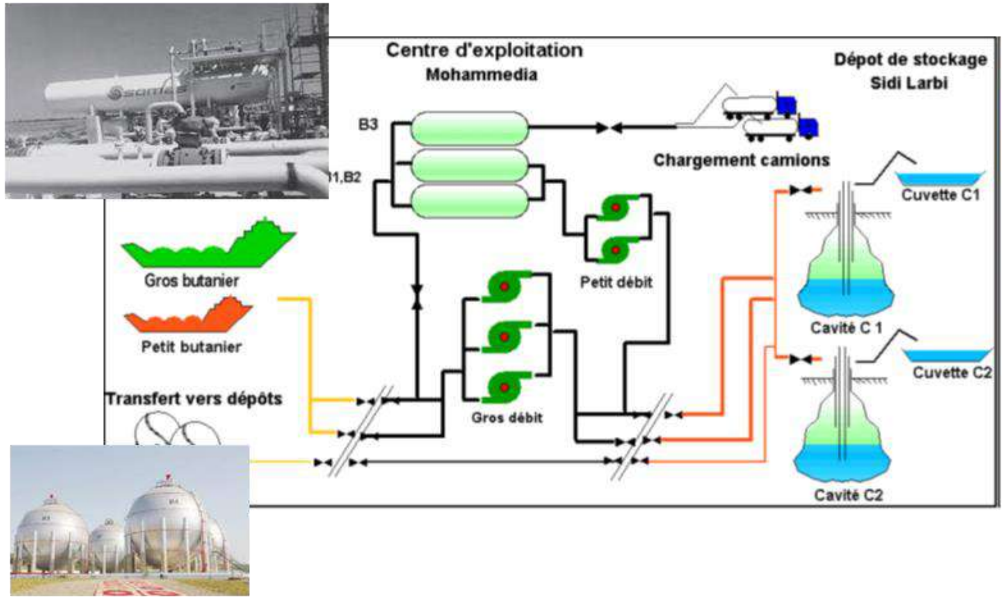


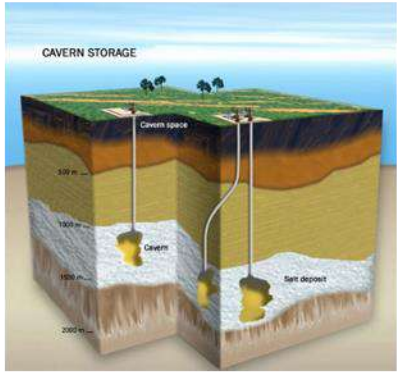
- Project « PtX Pathways » (Power-To-Liquid – PtL)
- Capacity: ~ 1 MWe || ~100kg-1ton/day
- Objectives:
  - Technology Assessment
  - Scale-Up Perspectives
  - Applications: Local Market and Exports

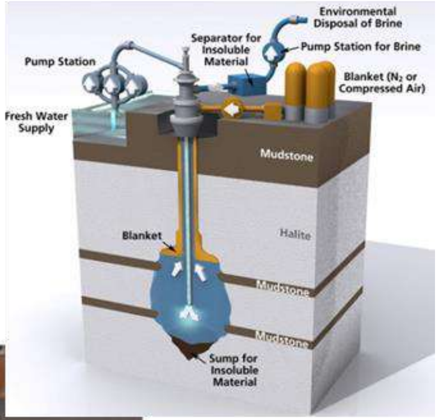
GREEN H2A R&D PLATFORM
INNOVATION TO CO-LOCALIZE PTX INDUSTRY

Green H2A
Hydrogen Ammonia

HDF ENERGY · enagas · SOMAS الشركة المغربية للخزن SOCIÉTÉ MAROCAINE DE STOCKAGE · Park green energy · Université Ibn Tofaïl





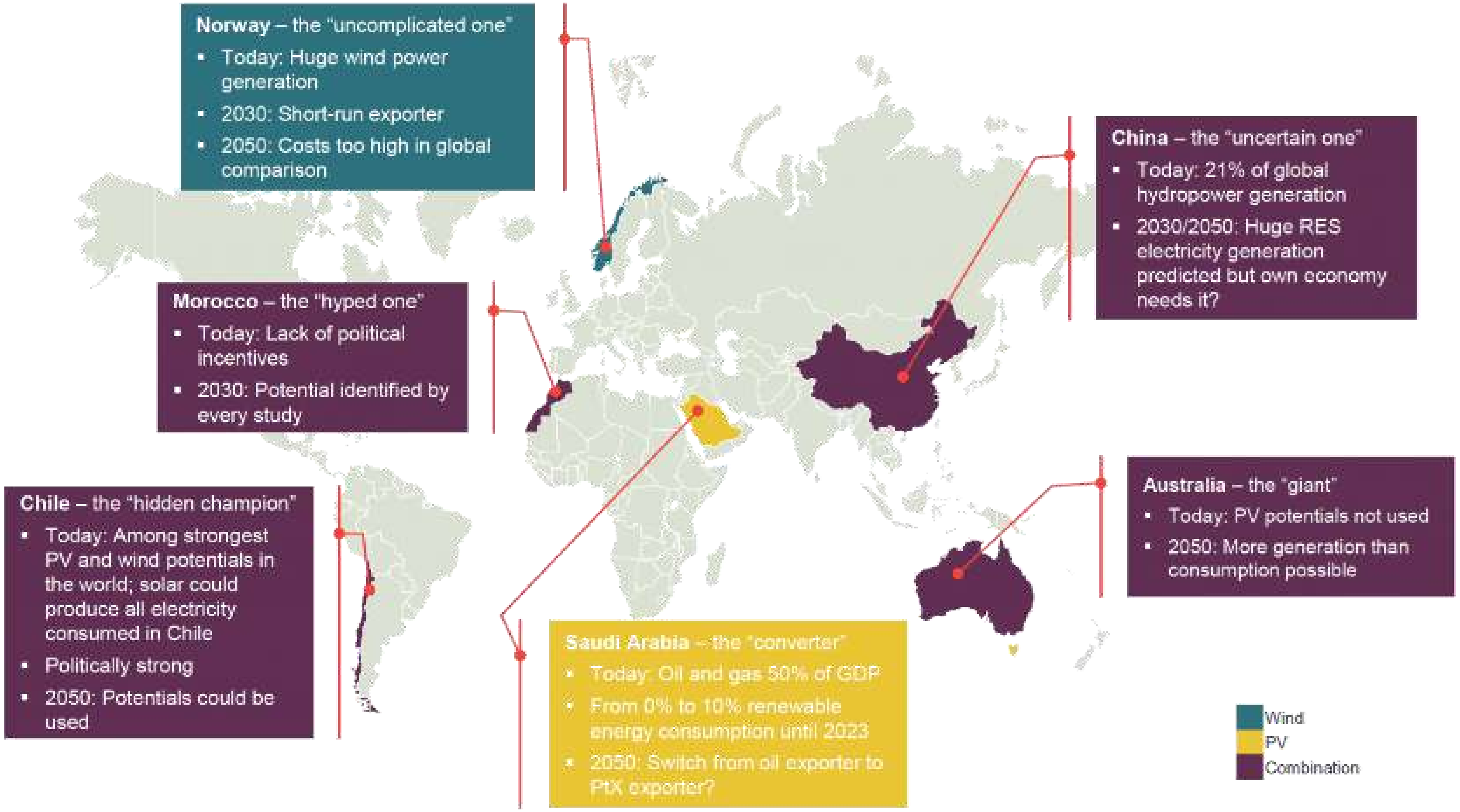


- Projevt « MELHY »
- Objective: Feasibility Study of Storing Green Hydrogen in Moroccan Salt Caverns

HYDROGÈNE VERT AU MAROC : CHEMIN PARCOURU À CE JOUR

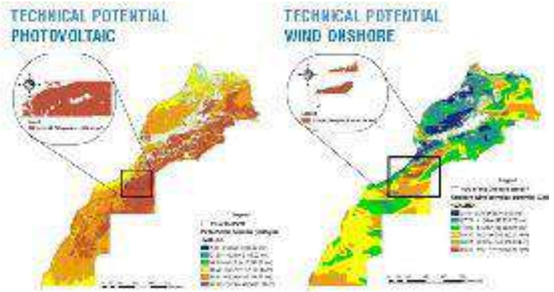
EXPORT POTENTIAL FOR PTX PRODUCTS: FRONTRUNNER POSITION

Source : World Energy Council Germany, Frontier Economics 2018 Study
Fraunhofer ISI, Etude Opportunités PtX pour le Maroc, 2019



MOROCCAN POSITIVE CONTEXT

HIGH REN. POTENTIAL



	Photovoltaic (PV)	Wind Onshore
Technical Potential (TWh)	49 000	11 500
Technical Potential (GW)	20 000	6 000
5% of the Tech. Pot. (GW)	1 000	300

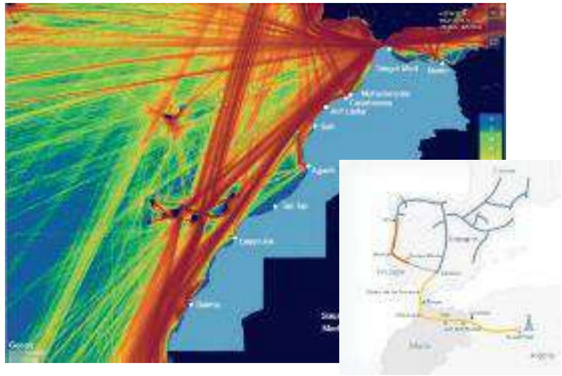
STRONG POLITICAL SUPPORT & INTERNATIONAL PARTNERSHIP

SUCCESSFUL DEPLOY. OF REN.

GROWING R&D INFRASTRUCTURE AND CAPACITY BUILDING

INVOLVMENT OF THE INDUSTRY AND THE PRIVATE SECTOR

STRONG PROXIMITY + MARITIME & GAS CONNECTIVITY WITH EU



GREEN HYDROGEN IN MOROCCO: FIRST STEPS, INITIATIVES & DRIVERS

3 important studies conducted since 2018 on « H2 - Power to X in Morocco »

MARKET & TECHNOLOGIES

with Fraunhofer IMWS

Keywords: Electrolysis, Green Hydrogen & Ammonia

OPPORTUNITIES & POTENTIAL FOR MOROCCO

with Fraunhofer ISI

Keywords: H2 / PtX Potential, Grid, Infrastructure, Impact, Exports

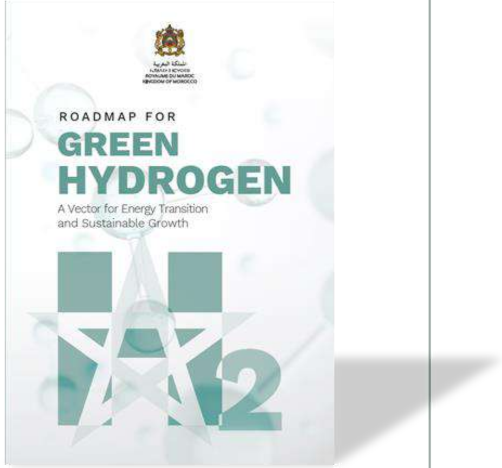
MOROCCO'S PTX 2050 ROADMAP

with frontier economics

Keywords: R&D, Innovation & Industrial opportunities

NATIONAL GREEN H2 STRATEGY

Published in August 2021



MOROCCO-EU Partnership

Morocco signed an agreement with Germany in June 2020 ,to develop a regional market of PtX

COMMISSION NATIONALE HYDROGENE

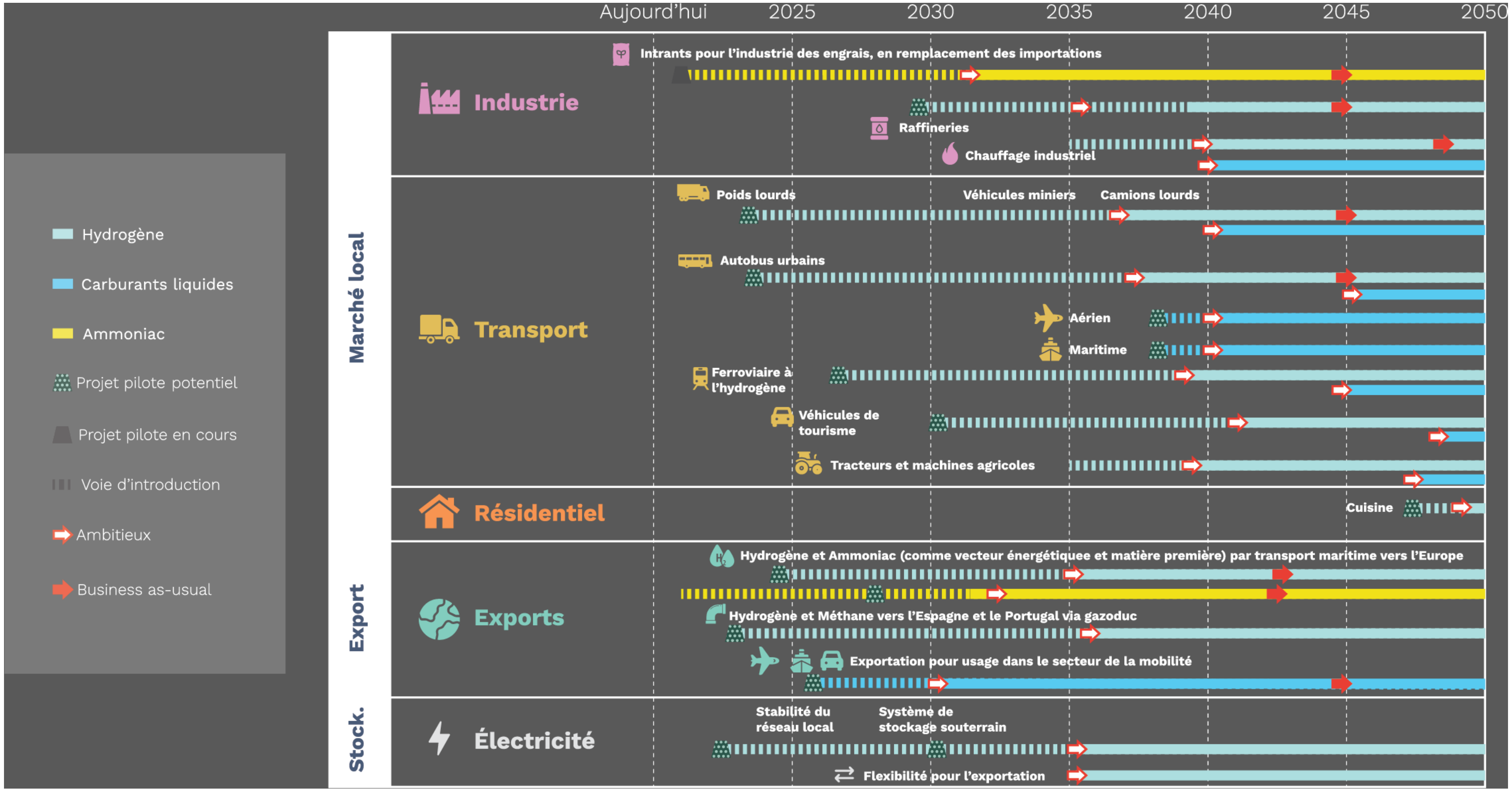
Creation of a National Commission for Power-to-X by the Moroccan Energy Ministry on Feb. 11th, 2019

CLUSTER GREEN H2

Creation of an industrial Green Hydrogen Cluster

GREEN HYDROGEN IN MOROCCO: ROADMAP (1/4)

Market Opportunities & Applications



GREEN HYDROGEN IN MOROCCO: ROADMAP (2/4)

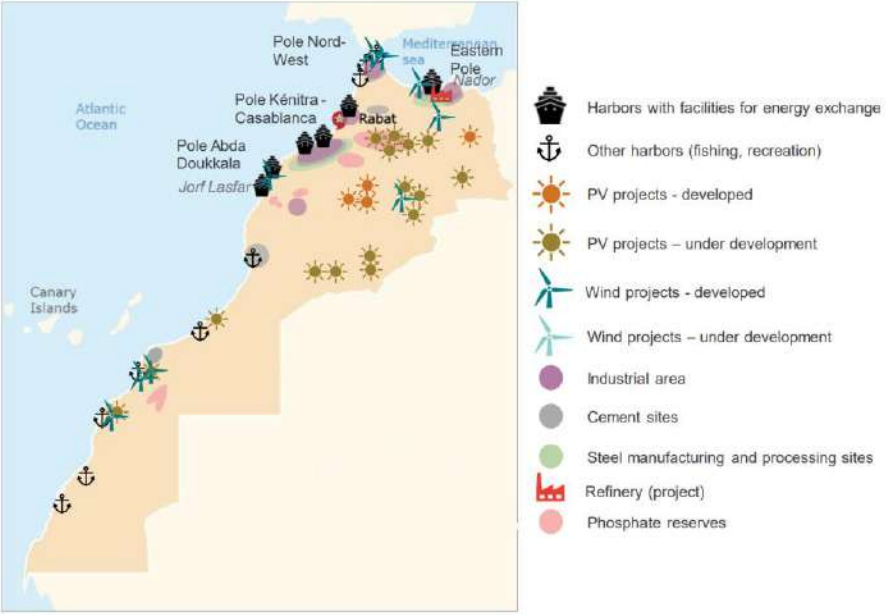
Sustainable framework to develop the **PtX industry** in Morocco & **Action Plan**

1. **Facilitating costs reduction** along the PtX value chain.
2. **R&D:** Setting-up a **Moroccan** and **international research cluster**.
3. Defining the relevant measures for **local content**.
4. Setting-up an industry cluster and develop related **infrastructure masterplan**.
5. **Securing financing** to developing the PtX industry.
6. Creating the **conditions for exporting PtX** products from Morocco.
7. **Assessing** in detail a **storage** plan for the electricity sector.
8. Developing **domestic markets.**

Source : Frontier Economics

Set up an **Industry Cluster** & develop related **infrastructure masterplan**

Location of renewable energy sources, industry and ports



Source: Frontier Economics based on Masen (2020) for RES deployment, the Ministry of Industry (2020) for industry location, Ministry of Transport (2011) for harbours , Ayad, A. et al. (2019) for phosphate reserves and CemNet (n.d.) for cement sites.

- The locational array of the PtX industry strongly determines infrastructure requirements and associated costs.
- Developing the industry in clusters may enable synergies in the use of infrastructure and lead to cost savings.
- Four options appear possible for Morocco:

Cluster	RES-E generation	RES-E transport	Carbon procurement	Hydrogen pipeline	Harbor adaption
South-South					
South-North (via H2)					
South-North (via electricity)					
North-North					

Drivers of cost differences

Recommended actions (short term)

- Conducting technical and cost studies to choose the cluster (or clusters) and its **related infrastructure**.
- Including **PtX in "Special Economic Zones" (SEZ)**, define its legal framework and market design
- **Assessing grid needs** and lead the dialogue on PtX grid access terms

GREEN HYDROGEN IN MOROCCO: ROADMAP (4/4)

CLUSTER GREEN H2

RECHERCHE - INNOVATION - INDUSTRIE

The main object of the GreenH2 Cluster is to promote the hydrogen sector in Morocco through the initiation, support and coordination of innovative collaborative projects in the field of green hydrogen in the Kingdom of Morocco and abroad, in order to encourage innovation and contributing to the emergence of a competitive hydrogen sector.

- Strengthen the technical and technological capacities of national players to produce, use and enhance hydrogen
- Develop innovation in the hydrogen sector
- Supporting national industries
- Support the National Hydrogen Commission in creating a regulatory and incentive framework for the development of the hydrogen industry
- Encourage and develop the production of hydrogen in Morocco
- Contribute to the promotion of Moroccan hydrogen on a regional and international scale

Kingdom of Morocco
Ministry of Energy, Mines and Environment

Kingdom of Morocco
Ministry of Industry, Commerce and Green and Digital Economy

Kingdom of Morocco
Ministry of National Education, Vocational Training, Higher Education and Scientific Research

Kingdom of Morocco
Ministry of Equipment, Transport

ONHYM · Fédération de l'Energie · OCP · masen · IRESEN · amee · UEMF · MAScIR · green energy · NAREVA · MAGHREB STEEL · AFRIQUIA · AKWA GROUP · Air Liquide · SNEP · enel · Sumitomo Corporation · ACWA POWER · Vestas · ENGIE · John Cockerill · BASF · thyssenkrupp · EDF · AAQIUS · SIEMENS energy

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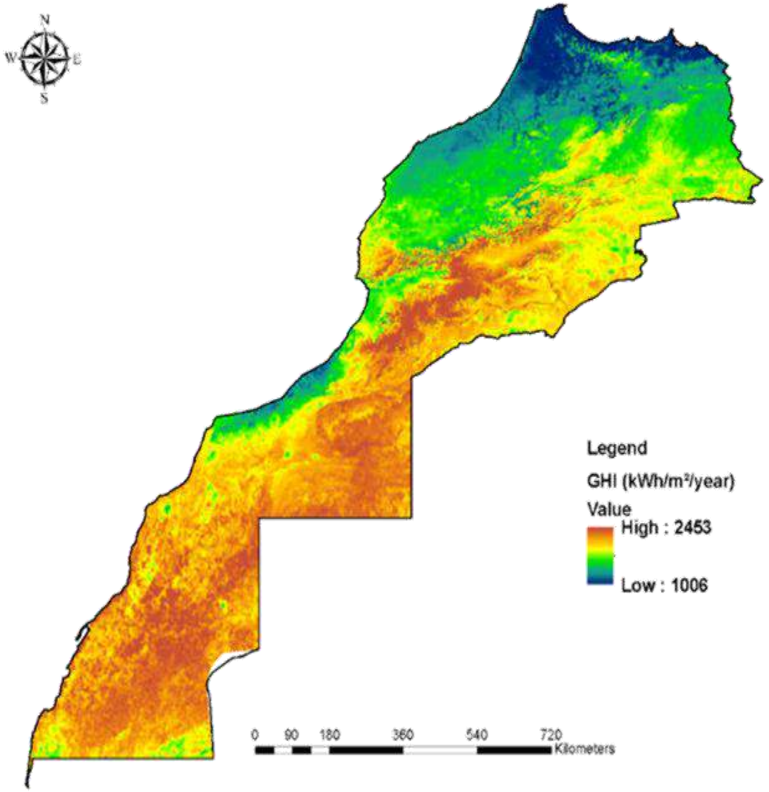
Institut de Recherche en Energie Solaire et en Energies Nouvelles

“GREENH2 MAROC” CLUSTER

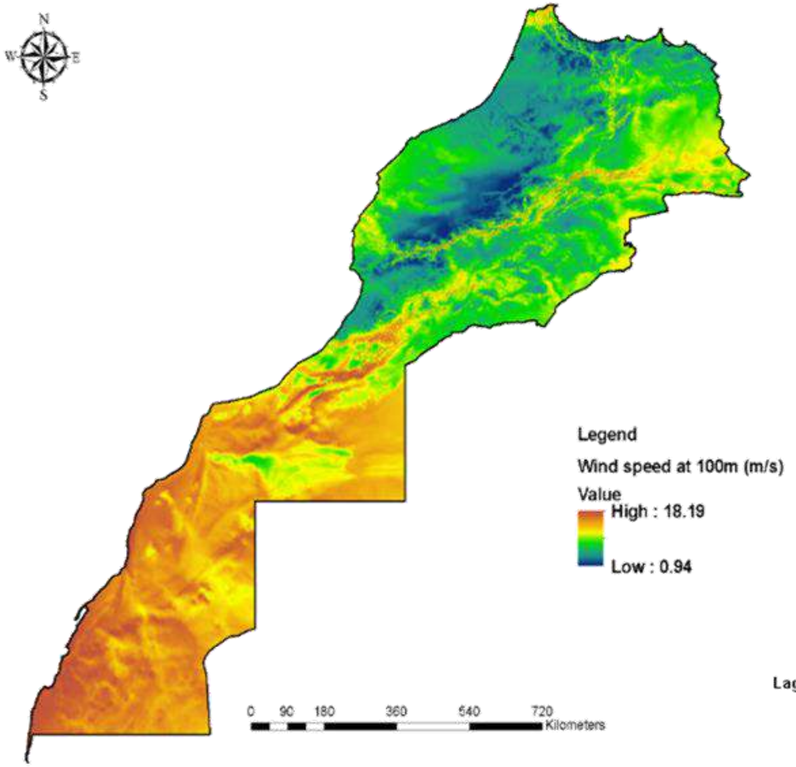
HYDROGÈNE VERT AU MAROC :
LE POTENTIEL ET LES OPPORTUNITÉS

POTENTIAL GREEN HYDROGEN VALLEYS IN MOROCCO

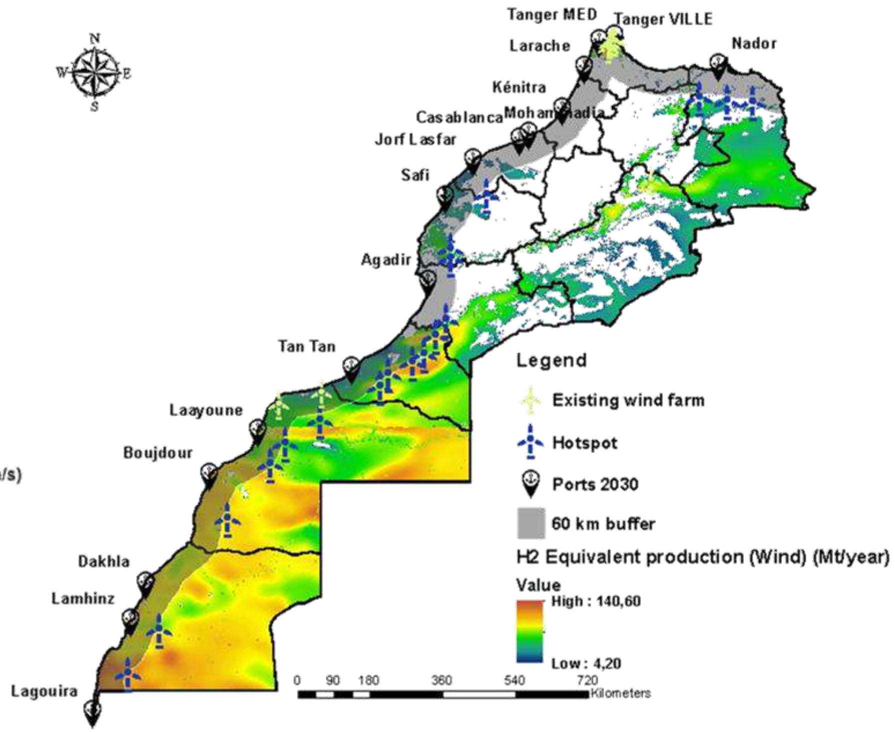
CRITERES DE SELECTION ÉNERGIE SOLAIRE PV



: Carte du rayonnement solaire global

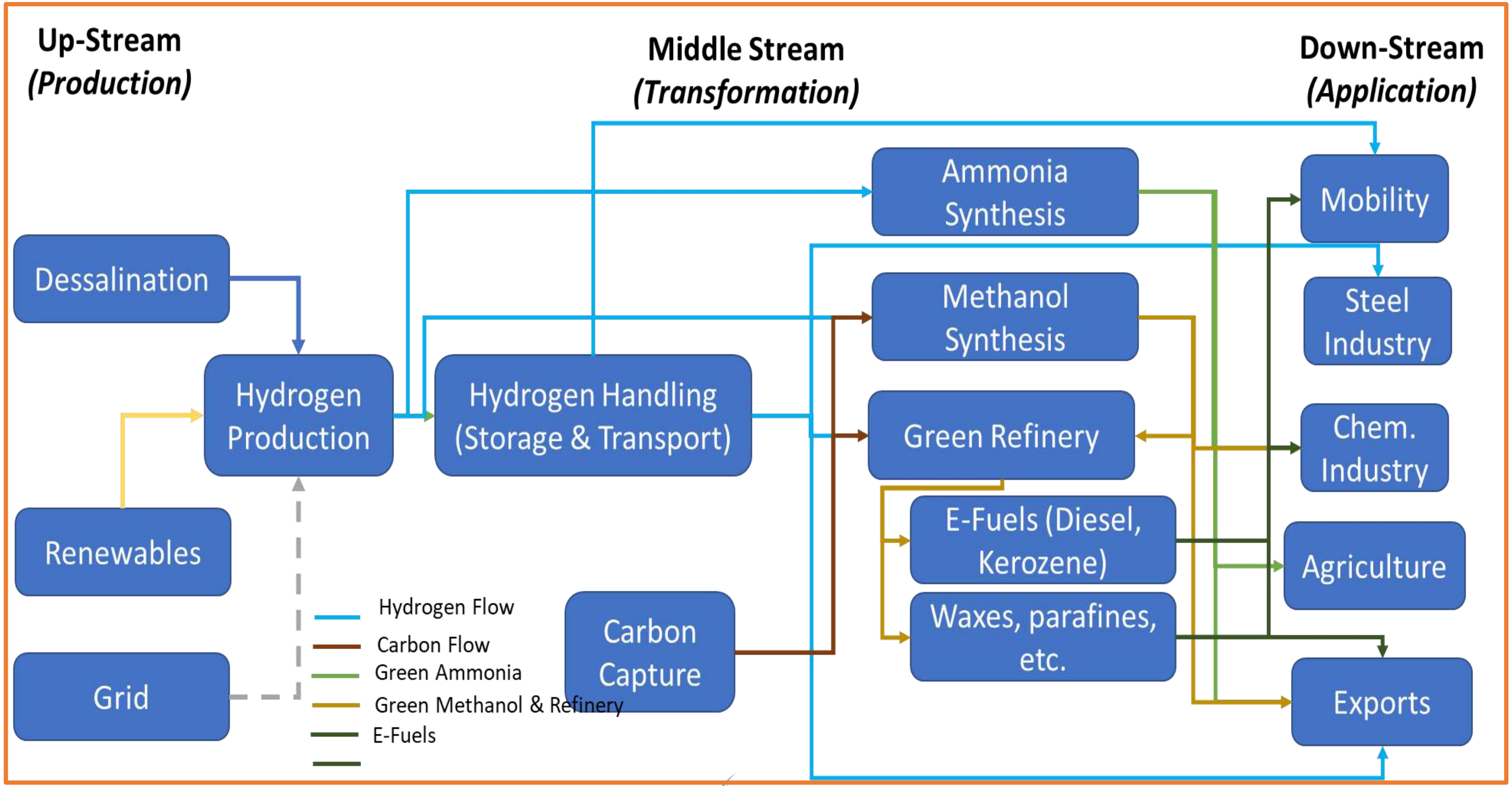


Carte de la vitesse du vent



Superposition + Infrastructure portuaire

HYDROGÈNE VERT: UNE CHAINE DE VALEUR INDUSTRIELLE



POTENTIAL GREEN HYDROGEN VALLEYS IN MOROCCO

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POTENTIAL GREEN HYDROGEN VALLEYS IN MOROCCO

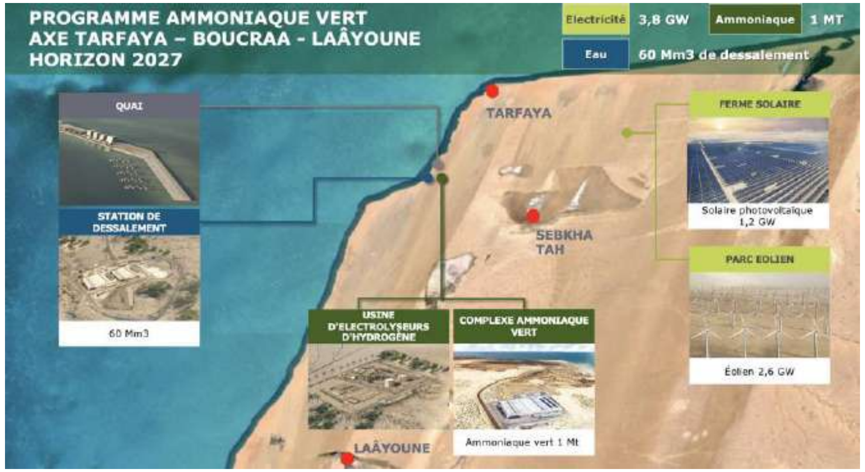
POTENTIAL GREEN HYDROGEN VALLEYS IN MOROCCO

HYDROGÈNE VERT AU MAROC: CONCLUSIONS

- Le Maroc possède un grand potentiel pour produire des molécules vertes à un coût compétitif
- Le Maroc a été pionnier et proactif dans la région pour l'exploration de son potentiel et de préparer les étapes nécessaires pour le déploiement de cette économie à forte valeur ajoutée
- Suite à la réunion du 22/11/2022, SM Le Roi que Dieu l'Assiste a donné Ses Hautes Instructions pour préparer l'Offre Maroc de l'Hydrogène Vert sur l'ensemble de la chaine de valeur

HYDROGÈNE VERT AU MAROC: PERSPECTIVES

- Exporter des molécules industrielle à haute valeur ajoutée (Marché à terme ~$1000 Mds)
- Décarboner l’économie locale:
  - Exemple → Annonce du dernier plan d’investissement du Groupe OCP:
  - 1MT d’Ammoniac Vert d’ici 2027, ~ 4GW de Puissance Renouvelables, ~ 2GW de Capacité d’Electrolyse
- Co-Localisation d’une chaine de valeur industrielle : pointue, propre et à fort Impact!
  - Annonce de la ‘Gigafactory’ d’Electrolyseurs de John Cockerill (04/01/2023)
  - Perspectives: Industrie EnR, Dessalement, Acier, Methanol et Chimie Lourde, etc.




lecho.be

L'Echo

ACTU > ENTREPRISES > ENERGIE

John Cockerill investit dans la filière hydrogène au Maroc

Après un investissement annoncé sur ses terres liégeoises, John Cockerill conclut un accord stratégique pour développer la filière hydrogène au Maroc. ©Valentin Bianchi / Hans Lucas

LOUISE RENSON | 04 janvier 2023 18:24

John Cockerill a conclu un accord stratégique avec une entreprise marocaine pour développer la filière hydrogène au Maroc. Point majeur de

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10 ans au service de la recherche et de l'innovation

Thank you for your attention

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“GreeN H2”

Dr. Chokri Boumrifak
DACHEMA

Germany

GreeN H2

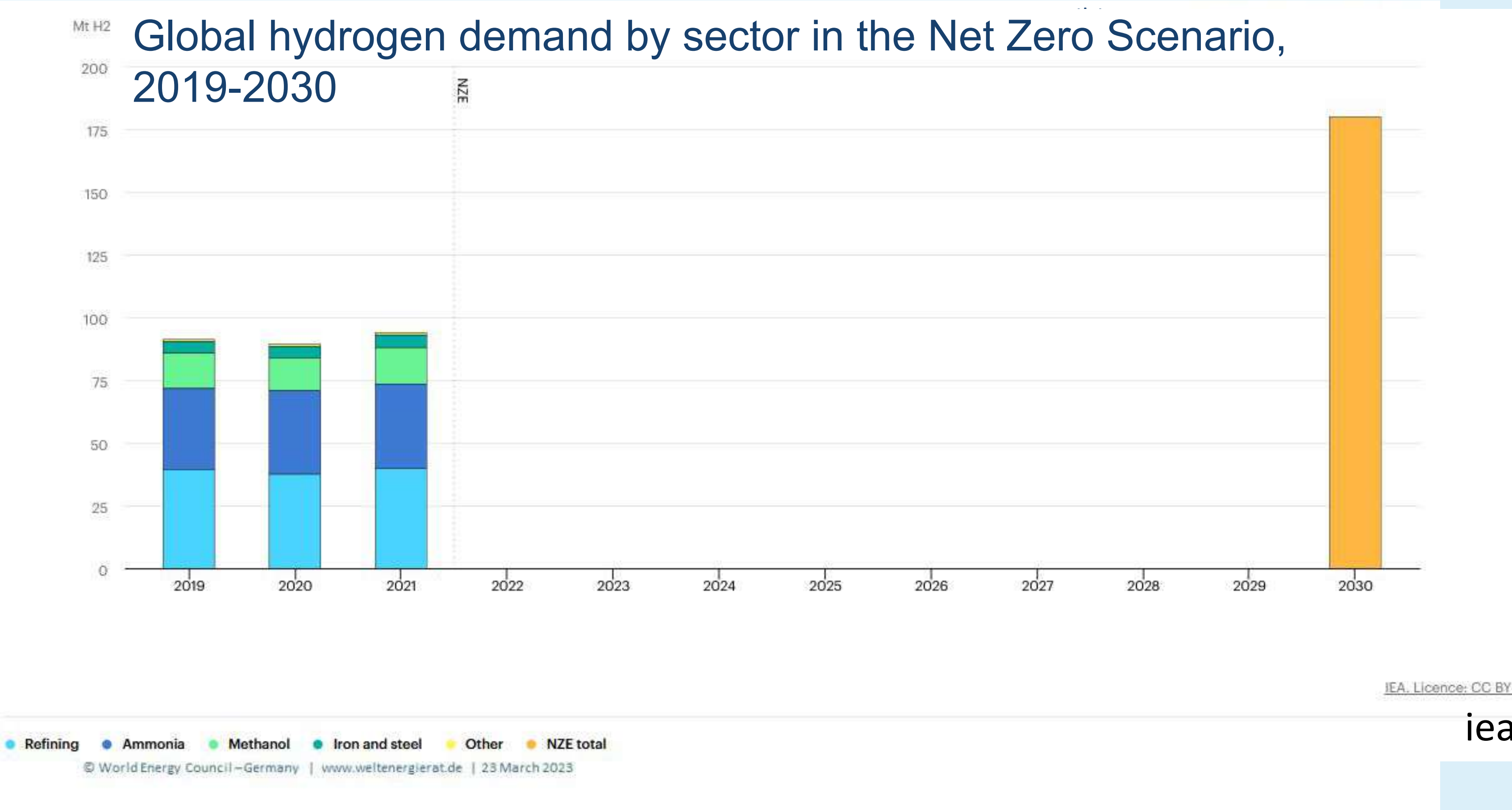
23.05.2023

DECHEMA
Gesellschaft für Chemische Technik und Biotechnologie e.V.

Institute for Social-Ecological Research

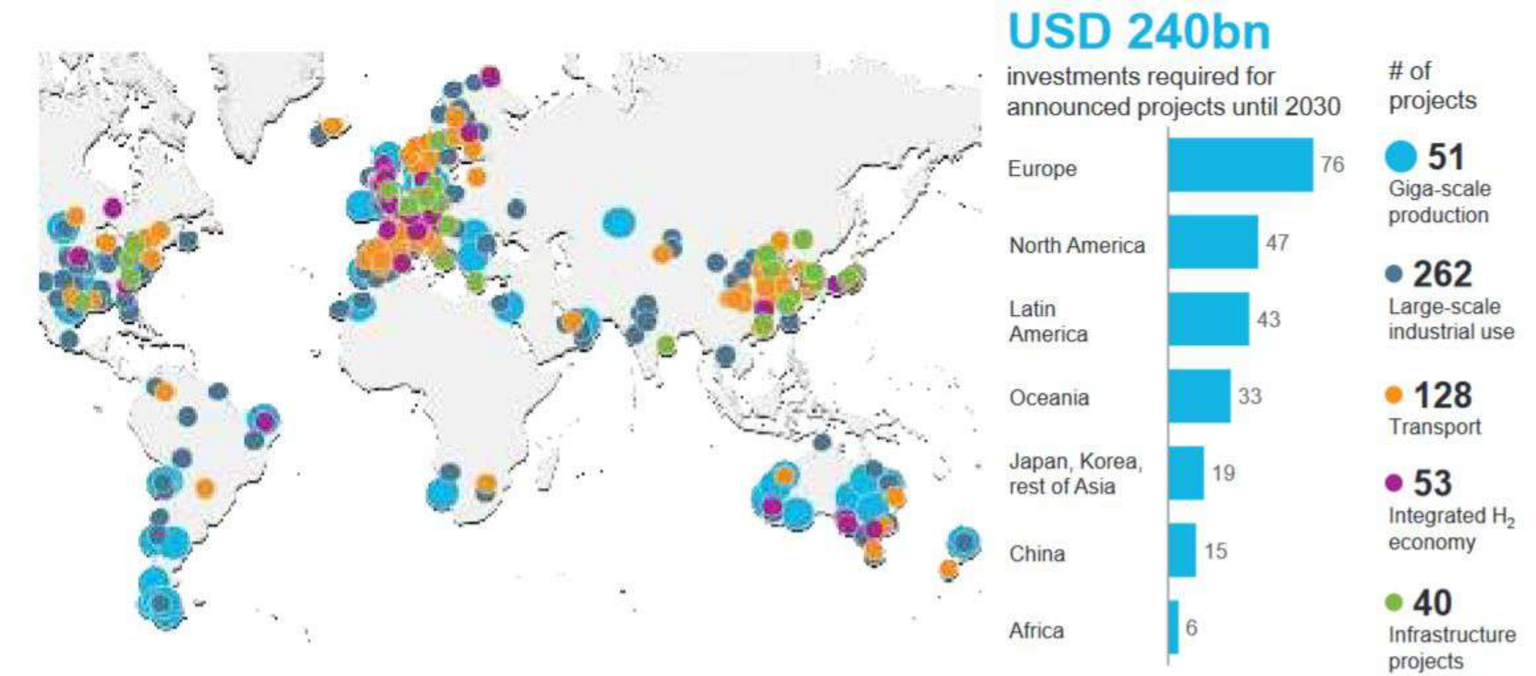
German-African Green Hydrogen Forum | Dr. Chokri Boumrifak

- 2020 was called the year of the strategies
- The demand for H_2 will definitely rise
- Potentials for green H_2 production is especially high in the global south
- Where will all the green H_2 come from?



H2 Investments

- Increasing Investments in H_2 projects
- H_2 projects mainly clusterd in the western world
- Global south with high potentials and low production costs



Hydrogen Council, McKinsey & Company, 2022

Africa‘s green energy potential

Source: Africa’s green energy revolution - Hydrogen’s role in unlocking Africa’s untapped renewables; report 2022

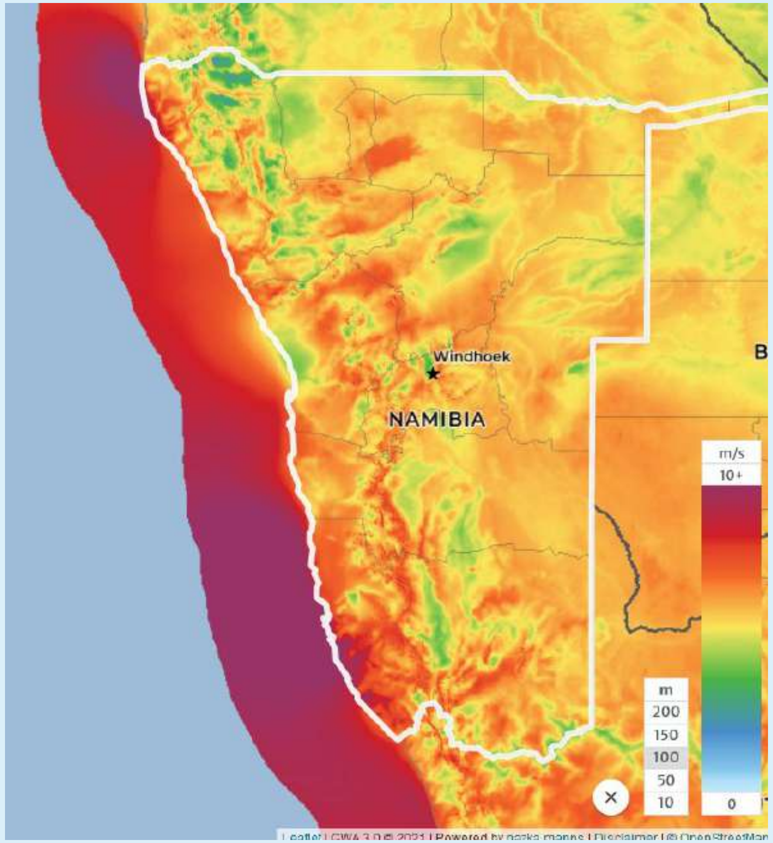
Namibia‘s main economic sectors

Today: mining,
fisheries,
agriculture and tourism

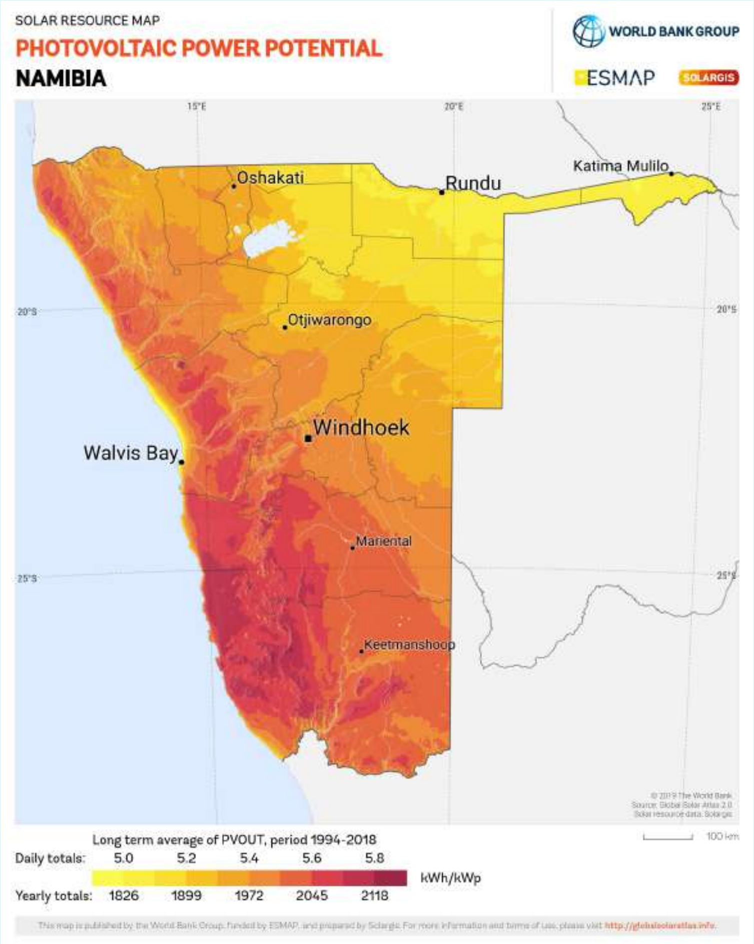
In the future:
hydrogen production

Great potential for renewable energies

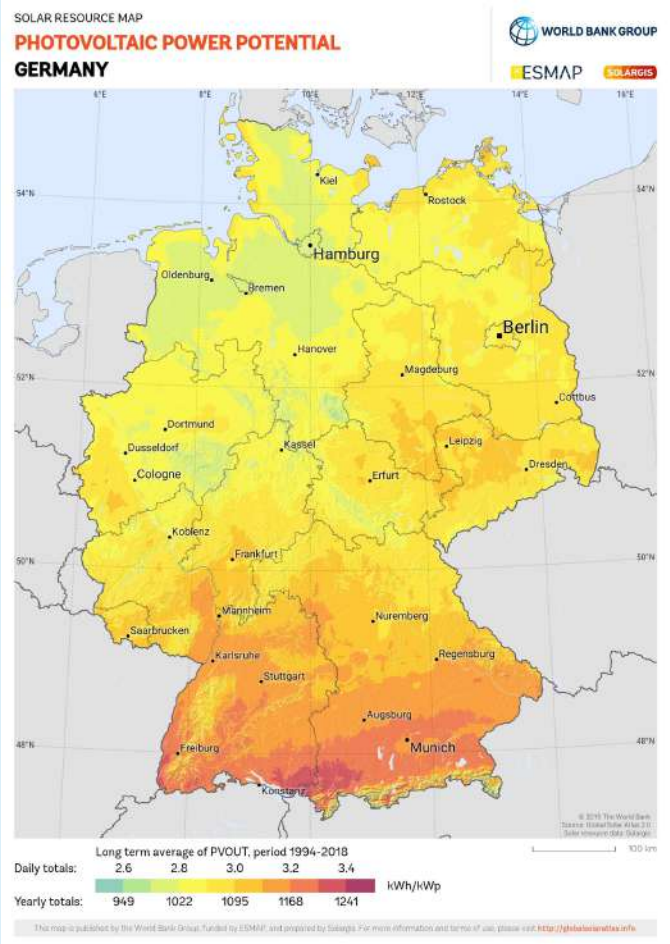
Wind and sun en masse



https://globalwindatlas.info/en/area/Namibia

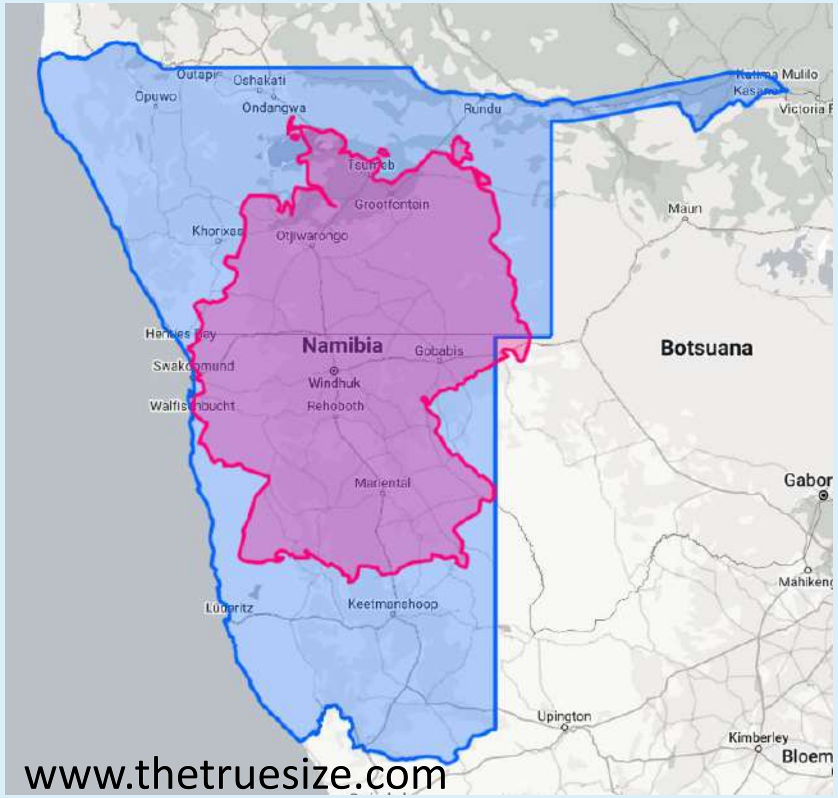


https://globalsolaratlas.info/download/namibia



Direct Comparison

- GER: 357,114 km² with 80 Mio residents
- NAM: 825,615 km² with 2 Mio residents



- Large potentials
- Small population
- Namibia‘s own demand should be covered

GreeN H2 - Namibia

The GreeN-H2 project bridges the gap between government and private initiatives and is dedicated to answering fundamental questions about the

- Infrastructure
- Stakeholders involved
- Economy

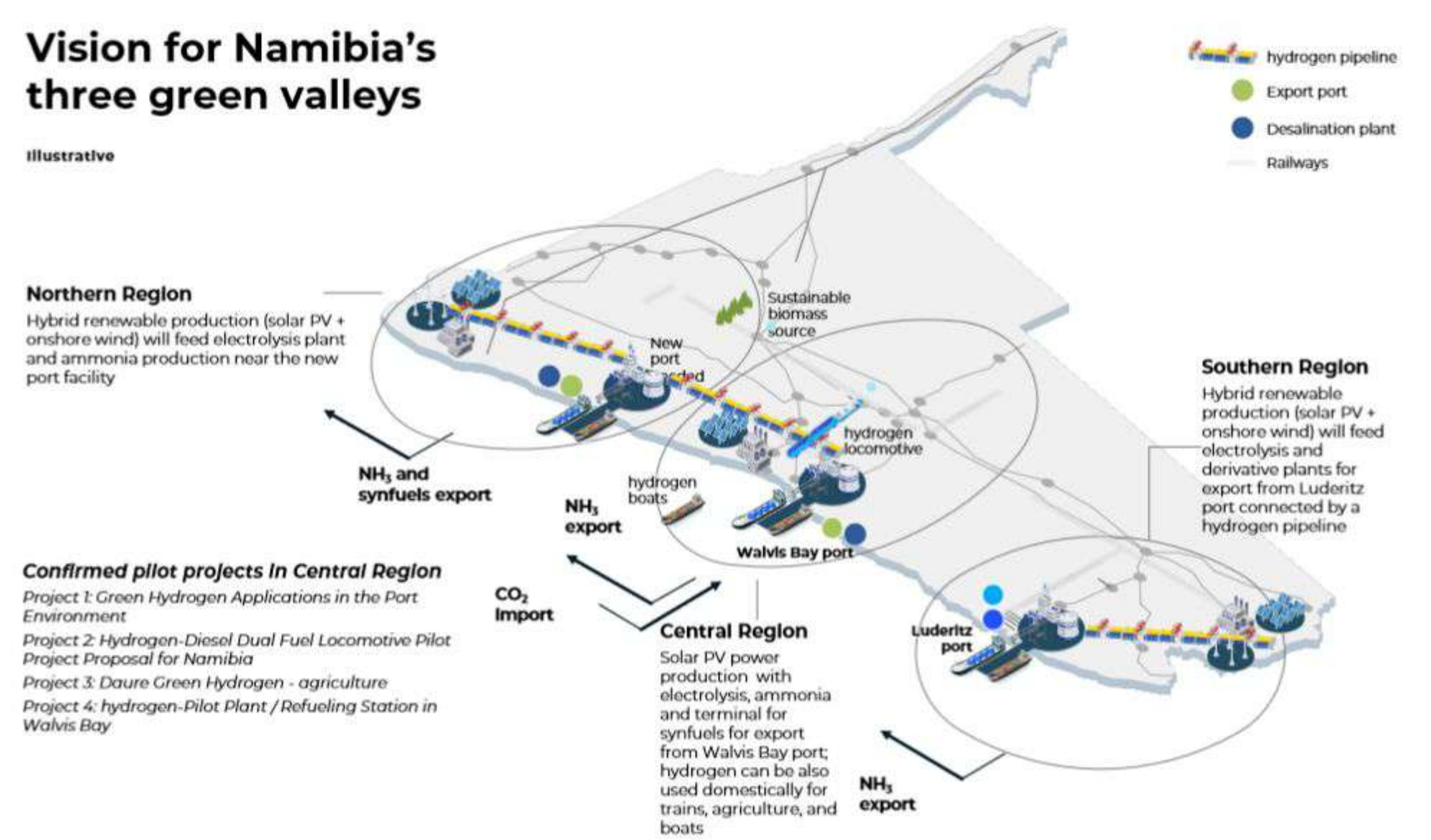
Project period: 01.10.2022 – 31.03.2025

Partner: DECHEMA & ISOE

Technical aspects

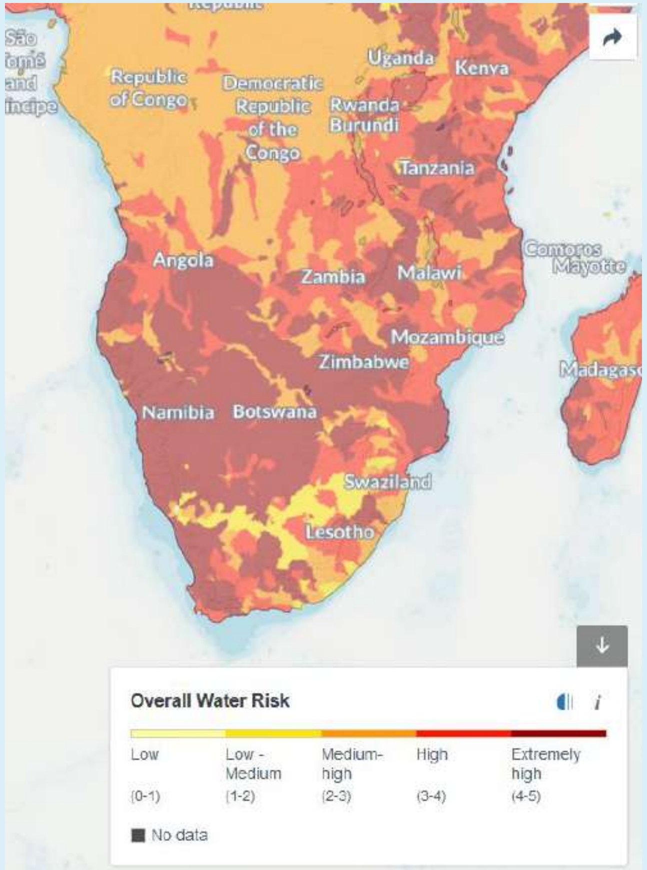
- Identification of the current state of energy and water supply
- Identification of sites for the hydrogen economy
  - Water, energy issues
- Requirements for production, storage, transport and refinement of hydrogen

Close look at complete value chains



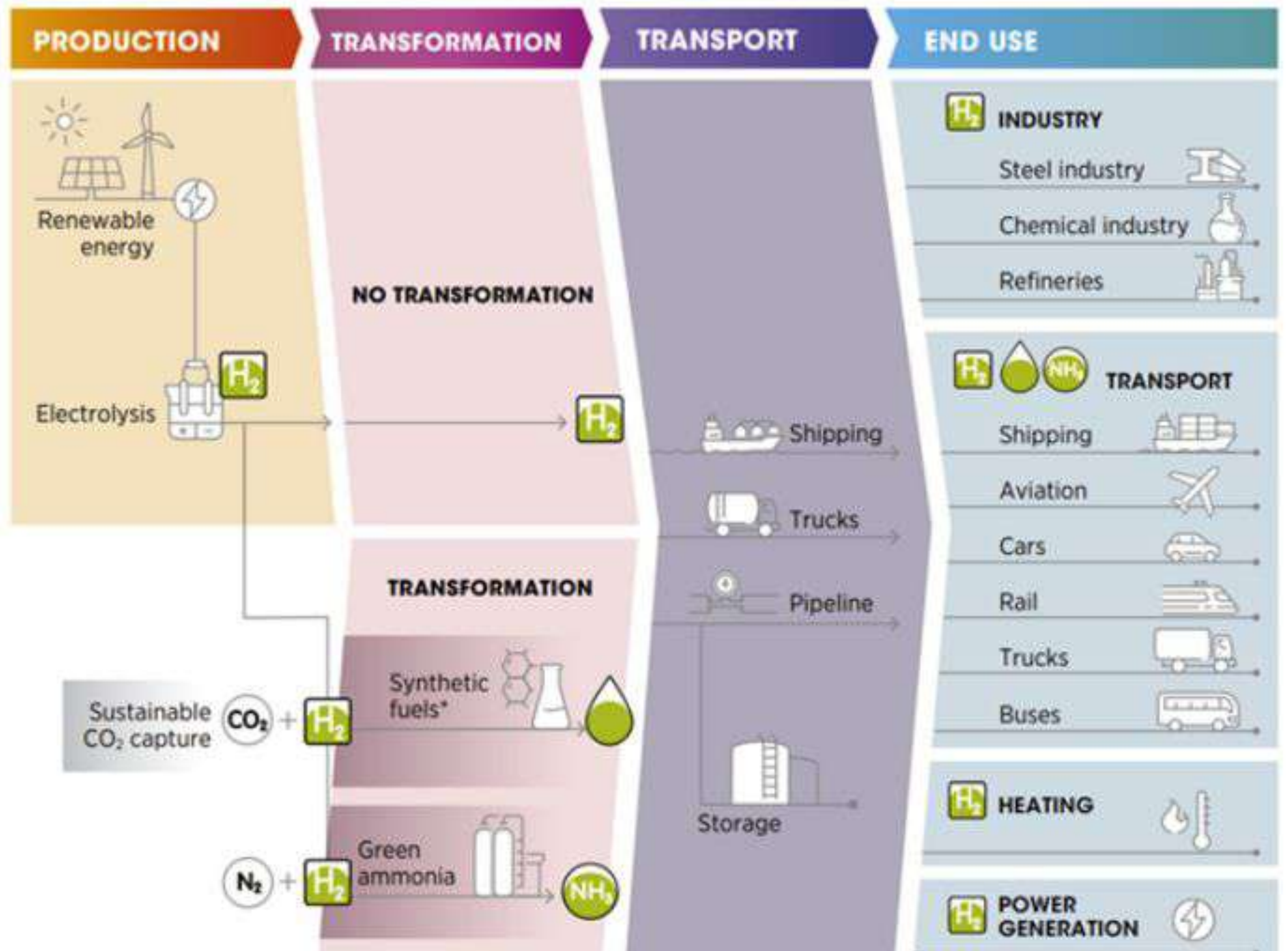
Green Hydrogen and Derivatives Strategy, Ministry of Mines and Energy Namibia

- GreeN H2 focuses on energy sources, infrastructure, water management, hydrogen production and PtX routes.
- Especially the developments in Namibia’s energy sector and measures against water scarcity.
- Operational requirements, such as maintenance, waste management (e.g., lye of alkaline electrolysis), heat management etc., will be assessed.



https://www.wri.org/applications/aqueduct/water-risk-atlas

- An overall assessment will be applied to analyse the costs concerning CapEx and OpEx of an allocated hydrogen production.
- The Considered products within the scope of the study will include: Fischer-Tropsch (FT-diesel, -gasoline, -naphtha), methane, methanol and ammonia.
- Additionally, potential CO_2 demand and sources for PtX processes will be evaluated.

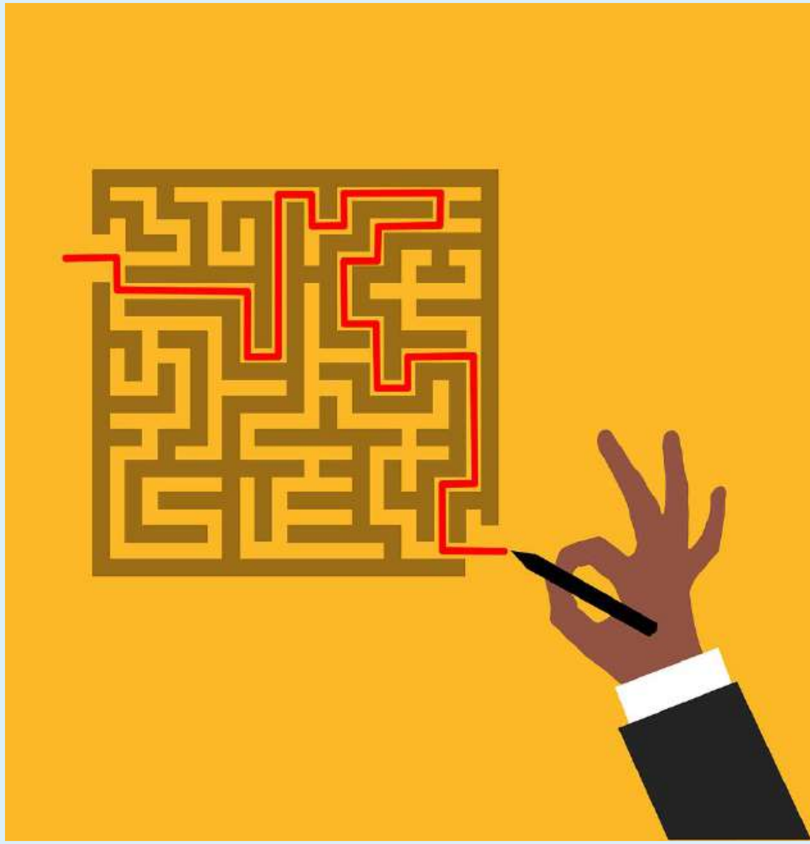


IRENA

Transformation management

- Creation of desirable and sustainable scenarios for the hydrogen economy in Namibia.
- Identification of barriers & risks of the transformation of the energy sector, incl. ecological and social impacts
- Supplementary market and cost considerations

- The description of socio-ecological transformation on a national and micro scale
- The study displays desirable and sustainable future target scenarios of green H_2 production, processing and distribution in Namibia and identifies transformation pathways to achieve the target scenarios
- socio-ecological impacts, transformation barriers as well as measures that to prevent risks and overcome barriers.
- Evaluation of regulatory aspects and cost trends in the sector.



Current state

- Stakeholder engagement
- First publications (June 2023):
  - Brine report
  - Overview about the Namibian energy sector

Our team

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“Report on seawater desalination, brine treatment, disposal options and its potential impacts on maritime life”

Robert Schmidt
DACHEMA

Germany

Report on seawater desalination, brine treatment, disposal options and its potential impacts on maritime life

GreeN H2

24.05.2023

Robert Schmidt

DECHEMA
Gesellschaft für Chemische Technik
und Biotechnologie e.V.

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GreeN-H2 - Namibia

The GreeN-H2 project bridges the gap between government and private initiatives and is dedicated to answering fundamental questions about the

- Infrastructure
- Stakeholders involved
- Economy

Objective:

Support Namibia in the build-up and identification of green-H2 platforms for their ambitious aim to become a relevant global player.

Duration: 01.10.2022 – 31.03.2025

Background:

Hydrogen Partnership between Namibia and Germany, part of BMBF funding scheme for Green Hydrogen in Namibia, including pilot projects and a exchange scholarship program

DECHEMA
Gesellschaft für Chemische Technik und Biotechnologie e.V.

Institute for Social-Ecological Research

Funding & Cooperation

SPONSORED BY THE
Federal Ministry of Education and Research

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management

Current Satus of Green Hydrogen Industry in Namibia

First projects start working:

- 4 Projects funded by the BMBF
  - Daures Green Hydrogen Village Project → Phase 1: 31 t H_2/a; …; Phase 4: 60,544 t H_2/a
  - Refueling Station in Walvis Bay → 5 MW Electrolyser, ~300 t H_2/a
  - Green Hydrogen Applications in the Port Environment → 5 MW Electrolyser, ~300 t H_2/a
  - Hydrogen-Diesel Dual Fuel Locomotive

Visions and current goals on a national scale:

HYPHEN	→	0.35 Mt H_2/a	by 2030
SCDI	→	3 Mt H_2/a	by ?
Namibia GH2 Strategy	→	10 – 12 Mt H_2/a	by 2050

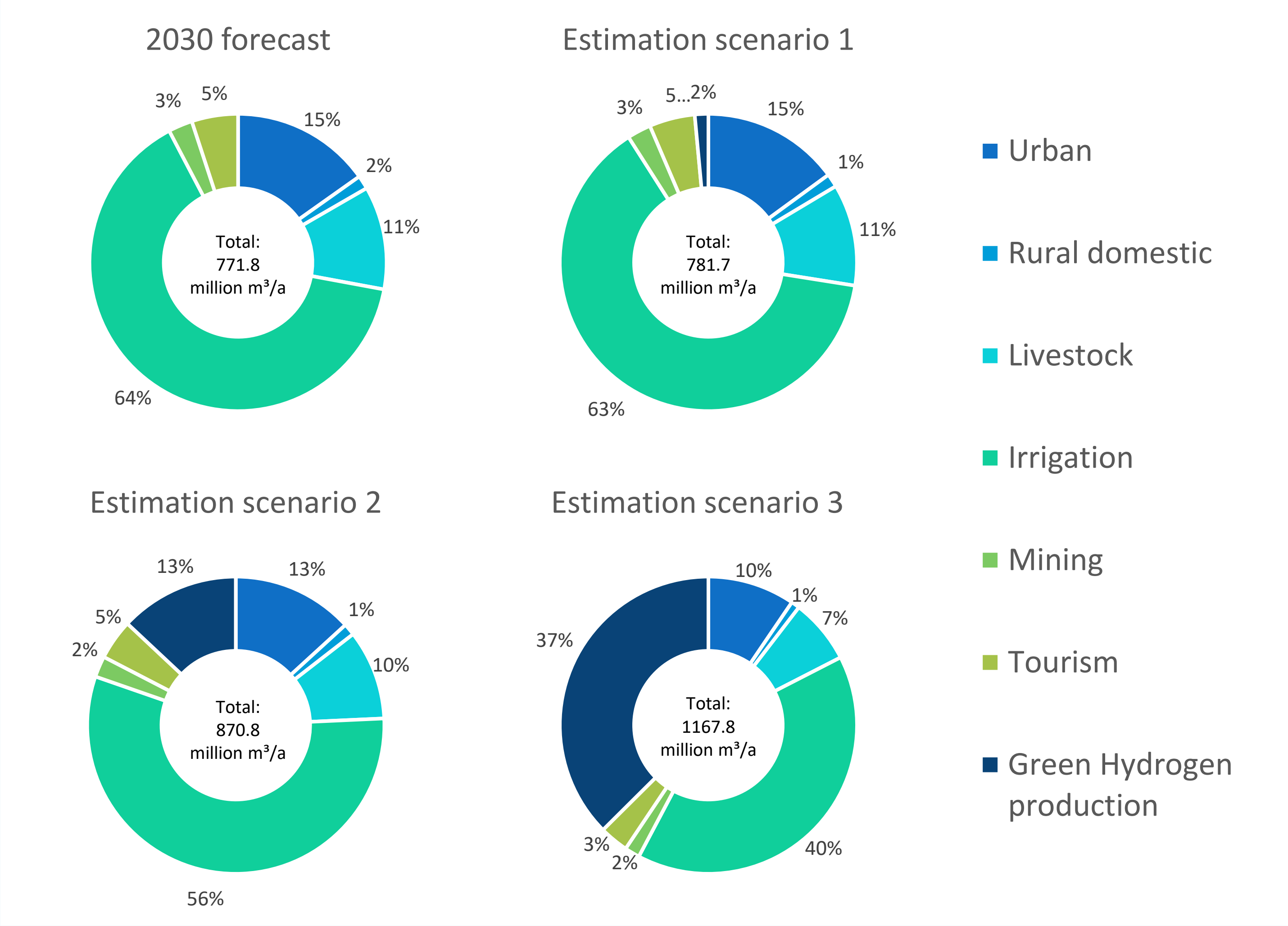
Questions regarding the water sector

1. How much water will be needed?

2. How do we get this water?

3. Which impact is generated by that?

Water demand in Namibia



Estimated Values for 2030: report from 2010

Scenario 1: Hyphen Scenario

350,000 t/a H_2

~ 11.5 million m³/a desalinated Water

Scenario 2: SCDI scenario

3,000,000 t/a H_2 production

Scenario 3: GH2 Strategy scenario

12,000,000 t/a H_2 production

Water Supply

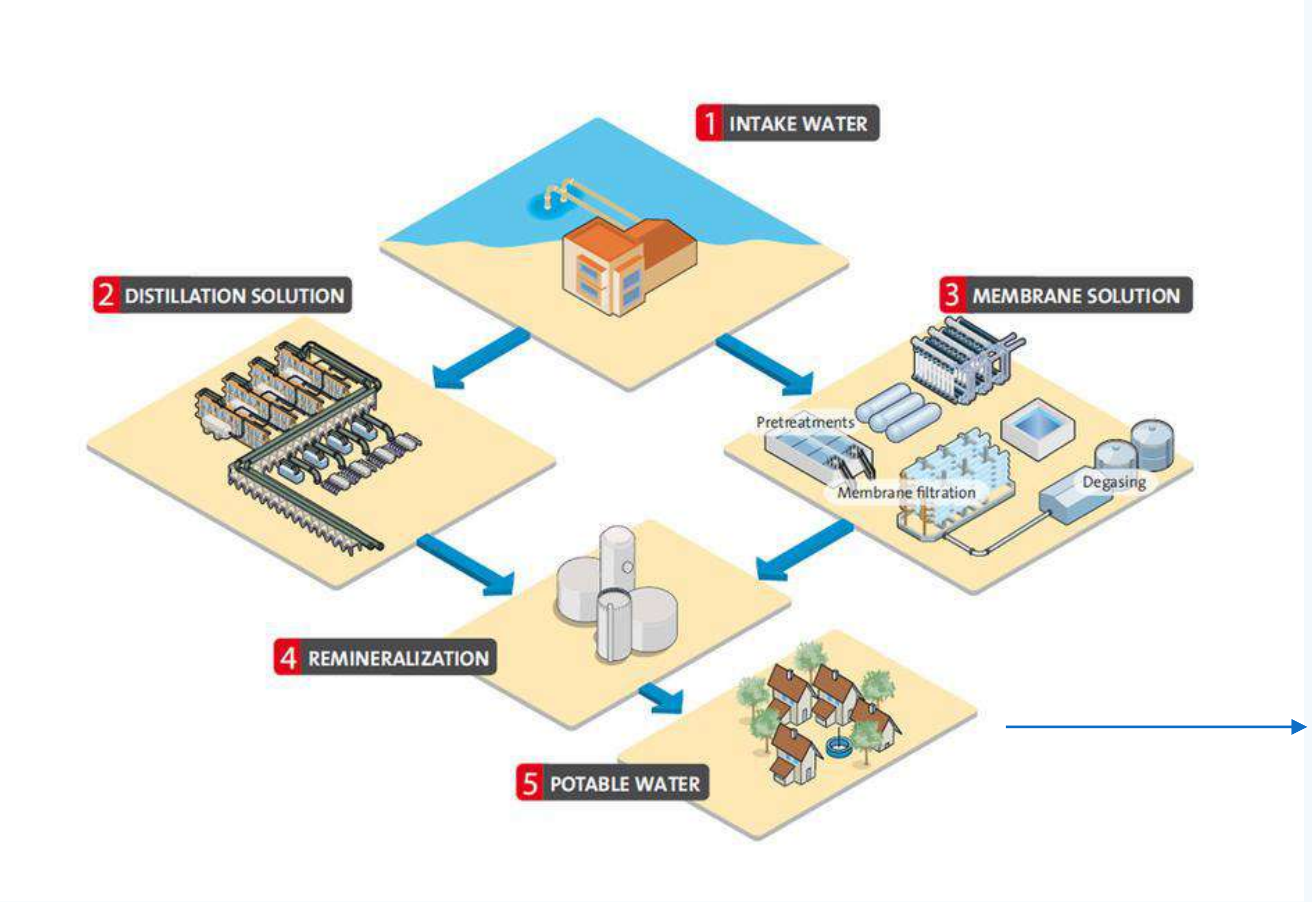
- Hentis Bay, Swakopmund, Walvis Bay, mines
  - Groundwater from 2 aquifers
  - 25 million m^3/a Desalination Plant
  - 2^{nd} Desalination Plant planned

- Lüderitz (Nationalpark Sperrgebiet/ SCDI)
  - Groundwater from aquifer
  - plans for port expansion

→Groundwater resources can provide supply right now

→Questions regarding further supply by groundwater resources

Desalination – How does it work?

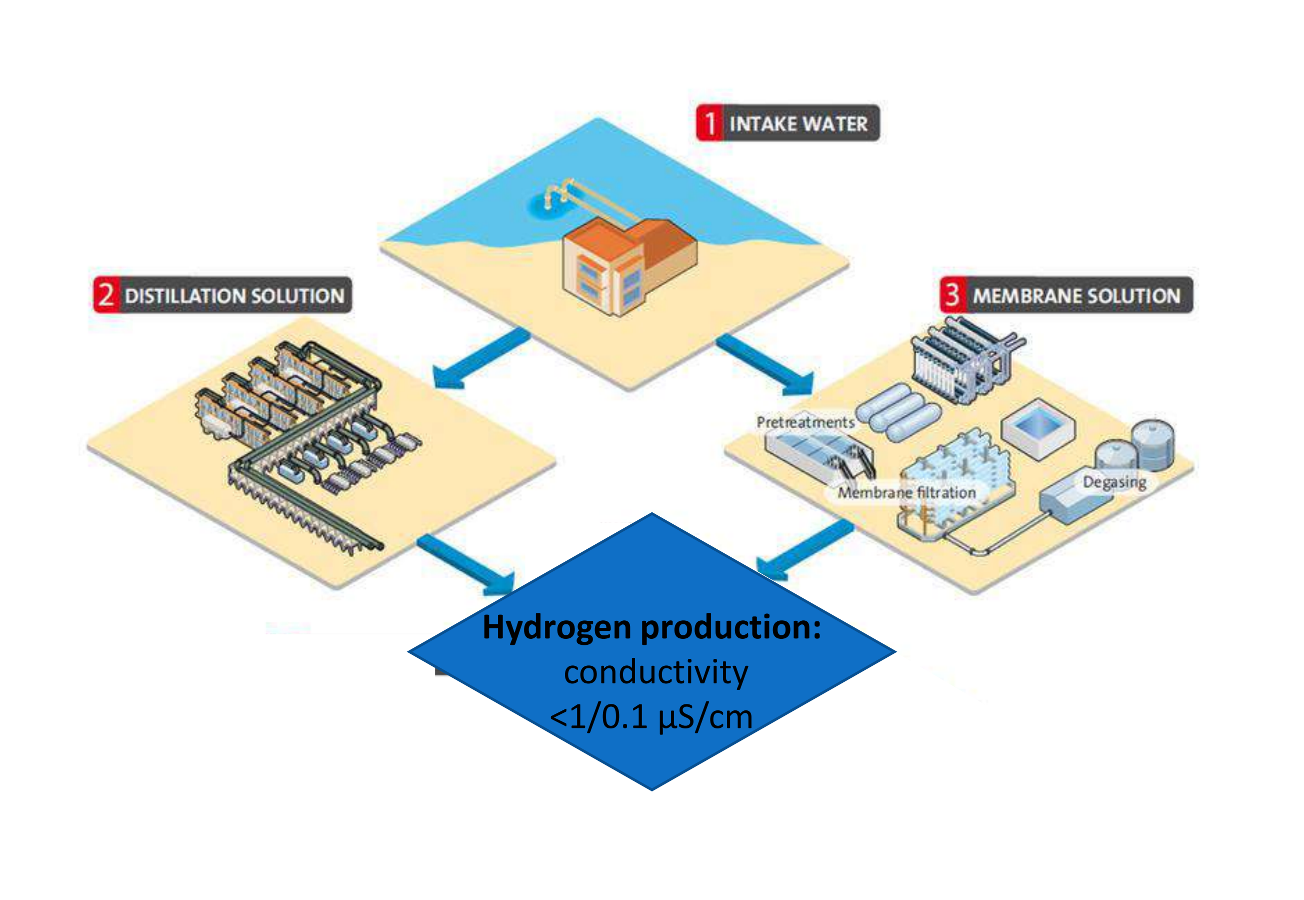


[Veolia, 2023]

Wastewater Treatment Plants

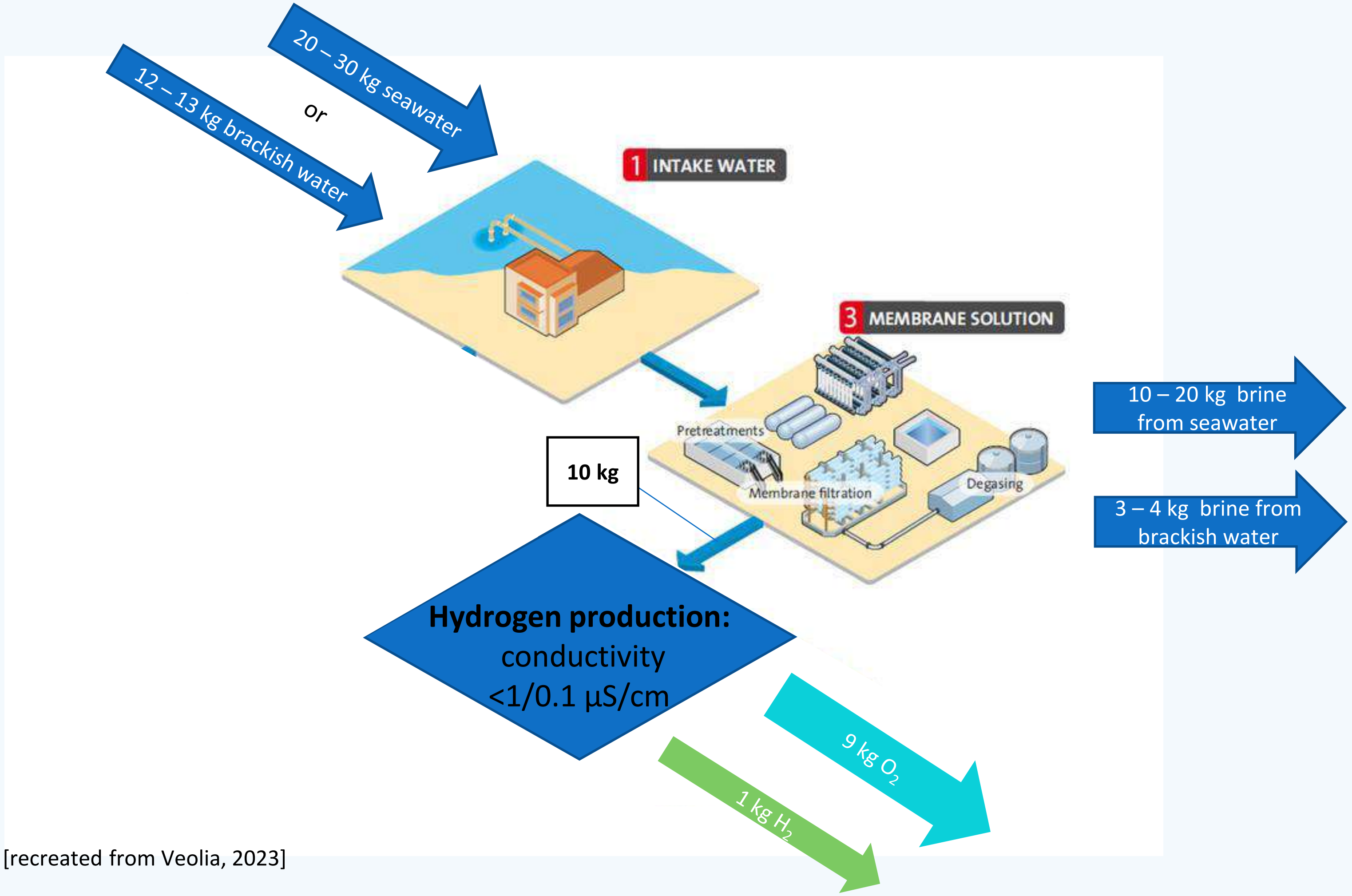
Seepage or DPR

Desalination – How does it work?



[recreated from Veolia, 2023]

Desalination – How does it work?



[recreated from Veolia, 2023]

Brine treatment options

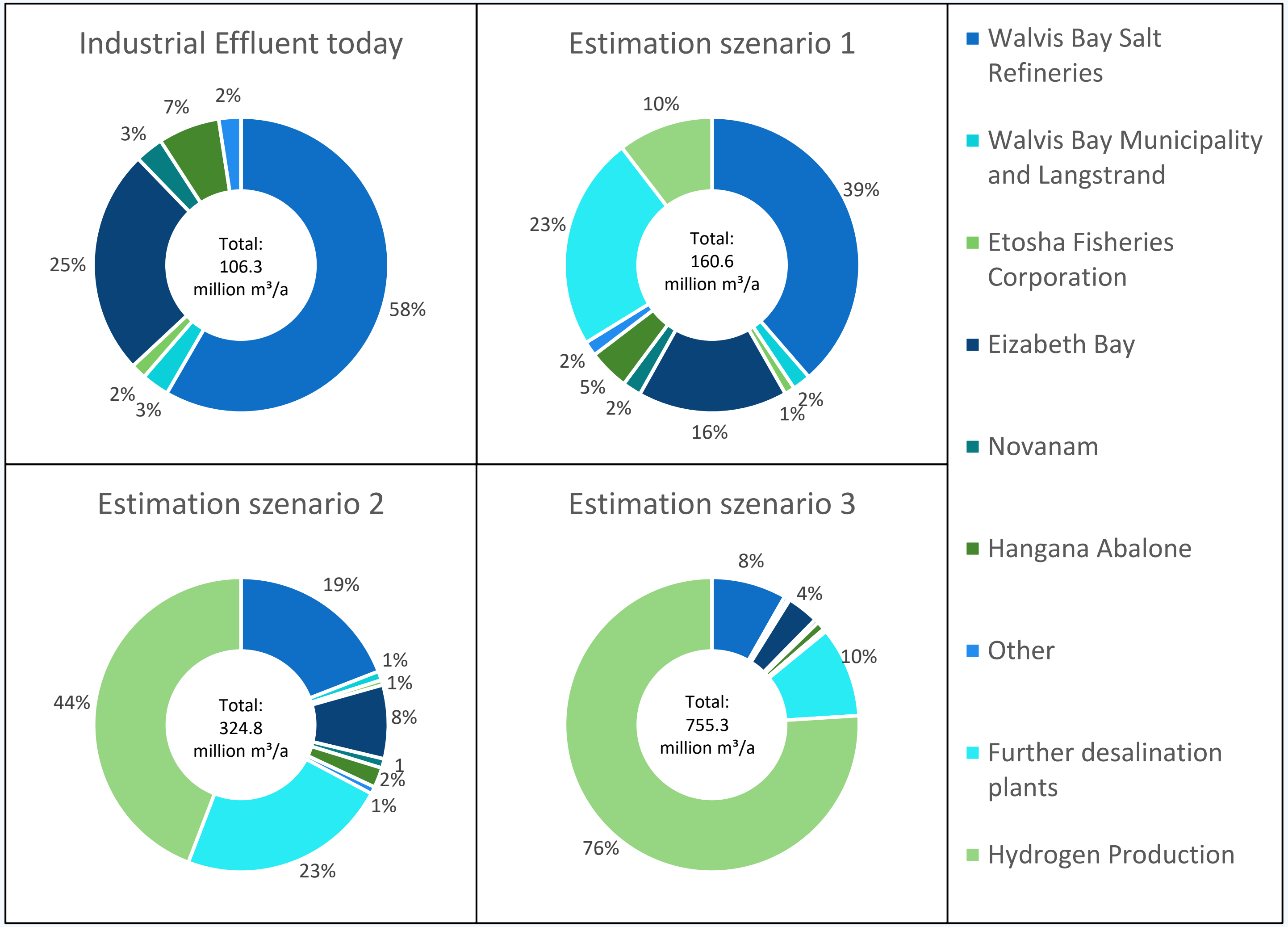
Brine, TDS: 50,000 – 65,000 ppm

Discharge into the ocean

Evaporation ponds

Further brine treatment

Industrial Effluent into the ocean in Namibia



Estimated Values for Namibian MSP 2nd edition, 2019

Scenario 1: Hyphen Scenario

350,000 t/a H_2 with RO-Desalination:
~ 11.5 million m³/a desalinated water
~ 14.8 million m³/a brine
& Production of 25 million m³/a drinking water
~ 62.5 million m³/a seawater

Scenario 2: SCDI scenario

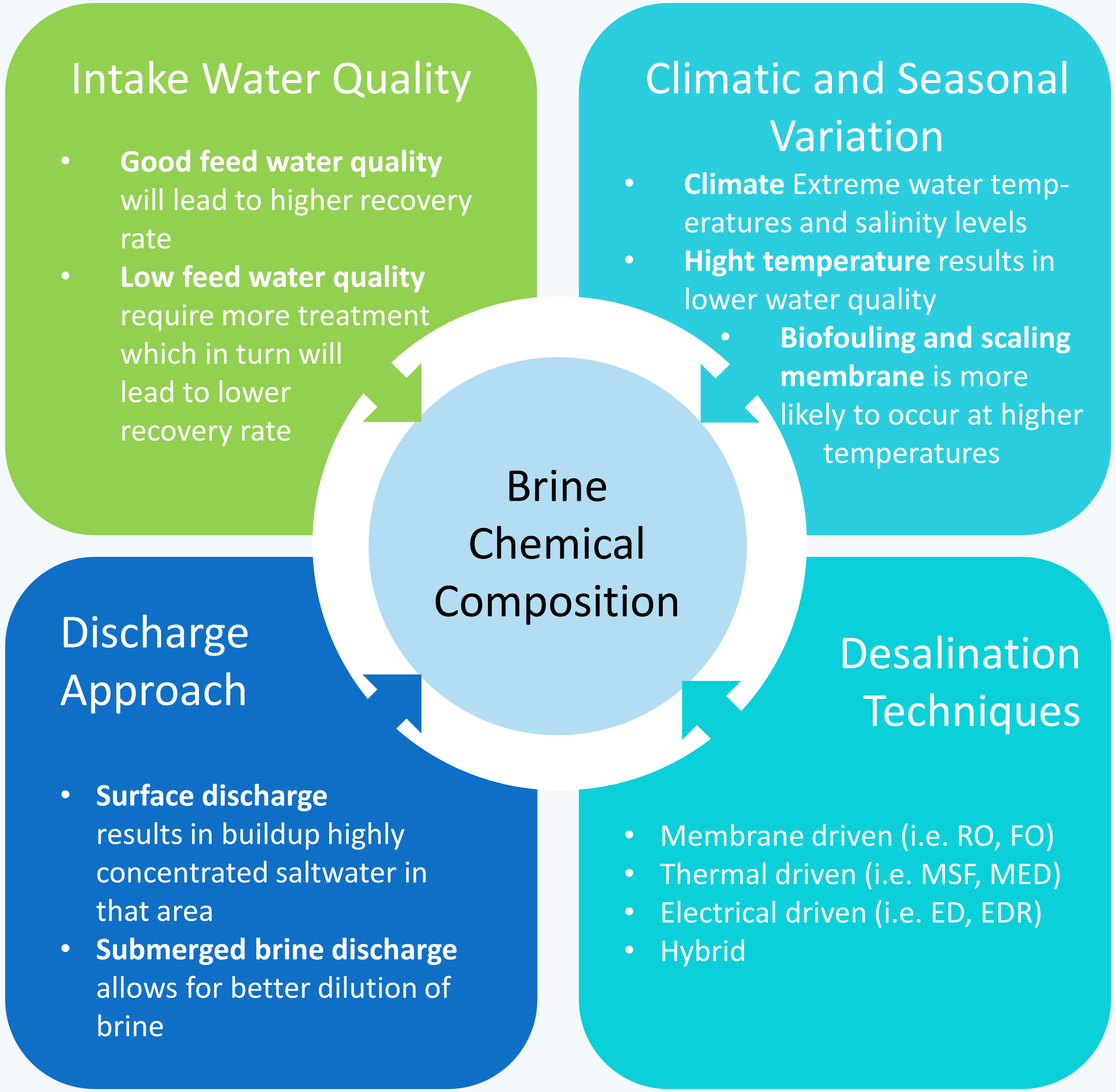
3,000,000 t/a H_2 with RO-Desalination:
~ 99 million m³/a desalinated water
~ 148 million m³/a brine
& Production of 50 million m³/a drinking water
~ 125 million m³/a seawater

Scenario 3: GH2 Strategy scenario

12,000,000 t/a H_2 with RO-Desalination:
~ 396 million m³/a desalinated water
~ 574 million m³/a brine
& Production of 50 million m³/a drinking water
~ 125 million m³/a seawater

Brine discharge into the ocean

- Typical discharge options:
  - Surface water discharge
  - Sewer discharge
  - Deep Well Injection
  - Evaporation Ponds
  - Land Application

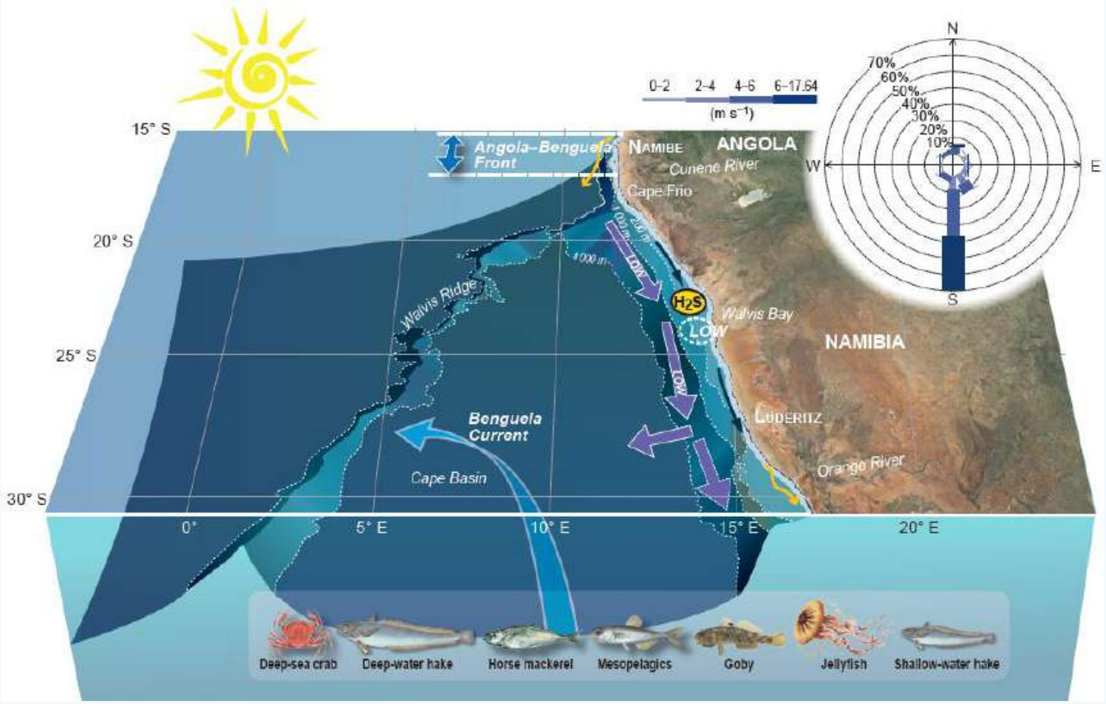


[recreated from Omerspahic et al., 2022]

Brine discharge into the ocean

- Ocean is used as fishing ground
  - Large industry for Namibia
  - Good and constant monitoring around the discharge points will be crucial

- Challenges with occurring H_2S plumes around Swakopmund and Walvis Bay
- Higher amount of brine → regional impacts to be expected



[Kirkman et al., 2016]

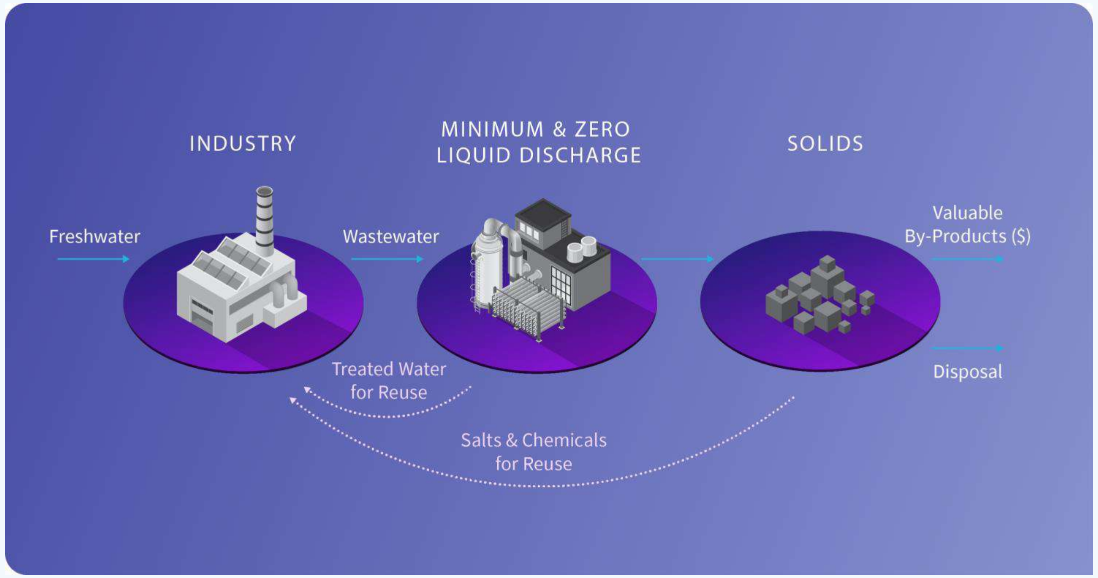
Further brine treatment

- Minimal and Zero Liquid discharge are emerging concepts
- Reported OPEX: 3 – 27 US$/$m^3$
- Require much more energy than typical treatment options

- Environmental impacts could be drastically reduced
- Potential of resource recovery from seawater

→ Potential new market for resources

- Costs of water treatment in comparison to H_2 production are very low



[gradiant, 2023]

Conclusions

- Water demand will rise with the emerging Green Hydrogen Industry
  - Groundwater will not be able to cover the demand at later stages
  - Upcoming usage conflicts, Seawater Desalination is a solution to overcome the supply hurdles
- Brine discharge into the ocean
  - Monitoring
  - Regional impacts
  - H_2S plumes
- Further brine treatment can be an option for the future
  - Environmental impacts can be lowered
  - Potential market for salt and other recovered resources

Outlook

- Draft-Report on the findings will be be published
- Data used will be updated depending on stakeholder feedback
- Regional impacts seem to become more importat

  → analysis of 2- 3 regions in the report

Thank you for your attention!

If you have follow-up questions, you can contact:

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Picture Sources

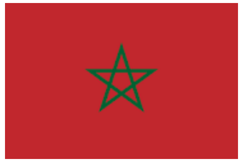
[Veolia, 2023]	Webpage: https://www.sidem-desalination.com/applications/seawater-desalination Access: 10.05.2023
[Soltau & van Eden, 2014]	C. Soltau and F. van Eeden, ‘Brine Discharge Specialist Study; SOCIAL AND ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED RÖSSING URANIUM DESALINATION PLANT NEAR SWAKOPMUND’, Oct. 2014.
[Omerspahic et al., 2022]	M. Omerspahic, H. Al-Jabri, S. A. Siddiqui, and I. Saadaoui, ‘Characteristics of Desalination Brine and Its Impacts on Marine Chemistry and Health, With Emphasis on the Persian/Arabian Gulf: A Review’, Front. Mar. Sci., vol. 9, p. 845113, Apr. 2022, doi: 10.3389/fmars.2022.845113.
[Kirkman et al., 2016]	S. Kirkman et al., ‘Spatial characterisation of the Benguela ecosystem for ecosystem-based management’, Afr. J. Mar. Sci., vol. 38, no. 1, pp. 7–22, Apr. 2016, doi: 10.2989/1814232X.2015.1125390.
[gradiant, 2023]	Webpage: https://www.gradiant.com/solutions/mld-and-zld/ Access: 10.05.2023

“Mysol PV: first integrated manufacturing plant for solar modules in Morocco”

Prof. Dr. Ralf B. Wehrspohn
ITEL German Lithiuminstitute

Germany

Mysol PV
first integrated manufacturing plant for solar modules in Morocco

Ralf B. Wehrspohn
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Co-CEO ITEL German Lithiuminstitute
Partner of mysol PV SA
former EVP Fraunhofer Society
former member of German Coal Exit Commission
Germany

Köthen 24.5.2023

Industry also need to decarbonize!

Expected **hydrogen** demands or **CO_2-storage requirements** in the German Steel and Chemical industries

	2020	2050
Steel Industry	~0 Mt **H2 +** 70 Mio t CO_2	+ 1,8 Mt H_2 * or 0 Mio t CO_2
Chemical Industry	~ 1 Mt H_2 + 37 Mio t CO_2	7 Mt H_2 or 0 Mio t CO2 **

- Concept steel, BMWI,

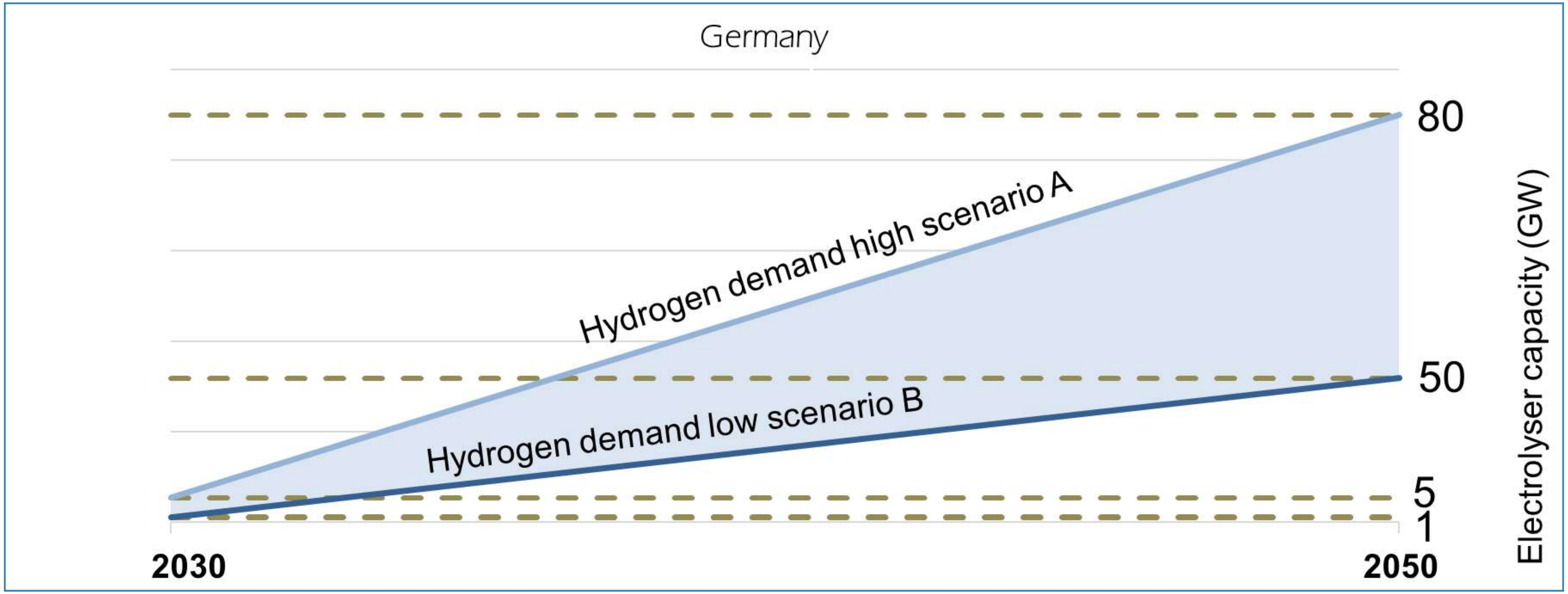
Comment: in Korea roughly a factor of two, China factor of 25

** VCI, 2020.

Fraunhofer Roadmap
Expected demand for green hydrogen in Germany

Scenario A: Efficiency-optimized world with low share of synthetic fuels

Scenario B: World with higher share of synthetic fuels or barrier in electric energy coupling

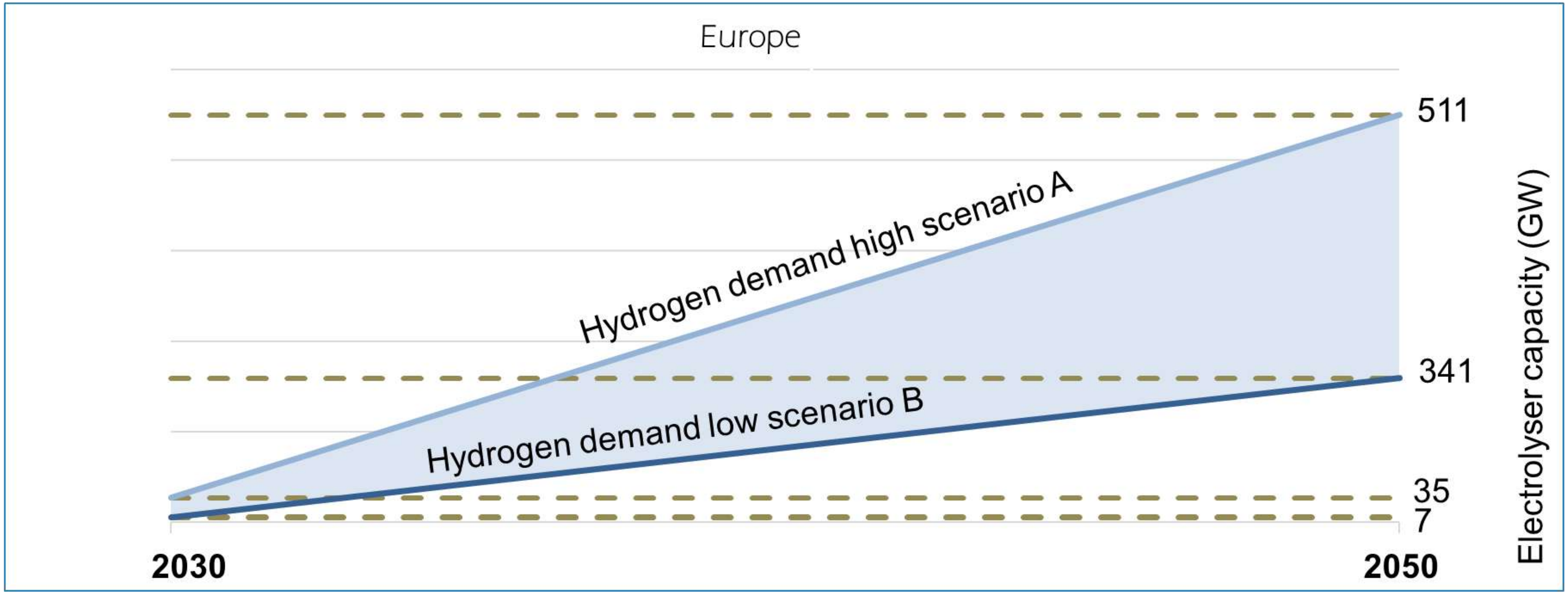


https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/2019-10_Fraunhofer_Wasserstoff-Roadmap_fuer_Deutschland.pdf

Fraunhofer Roadmap
Expected demand for green hydrogen in Europe

Scenario A: Efficiency-optimized world with low share of synthetic fuels

Scenario B: World with higher share of synthetic fuels or barrier in electric energy coupling



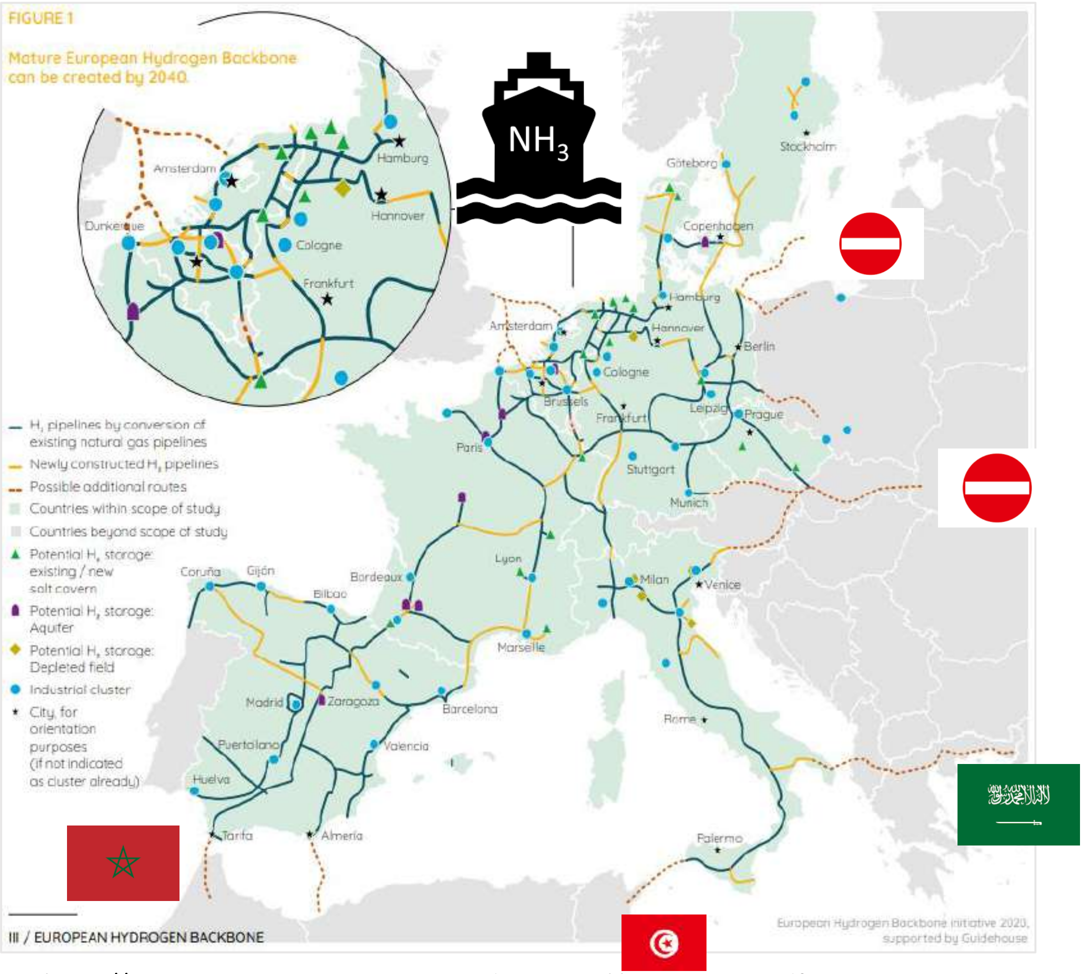
https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/2019-10_Fraunhofer_Wasserstoff-Roadmap_fuer_Deutschland.pdf

Hydrogen Backbone for Europe

Goals: Resilient hydrogen infrastructure for Europe

- **Key facts:**
  - Peak load of natural gas in 2019 **> 1 Terawatt**
  - Transmission length in Europe **> 220,000 km** (more than all highways in Europe)
  - Plans for a **hydrogen backbone network** in Europe: **53,000 km length** until 2040
  - Development of several **hydrogen caverns** (salt) for storage
  - European demand in 2050 about **100 Mt** of hydrogen / a

- **Challenges:**
  - **H_2 import**: Cooperation with hydrogen exporting countries and ammonia shipping countries**.**
  - Even in sunny countries, 3-4 times more capacity of photovoltaic systems is needed in comparison to electrolyser capacity **(e.g. 1200 to 1600 GWp of solar)**

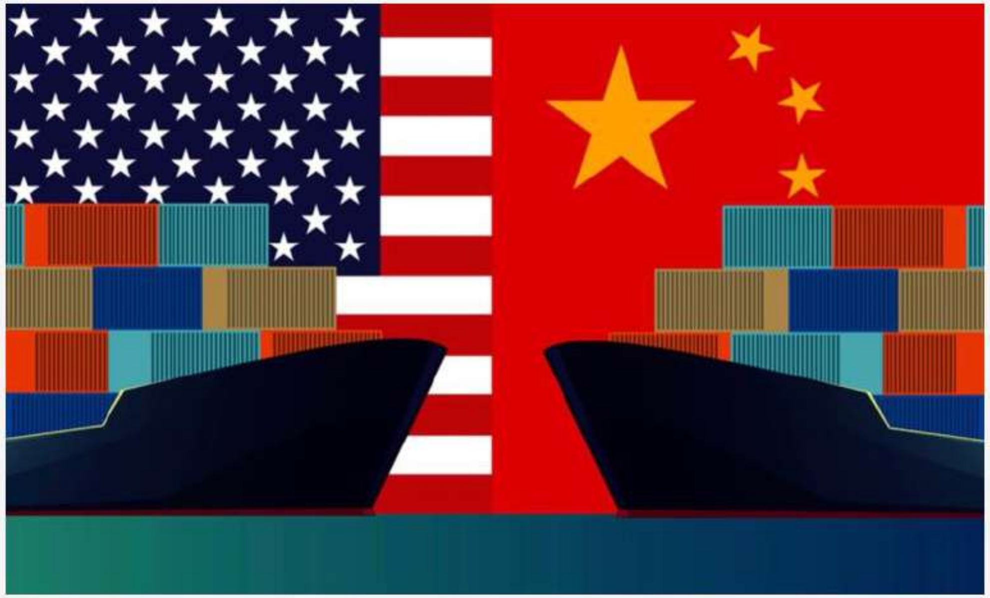


See https://oge.net, 20200715_European Hydrogen Backbone_Report.pdf

German Initiators: SALZGITTER AG, nowega, gasunie, VNG, RWE, Fraunhofer

https://ehb.eu/

Trade war US vs. China



US and China trade tensions could be set to rise again. Image: Twitter / Global Times

ASIA TIMES EST 1995

China Opinion Newsletters Membership

TECH WARS

China bans export of core solar panel technologies

Reverse Golden Rule – treat others as they've treated you – is meant to keep lead status in making large silicons

By JEFF PAO
FEBRUARY 1, 2023

What is the strategy of Europe and Africa ?

GI3

GREEN INNOV INDUSTRY INVESTMENT

MYSOL PV

INTEGRATED SOLAR PV MANUFACTURING PLANT

mysolPV
SOLAIRE PHOTOVOLTAÏQUE

GREEN INNOV INDUSTRY INVESTMENT

Leadership & Royal commitment for renewables

MESSAGE FROM HIS MAJESTY THE KING, MAY GOD ASSIST HIM, AT THE WORLD FORUM ON ENERGY EFFICIENCY IN MAY 2017

> "Our commitment to the development of an efficient and carbon-free energy model for the benefit of the well-being and prosperity of our citizens is based primarily on the rise of renewable energies and the strengthening of energy efficiency.

MYSOL PV Team

The drive force of the MYSOL PV project is a team of professionals in the photovoltaic sector, who master all the parts of the value chain of integrated production as well as the international commercial challenges of the PV sector. This industrial experience of the management team is the main asset of the project, in an industry where the major industrial expertise is now in China, Japan and Germany.

Nasser BOUAZZA
ASSOCIATE PARTNER

30 years experience

- graduated from Institute Glion,
- President of HimVest Group Holding,
- President of Gi3,
- Business man, Investor

Badr IKKEN
ASSOCIATE PARTNER

20 years experience

- graduated from the Berlin Institute of technology,
- Executive president of Gi3,
- Former Director General of the National research Institute for Solar Solar Energy and New Energies IRESEN, President of the Green Energy park,
- Expert in PV technology and manufacturing technologies

Zakaria NAIMI
ASSOCIATE PARTNER

14 years experience

- Graduated from the EMI engineering School,
- Director General of Gi3,
- Former Director of the Green Energy Park (GEP),
- Former PV Director of the National Research Institute for Solar Energy and New Energies,
- Expert in PV technologies and electrical engineering

Prof. Ralf WEHRSPOHN
ASSOCIATE PARTNER

28 years experience

- Graduated from the Oldenburg University and from Ecole Polytechnique,
- Director General of the German Lithium Institut,
- Former VP the FRAUNHOFER Society, Former Director General of FhG IMWS Center for Siclicon Photovoltaic, former researcher at Philips Research and Max Planck.
- Expert in Solar energy and industrial innovation

Dr. Karl-Heinz KUESTERS
TECHNICAL ADVISOR

39 years experience

- Technical advisor of Gi3,
- Former VP technology of Hanwha Q-Cells,
- Former technology development Director of Hanwha-Q-Cells, Former technology development Director of Infenion-Quimonda

mysol PV

SOLAIRE PHOTOVOLTAÏQUE

PV CELLS AND MODULES PRODUCTION

800 MW/year Cells
1000 MW/year PANELS

High quality certified PV panels with M10 and M12 solar cells (PERC and TOPCON)
72 cells or 144 half cells
2274 mm x 1134 mm
500Wp – 550 Wp per PV panel (up to 2,6 m²)

Technical Advisor

International Solar Energy Research Center Konstanz

ISC

GREEN INNOV INDUSTRY INVESTMENT

An industrial model allowing a flexible adjustment of the production capacity and allowing to adapt to the demand of the Moroccan, European and International market, with an optimization of the profitability:

- **An annual production capacity of 800 MW of cells,**
- **An annual capacity of at least 1000 MW of module production, of which more than 2/3 for export to Europe and the United States of America,**
- **A project ready to start immediately: negotiations completed with the equipment manufacturers, technology partners and raw material suppliers as well as potential off takers.**

mysolPV

INDUSTRIAL PARK

AÏN JOHRA, TİFLET

By integrating the Aïn Johra industrial zone of Tiflet, 50 kilometers from Rabat, Gi3 will contribute to the creation of a national industrial ecosystem in the field of photovoltaic solar energy and is positioned next to a major industrial acceleration zone.

The MYSOL PV plant will be spread over 7 hectares and will enjoy several advantages, including the incentive on the land and up to 30% subsidy on the investment cost.

FACTORY

Vision

BECOME IN 2030 ONE OF THE LARGEST PLAYERS IN THE GREEN INDUSTRY IN AFRICA, IN THE FIELDS OF PHOTOVOLTAIC, THERMAL SOLAR ENERGY AND ENERGY STORAGE.

CHAPTER 3. EDUCATION AND TRAINING REQUIREMENTS FOR THE GREEN HYDROGEN ECONOMY

"Building the Workforce for the Green Hydrogen Economy – Opportunities and Challenges for Africa"

Christiane Naumann
DCG Halle

Germany

German-African Green Hydrogen Forum

Building the Workforce for the Green Hydrogen Economy – Opportunities and Challenges for Africa

Bernburg, 23.05.2023

- Christiane Naumann

DCG Halle gGmbH
INTERNATIONAL INSTITUTE

Massive investment into hydrogen projects planned

Various countries in Africa heavily invest into green hydrogen projects, e.g.

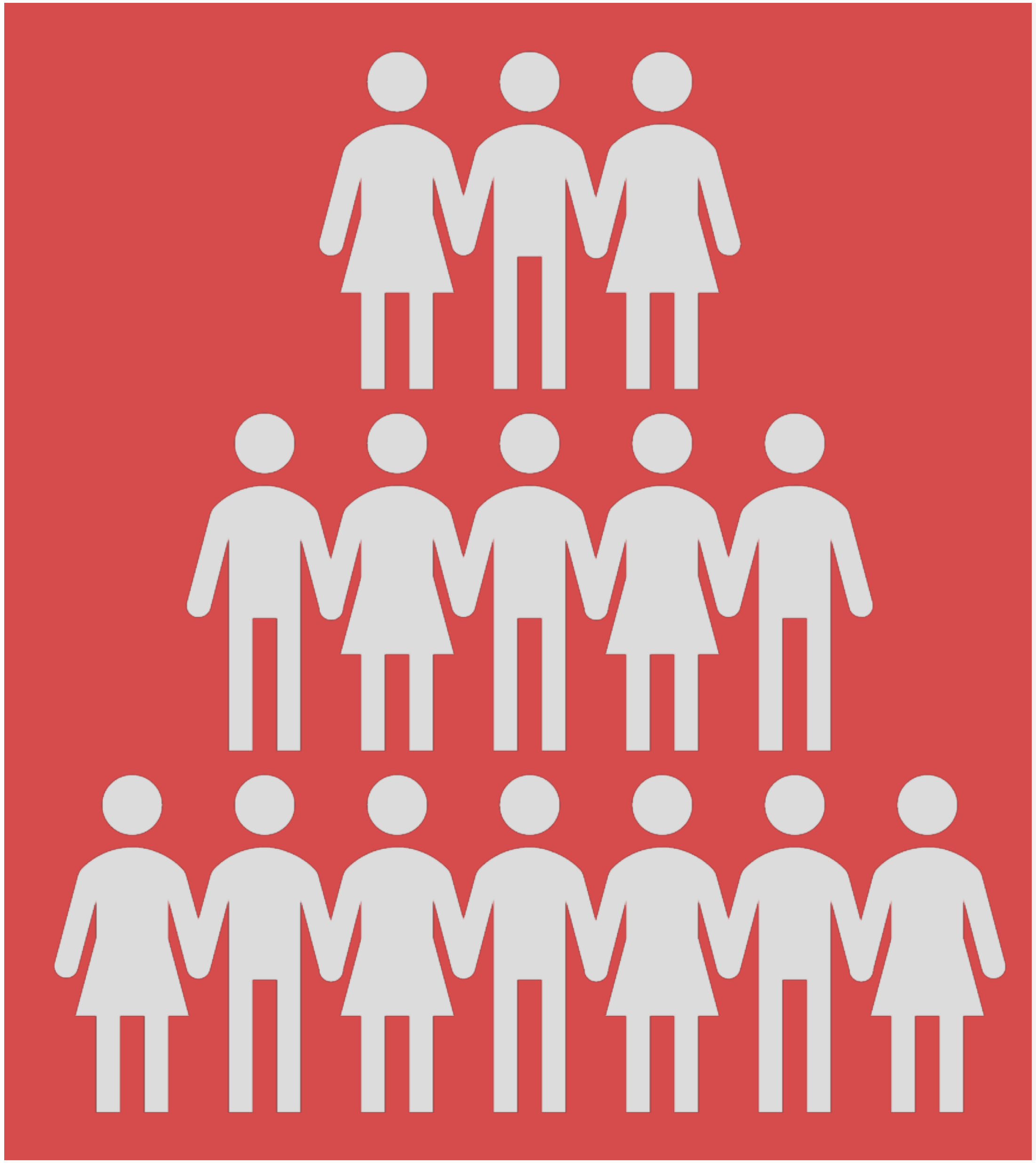
- South Africa $17.8 billion over the next decade
- Nambia $9.4 billion until 2026

Investment needed for…

- Collaborative innovation platforms
- Infrastructure for the hydrogen sector
- Establishment of legal frameworks
- **Building the specialized workforce**

Source: https://www.un.org/africarenewal/

DCG Halle gGmbH
INTERNATIONAL INSTITUTE



Opportunities for Job creation

Estimated that the hydrogen energy sector has great potential for long-term job creation in Africa

- e.g. recent reports state that in South Africa up to 1.6 million jobs can be created by 2050
- Skilled jobs that require either university or vocational education
- Jobs in the area of operations, maintenance, transportation, construction, industrial manufacturing

Source: saiia.org.za

Priority to build an adequate pipeline of trained workforce for this rapidly growing industry sector

DCG Halle gGmbH
INTERNATIONAL INSTITUTE

A new industry with new requirements

The challenge:

- a new industry which still requires extensive research
- partnership initiatives with foreign (research) institutes and industry players will be important
- Upskilling and training initiatives locally

Two main pillars for education

1

University Education

- Bachelor and Master programs on green hydrogen technologies
- Goal: scientists, researchers, highly specialized individuals, engineers

2

Vocational training

- Training, upskilling and re-training
- Goal: professional workers in the area of installation, operation, maintenance, transportation, Health & Safety

Focus should be to educate in African countries locally!

DCG Halle gGmbH
INTERNATIONAL INSTITUTE

Experience from higher education in Ghana

The role of DCG is the handling of all non-academic affairs

Students learn in accordance with the German curriculum

14 modules: 11 by Ghanaian partner, 3 by German partner

Regular audits, approval of examinations

Master thesis: 1st supervisor from German & 2nd supervisor from Ghanaian partner

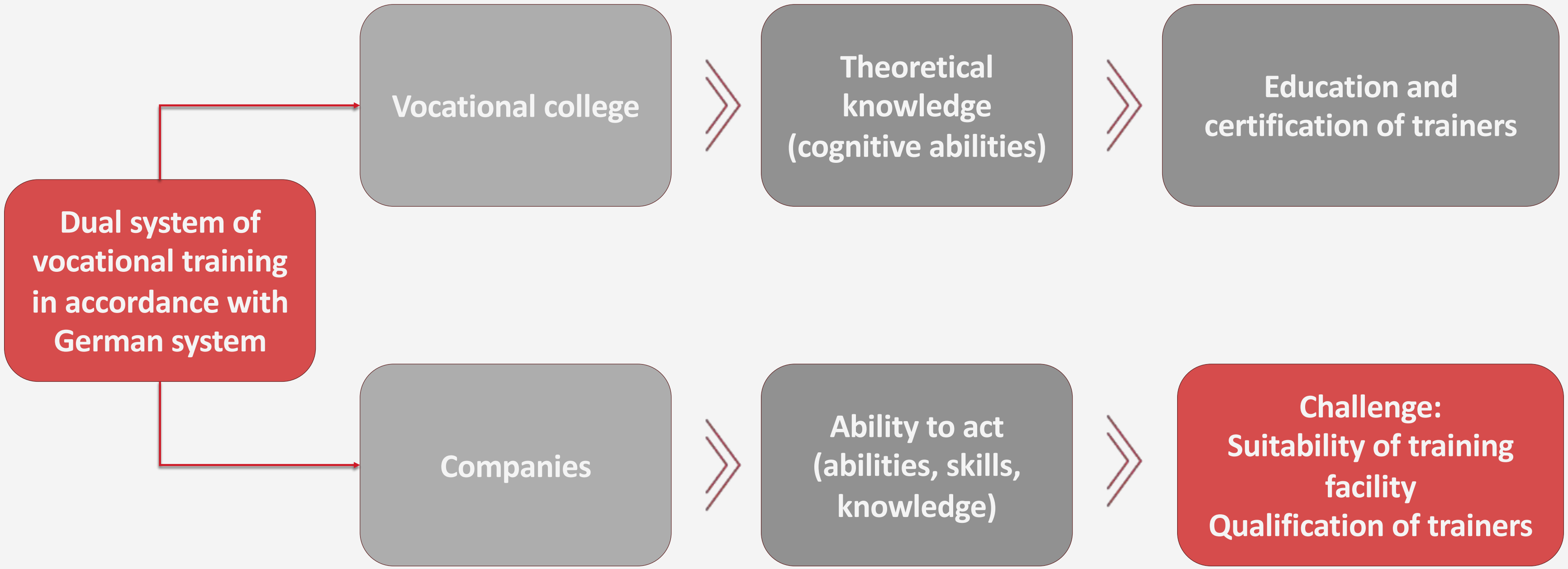
Graduates stay within their country of origin while getting a German Master's certificate

Since 2013: 224 participants (180 graduates)

Cooperations within the higher education system can be implemented relatively quickly due to known international standards and the former Bologna process

DCG Halle gGmbH
INTERNATIONAL INSTITUTE

Experience from vocational training



The dual system is not known outside the German speaking countries, especially in companies that shall educate its workforce.

DCG Halle gGmbH
INTERNATIONAL INSTITUTE

Challenges faced and possible solutions

	Challenges	Possible solutions
1	Dual system not established, thus value of young workforce often under-estimated by companies	Train-the-trainer programs in order to design own training programs and content
2	Trainees often not paid Seen as unskilled labour	Politics: creating supportive infrastructure
3	Dual system not established, young workforce not aware of possibilities	Awareness campaigns, companies offering trainee jobs may get competitive advantage for recruitment
4	Coordination of contracts between vocational school, company and trainee	Dedicated project management at vocational school supporting companies and trainees

DCG Halle gGmbH
INTERNATIONAL INSTITUTE

Proven experience for more than 20 years

1999	Foundation of DCG association
2000	Language students (until 2006)
2001	Start Professional Education with Educational Center from Chamber of Commerce and Industry
2004	Start Bachelor Double Degree Programs between German and Chinese universities
2008	Start Master Programs between German and foreign universities
2008	Start Professional Education with Educational Center from Chamber of Crafts
2013	Start of MBA of Anhalt University of Applied Sciences in Ghana (1st of its kind)
2019	Start of Online Study work

DCG has a well established network of different partners to support in the workforce development in this new industry

Universities of Applied Sciences

Online Learning platform

Educational Center from Chamber of Commerce and Industry

German vocational training centers

DCG
Halle gGmbH
INTERNATIONAL INSTITUTE

In case of any questions…reach out to us!

DCG Halle gGmbH
Dorflage 18a
06116 Halle (Saale)

GERMANY

web: www.dcg-halle.de

email: info@dcg-halle.de

DCG
Halle gGmbH
INTERNATIONAL INSTITUTE

“Education and Training Activities of the Competence Centre H2SAFETY @ BAM”

Dr. Kai Holtappels
BAM

Germany

Sicherheit in Technik und Chemie

BAM
Bundesanstalt für Materialforschung und -prüfung

23.05.2023

EDUCATION AND TRAINING ACTIVITIES OF THE COMPETENCE CENTRE H_2SAFETY@BAM

Kai Holtappels, Teresa Orellana Pérez, Anne-Katrin Patzelt
Bundesanstalt für Materialforschung und –prüfung (BAM)

www.bam.de

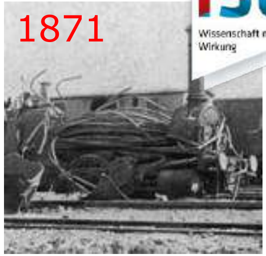
H_2Safety@BAM

Safety in Technology and Chemistry

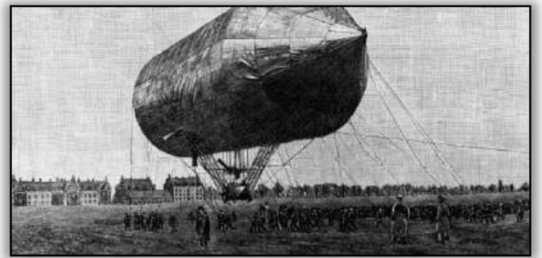
BAM

BAM is a senior scientific and technical Federal institute with responsibility to Federal Ministry for Economic Affairs and Climate Action

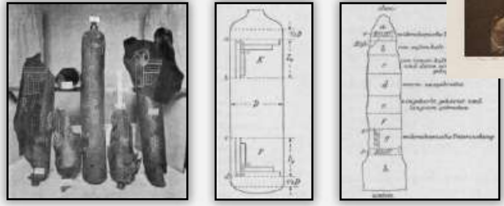
Federal Ministry for Economic Affairs and Climate Action



150 JAHRE BAM
Wissenschaft mit Wirkung



Berlin-Tempelhof 25.05.1894

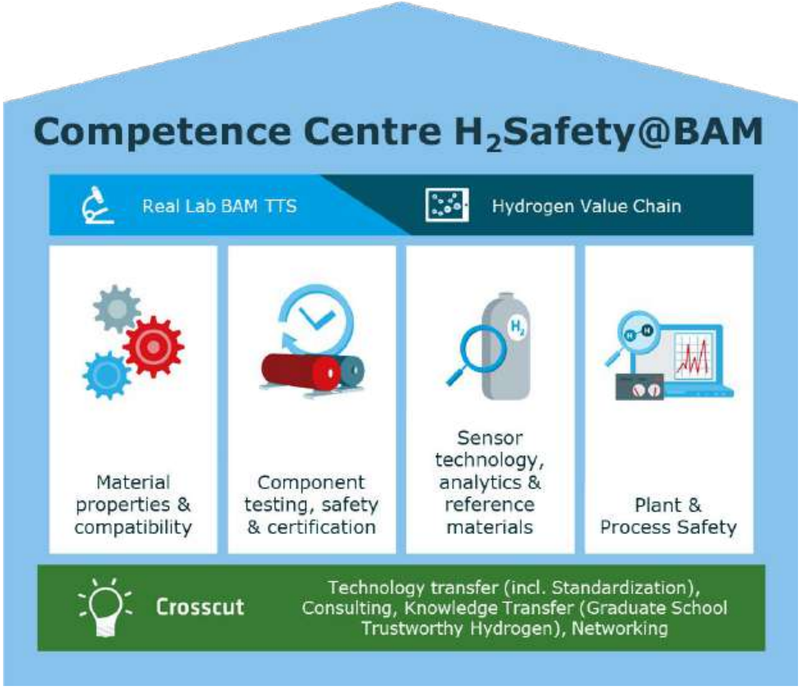


A. Martens, Journal of the Association of German Engineers, 40 (1896), No. 26, pp. 717 – 723 in German

H_2Safety@BAM

The competence centre

- established in 2020
- summarizes the expertise at BAM and coordinates all H_2 activities
- more than 125 years of experience in hydrogen safety
- Our vision: We build trust in hydrogen technologies!
- Our mission: We create the prerequisites for a successful application of H_2 technologies on a national and European level.
- Visit our website: H_2Safety@BAM



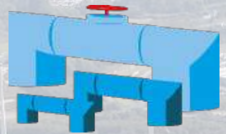
Competence Centre H_2Safety@BAM

Safety Issues along the Hydrogen Value Chain

Production

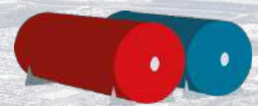
- Scale-Up
- Consequences of Cross-Over
- Materials degradation
- Protection areas
- Safety guidelines

Transport



- Materials compatibility
- Explosion protection
- Consequences of failure
- Gas quality influences

Storage



- Operation-dependent safety assessments
- Structural health monitoring
- Life time assessment
- Isolating materials for cryogenic storage
- Advanced storage technologies

Use

- Proof of safety concepts
- Leak monitoring
- Hydrogen quality
- Digital quality infrastructure
- Consequences of failures & safety measures
- Tribology and Lubricants

Acceptance | **Education and Training** | **Regulation, Codes and Standards**

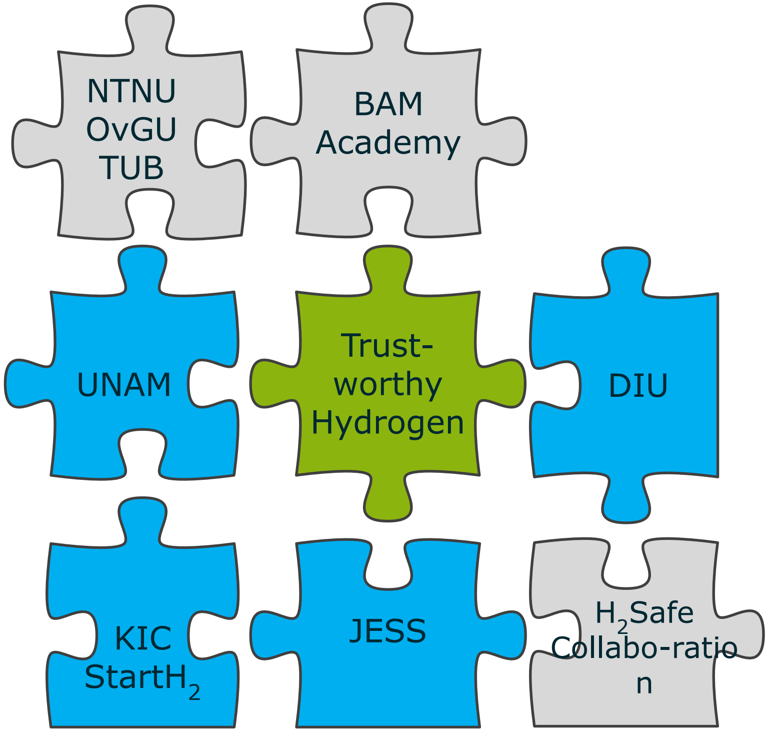
www.nordsee-zeitung.de Bremerhafen

Education and Training Activities at H_2Safety@BAM

www.bam.de

Overview of all activities

- Trustworthy Hydrogen: Graduate School of BTU Cottbus and BAM
- BAM Academy: Learning platform for the training & conference portal of BAM (under construction for hydrogen)
- KIC StartH_2: Accelerating Sustainable Hydrogen Uptake Through Innovation and Education
- JESS: Joint European Summer School
- UNAM: Joint Master and Doctorate Programme, Joint lectures
- DIU: Joint lectures
- H_2Safe Collaboration: Exchange of experts and PhD students
- NTNU, OvGU, TUB: Joint Master Thesis, Exchange of PhD students and Post Docs



Graduate School Trustworthy Hydrogen

Brandenburg
University of Technology
Cottbus - Senftenberg

- first graduate school in Germany focused on hydrogen trustworthiness and safety
- combines the unique competences of BAM and BTU to train the next generation of interdisciplinary hydrogen scientists
- hydrogen focused qualification programme providing all PhD students with a holistic understanding of the hydrogen value chain and the regulatory framework conditions
- wide range of soft skill courses
- close interaction with industry (embedded in international networks of BTU and BAM)
- Initial launch with seven PhDs
- PhDs from other cooperations will be associated to the graduate school

Graduate School Trustworthy Hydrogen

- initial launch with 7 PhD topics

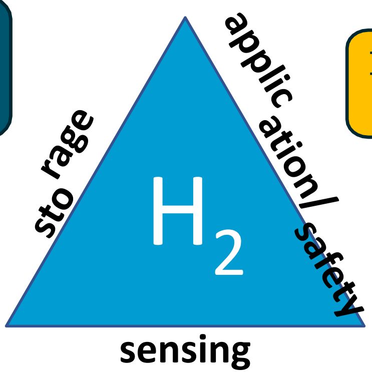
Brandenburg University of Technology Cottbus - Senftenberg

BAM

Influence of manufacturing process-related residual stresses in wound composite material on the operational safety of H_2 pressure vessels

Influence of manufacturing-induced imperfections on the operational safety of composite H2 pressure vessels

Efficient polymer matrix composites qualification strategies for next generation H2-pressure vessels



Influence of fires on tanks for cryogenic fluids

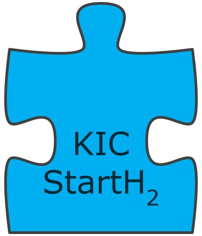
Trust-worthy Hydrogen

Evaluation of the influence of lubricants on pre-ignition of hydrogen for engine-relevant conditions

Digital sensor twins for hydrogen applications

Novel materials and coatings for the detection of hydrogen and hydrocarbons

Accelerating Sustanable Hydrogen Uptake through Innovation and Education (KIC StartH$_2$)



- aims to accelerate the introduction of hydrogen across Europe through education and innovation by targeting students and industry professionals
- consortium of nine universities, two research institutes and one SME consultancy (TeacHy partners)
- Development of niche education methodologies covering not only content on hydrogen technologies but also innovation methods in business and management
- project started in summer 2022
- four e-learning modules (integration in master studies at participating universities)
  - Innovation Management and Business Development
  - Hydrogen Safety
  - Hydrogen handling and infrastructure
  - Rules, Codes and Standards (RCS) and market development

Joint European Summer School (JESS)

on Fuel Cell, Electrolyseur and Battery Technologies

- every year for two weeks in September and in Athen
  (10.-23.09.2023 https://www.jess-summerschool.eu/)
- Targeted audience: University students (MSc and PhD levels), Post-doctoral researchers, experienced researchers and engineers (industry) for continuous professional development
- BAM lectures on hydrogen safety:
  - Challenges with metallic materials in H_2 technologies – O. Sobol
  - Explosion Protection for H_2 Applications Part I – E. Askar
  - Explosion Protection for H_2 Applications Part II and exercises – E. Askar
  - Sensors for safety and process control in H_2 technologies – C. Tiebe
  - Safety assessment of hydrogen gas storage systems – S. Günzel
  - Legal and policy framework & RCS of hydrogen technologies – T. Orellana

University of Namibia (UNAM)

- Five PhD students will start in 06/2023 on the topics of safe handling of H_2 and material compatibility in BAM (all associated to Trustworthy Hydrogen
- Initiated Research Project(s):
  - Cleanergy Hydrogen Plant (granted)
  - HyRail/DualFuel Locomotives (under discussion)
- Participation to master program at UNAM with two lecture streams from BAM and seven master theses at BAM (SASSCAL/BMBF Joint Call of Interest: Youth for Hydrogen (Y4H2)
- Welding Education and Training – not only for GH_2T

Cleanergy: H_2 Production & Refueling Plant

Capacity building: research and testing lab for GH_2T in Namibia

H_2Safety@BAM

MSc education together with UNAM

- 1^{st} Year: Tuition at UNAM, 2^{nd} Year: 6 month research stay at BAM
- 1^{st} Year: BAM contributes to lecturing: MRE streams at Unam (online and in presence)
  - 18 h: Hydrogen-Metal-Interactions & Materials Compatibility
  - 12 h: Hydrogen Safety and Handling
- 2^{nd} Year:
  - MSc students (max. 7) connected to the doctoral students at BAM


Sicherheit in Technik und Chemie

MSc & MEng at UNAM, incorporating a research stay at BAM on 'Safety in Green Hydrogen Technologies'

Opportunities for Specialization and further Career Development in Materials Compatibility and Hydrogen Safety at BAM within the MSc and MEng Programs at UNAM

MSc education together with UNAM

Welding Education and Training – not only for GH2T

- High-level workshop: Industry, UNAM, Ministry of Education
- Establish an Authorized Nominated Body (ANB) under the IIW
- Create a Master of Welding Engineering Program at UNAM
- Establish several Authorized Training Bodies (ATBs)

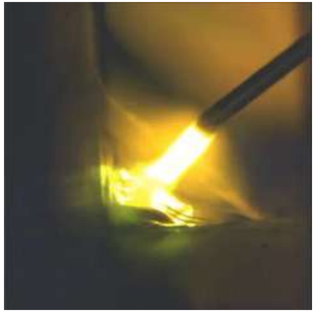
Qualification Levels / Guidelines:

- **IWE/EWE** – Engineer
- **IWT/EWT** – Technologist
- **IWS/EWS** - Specialist
- **IWP/EWP** – Practitioner
- **IWIP/EWIP** – Inspection Personnel (3 levels)
- **IW/EW** – Welder (3 levels, 4 processes)
- **IWSD** – Structures Designer (2 levels)
- Distance Learning
- **International/European Mechanized, Orbital and Robot Welding** (2 levels)

ISCED Level 7	**Additional qualification in engineering**
ISCED Level 6	
ISCED Level 5	**Additional qualification in metal-work. Industry or handcraft + min. 3 years experience**
ISCED Level 4	

INTERNATIONAL INSTITUTE OF WELDING

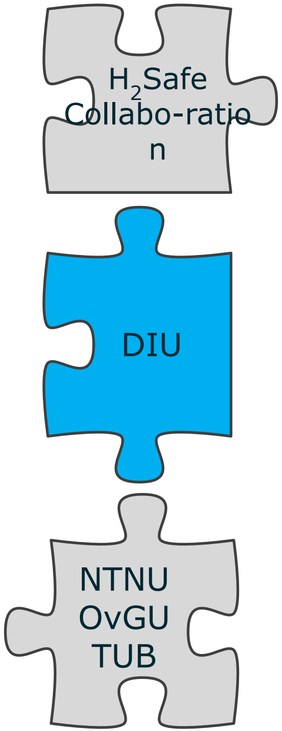
UNIVERSITY WEST



Cooperations with various institutes

BAM

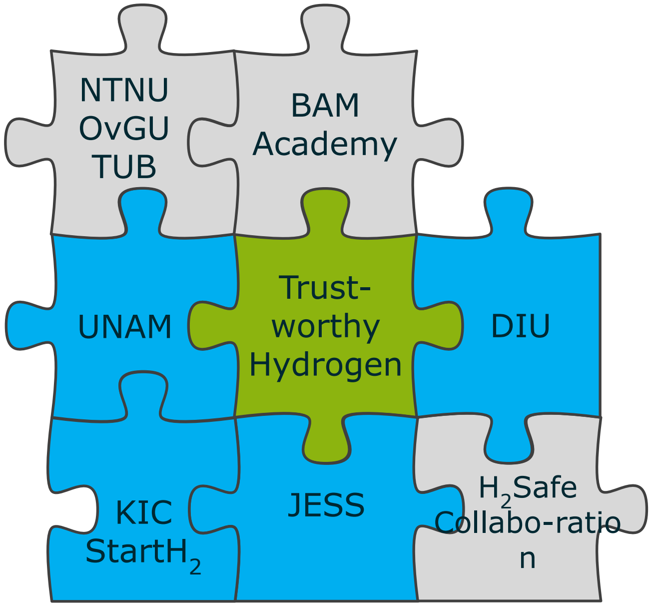
- H_2Safe Collaboration:
  - Establishment of an APRA research presence for hydrogen safety research between Germany and South Korea with partners from the Korea Gas Safety Corporation (KGS) and Hoseo University
  - Exchange of PhD students, Post-Doctoral students, experts
  - Joint master thesis
- Dresden International University (DIU)
  - Lectures in Module 8 within the study program “Hydrogen Technology and Economics”: Safety aspects, acceptance and materials engineering challenges of hydrogen
- Cooperations with Norwegian University of Science and Technology (NTNU), Otto-von-Guericke University (OvGU) and Technical University of Berlin (TUB)
  - Exchange of PhD students, Post-Doctoral students, experts
  - Joint master thesis



Summary

- BAM started many activities to tackle the problem of missing skilled workers in the field of Hydrogen Safety
- Trustworthy Hydrogen: first graduate school in Germany focused on hydrogen trustworthiness and safety
- Lectures on specific topics are used for the qualification program of Trustworthy Hydrogen and study programs at varius universities respectively summer schools
- Joint Master Thesis, exchange of PhD students and Post-Doctoral students in cooperation with various universities
- Activities together with UNAM are also considering further topics like welding and lab-capacity building

All activities have many interfaces.



Competence centre H_2Safety@BAM

We build trust in hydrogen technologies.

“German System of Apprenticeship Education”

Luise Maudanz
Zentralstelle für die Weiterbildung im Handwerk (ZWH)

Germany

ZUKUNFT. WEITERBILDUNG. HANDWERK.

ZWH

German System of Apprenticeship Education

Luise Maudanz Deputy Head of Department Sustainability and Internationalization of VET

www.zwh.de

Dual VET System

ZWH

Agenda

1. The basis for a dual vocational training system
2. The dual vocational training system
   - Tasks and responsibilities of vocational training facilitators
   - Advantages

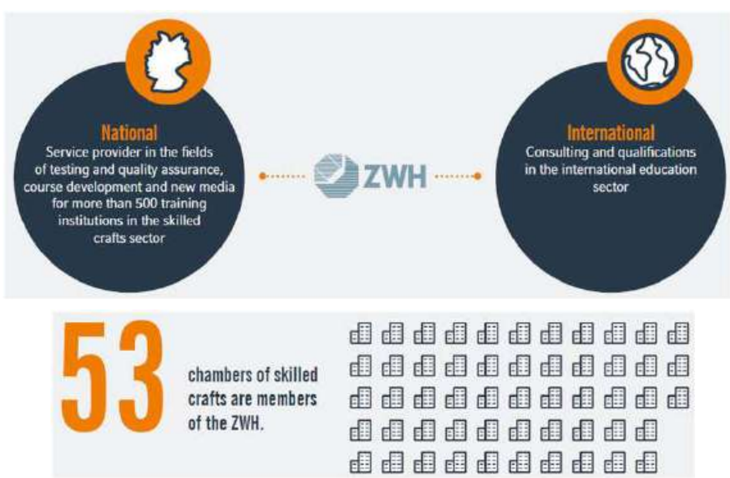
Speaker

Mrs. Luise Maudanz (Master of Arts)

- Deputy Head of the Department Sustainability and Internationalization
- 5 years of experience in developing innovative tools and training materials for dual VET in the international context, designing and conducting of national and international workshops

ZWH – Central Agency for Continuing VET in the Skilled Crafts

ZWH – VET-service provider for the skilled crafts sector in Germany and abroad



ZWH – VET service provider for the skilled crafts sector in Germany and abroad

- 53 chambers of skilled crafts with around 1 million companies
- 16,654 pages of developed course materials
- € 13.4 million total volume of projects and contracts
- 300 hours examination time

THE BASIS FOR A VOCATIONAL TRAINING SYSTEM

GO:VET German Office for International Cooperation in Vocational Education and Training

1. Motivation for Dual VET Engagement

Young people

"I want to work within a skilled occupation."

"I want to earn money."

"I want to learn something practical."

"I want further qualification."

"I want to attend upper secondary education."

"I want to become a …" (e.g. mechatronics engineer)

Seek and find a training place:

- **Look** for information on local employers providing VET.
- **Search** for a training place offer.
- **Apply** for training places at companies.
- **Select** a company.

GO:VET German Office for International Cooperation in Vocational Education and Training

1. Motivation for Dual VET Engagement

Employer

"I want employees who can competently fulfill the tasks and duties needed in my company, both now and in the future."

"I want workers to be loyal to my company."

"I want the productive and innovative contribution of apprentices."

"I want to save job familiarization and retraining costs."

"I have a social responsibility to offer training."

"I want to offer training."

Seek and find apprentices:

- **Obtain** a certification to provide training.
- **Offer** training place(s).
- **Assess** apprentices' applications.
- **Select** young person for VET.

GO:VET German Office for International Cooperation in Vocational Education and Training

1. Motivation for Dual VET Engagement

Government

"Government budgets for VET provision are limited."

"Highly skilled workers are needed for national economic growth and development."

"All young people need secondary education, so that they can achieve their full potential as citizens."

"Young people need to be ready for the labor market of today and tomorrow, so that they can find employment."

"We need to strengthen and regulate *Dual VET.*"

Supporting measures:

- **Set up** legal framework to regulate *Dual VET.*
- **Delegate** authority to stakeholders (chamber organizations, employers, labor unions, government institutions).
- **Open** access to *Dual VET* for everyone, regardless of prior qualification.
- **Include** *Dual VET* in compulsory secondary education.
- **Provide** part of *Dual VET* in public vocational schools.
- **Ensure** access for to higher education for *Dual VET* graduates.
- **Monitor and develop** *Dual VET* based on institutionalized VET research (BIBB).

GO:VET German Office for International Cooperation in Vocational Education and Training

2. Training Contract

Starting point for *Dual VET*

- similar to a **contract of employment**
- **legal basis** for in-company training in *Dual VET*
- provided and **registered by chamber organizations**
- **regulates:**
  - duration of training
  - beginning and end of training
  - probation period
  - vacations
  - content of training
  - training allowance
  - termination of contract
- Signing a training contract establishes a formal **training relationship** between the company and the apprentice.

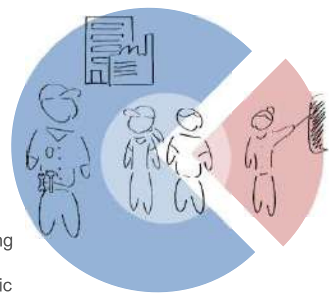
start of work-based learning in *Dual VET*

GO:VET
German Office for International Cooperation in Vocational Education and Training

3. Two Coordinated Venues for Learning

Two coordinated learning venues (*"Dual"*) for each VET program

70% of VET in-company



30% of VET in vocational school

In-company training:
- legal basis: training contract
- apprentice receives a "training allowance"
- Company provides systematic training under real-life working conditions (in-company trainer, up-to-date equipment, etc.).

Vocational school education:
- legal basis: compulsory education law
- Local government finances public vocational schools (facilities, teachers, etc.).
- Vocational schools offer lessons in vocational (2/3) and in general education (1/3) subjects free of charge.

approx. duration of Dual VET: 2–3.5 years

GO:VET
German Office for International Cooperation in Vocational Education and Training

4. Independent Examination

Multi-stakeholder examination board

Final examination:
- organized by chamber organizations

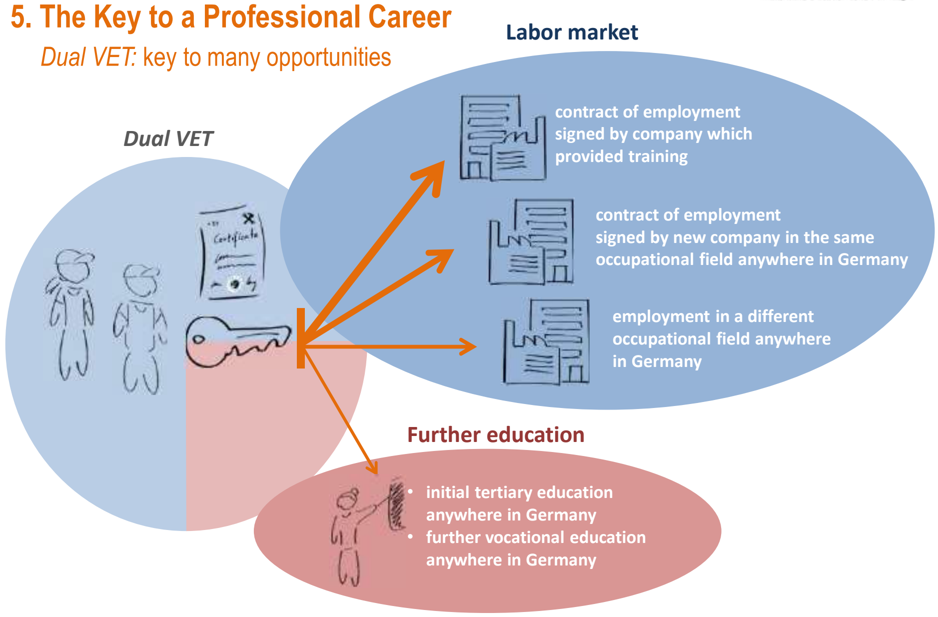
Examination board:
- composed of representatives of:
  - employers
  - employees
  - vocational school teachers (government)
- Those who trained the apprentice are generally not a part of the board.
- assesses and grades apprentice

***Dual VET* certificate:**
- issued by chamber organizations
- nationally recognized by government

Training contract ends | **Professional career begins**

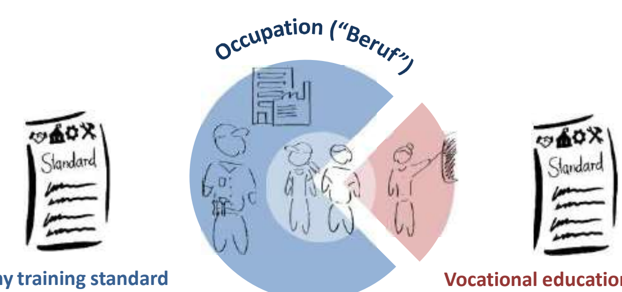
5. The Key to a Professional Career

Dual VET: key to many opportunities



6. Dual VET Standards Based on Requirements of the Working World

Demand-driven *Dual VET* standards guiding VET delivery in both learning venues



In-company training standard
("training regulations") includes:

- set of competencies for occupation to be trained (occupational profile/standard)
- how a company must teach the necessary skills for an occupation, as minimum requirements (training standard)
- what a trainee needs to know in order to pass the exam (examination standard)

coordinated

Vocational education standard
("framework curriculum") includes:

- learning objectives and content (structured in "learning fields") which form the basis for teaching vocational subjects in the vocational school
- the vocational theory required for working in a respective occupation

THE DUAL VOCATIONAL TRAINING SYSTEM – TASKS & RESPONSIBILITES OF VOCATIONAL TRAINING FACILITATORS

Tasks of Facilitators in the VET System

Day 1	Day 2	Day 3	Day 4	Day 5

Officially recognized training personnel
Core company-based training tasks:

- draws up a company training plan based on the training standard (training regulations)
- imparts wide-ranging occupational skills, knowledge and personal competence (types of behavior, ability to work as part of a team, autonomy, etc.)
- integrates apprentices into the company and supports them in possibly gaining permanent employment (recruitment)
- organizes the training process
- provides support in the preparation for exams and involves specialist department and colleagues

Teacher of prof. theory and gen. education
Core vocational school teaching tasks:

- organizes teaching on the basis of the framework curriculum
- imparts professional theory and principles of occupational practice in a wide-ranging manner
- imparts general knowledge
- imparts personal competence

Duration of Dual VET: 2–3.5 years

Different tasks carried out by training personnel and teachers **complement one another** within the scope of the **coordination between learning venues** in the Dual-VET system.

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German Office for International Cooperation in Vocational Education and Training

The Company as a Learning Venue – Training Personnel

Core tasks – an example

1 **"I work as a vehicle mechatronics technician at a garage where I teach my occupation to young people."**

2 "I teach apprentices how the company operates. I integrate them into the team and socialize them."

Certified trainer

6 "I network with my line manager, the parents, the chambers, the vocational school and the employment agency."

3 "I show apprentices things like how a car works and how it can be repaired."

5 "I plan and develop the training on the basis of standards specific to the occupation."

4 "As soon as an apprentice has some experience, I allow them to take on more and more responsibility for repairing cars, and I provide the necessary support."

- Company-based training personnel are **skilled workers who provide training** (mostly on a part-time basis).
- Training tasks are strongly aligned to the **requirements of the company.**
- Tasks usually extend **far beyond mere training activity and work instructions.**

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German Office for International Cooperation in Vocational Education and Training

The Company as a Learning Venue – In-Company Trainers

Why are they important for companies?

1 **"My company provides training, because it enables me to find and retain competent staff, and this is crucial for success."**

2 "In order for my company to provide training in the dual system, it needs to be officially recognized as a company that offers training. One criterion is employing state-recognized training personnel (BBiG)."

Company owner

3 "My skilled workers already train other staff members informally, but they need higher qualification to be able to provide training."

5 "My company provides training in the dual system. Staff members have better opportunities for further occupational development."

4 "I enable my skilled workers to pursue further education and take a chamber examination in order to become qualified trainers."

State-recognized training personnel is important for companies:

- Companies wish to **acquire and secure new skilled workers.**
- They seek to **strengthen their skilled workforce with additional competencies** (pedagogical) and create **incentives**.
- They want to be **permitted to provide training** in the dual vocational education and training system.

GO:VET German Office for International Cooperation in Vocational Education and Training

The School as a Learning Venue – Teachers

Core tasks – an example

1 **"I teach motor vehicle engineering and history at a vocational school."**

2 "In motor vehicle engineering, I equip apprentices with professional knowledge relevant to occupational practice, such as how an engine is structured and how it works."

6 "I network with the vocational school director, training personnel at the company, parents, the chamber and the employment agency."

Teacher of professional theory and general education

3 "I create practical foundations. Apprentices learn how to produce and install parts and what needs to be kept in mind."

5 "I plan and evaluate my teaching independently, whilst complying with the state's framework curriculum."

4 "I impart soft skills to the apprentices and I am available as a contact person for any social issues the young people may have."

- Teachers impart knowledge on **professional theory, the principles of occupational practice and general education.**
- Their tasks extend beyond mere teaching duties.
- The basis for their activity is the state's **educational mandate.**

GO:VET German Office for International Cooperation in Vocational Education and Training

The Vocational School as a Learning Venue – Teachers

Why are teachers important to the state?

1 **"We seek to provide young people with employability skills and integrate them into society. We need good skilled workers to produce a strong macro economy."**

2 In order to fulfil its economic and societal aims, vocational education and training should "enable pupils to practise an occupation and be involved in shaping the world of work and of society whilst fulfilling their social and ecological responsibility." (Source: KMK)

4 We train the necessary teaching staff at institutes of higher education and employ these teachers as public sector workers at vocational schools.

3 For this purpose, only qualified teachers are made available to the vocational schools in their function as learning venues. Both professional theory and general education are taught at the vocational school, so that apprentices may acquire employability skills.

Teachers of professional theory and general education are important:

- They impart **solid professional knowledge and general education** to young people.
- They thus implement the **educational policy's objectives** at vocational schools.

In-Company Trainers

- responsible for basic vocational training
- responsible for providing hands-on instruction
- provide step-by-step instruction during training in the work process
- take care of 70% of the total training
- contribute to the examination
- participate in the development of training standards

Vocational School Teachers

- responsible for basic vocational training
- responsible for systematic theoretical training
- also teach in general education subjects
- teach cross-professional skills, e.g., project work or learning techniques
- contribute to the examination

Managers of Vocational Training Institutions

- responsible for management, monitoring and support measures in the vocational training process
- implement results of research on vocational education and training
- guarantee inter-company training and thus the acquisition of skills that must be acquired within the duration of training
- may train staff members
- contribute to the examination, if necessary

THE DUAL VOCATIONAL TRAINING SYSTEM – ADVANTAGES

Advantages of a Dual Vocational Training System – Apprentices

- acquire skills and qualifications for the future
- acquire not only theoretical, but also practical knowledge under real conditions within the everyday working life
- Vocational education provides an opportunity for further education.
- Apprentices receive a training allowance.

Advantages of a Dual Vocational Training System – Companies

- They gain skilled workers, who exactly meet their requirements.
- Young professionals (former apprentices) are 100% productive from the 1st day on the job.
- No need for an introductory training saves expenses.
- Former apprentices identify with the company from the beginning.
- They can also influence training standards by helping to develop the occupation’s standards.

Advantages of a Dual Vocational Training System – State

- positive influence on society and economy
- instrument to manage the training of young people and influence quality of training
- capable of modernization and further development
- meets the economy's demand for skilled workers
- strengthens cooperation between stakeholders
- recognizes developments in the labor market at an early stage

ZUKUNFT. WEITERBILDUNG. HANDWERK.

Thank you for your attention!

Do you have any questions?

Luise Maudanz, ZWH
Phone: +49 178 4918753
Email: lmaudanz@zwh.de

zwh.de/our-service-porfolio

CHAPTER 4. LOGISTICS OF GREEN HYDROGEN BETWEEN AFRICA AND GERMANY/EU

“Green hydrogen production, transportation and utilization in the marine sector”

Dr. Han Sol Jung
KSOE

South Korea

HD KOREA SHIPBUILDING & OFFSHORE ENGINEERING

Green hydrogen production, transportation and utilization in the marine sector

May. 24th, 2023

Dr. Han Sol Jung, Senior Researcher

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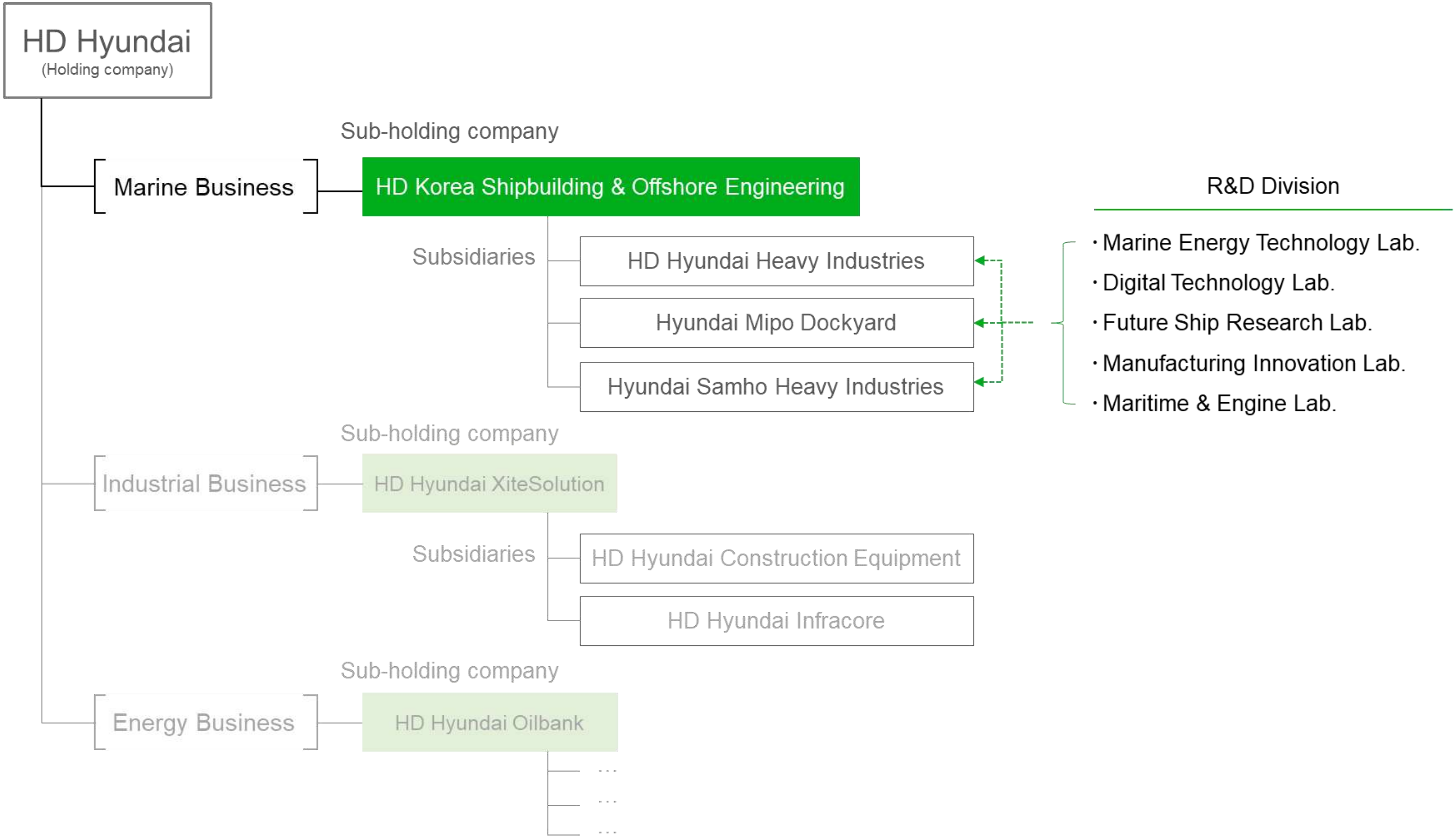
About us : HD Hyundai group

HD KOREA SHIPBUILDING & OFFSHORE ENGINEERING

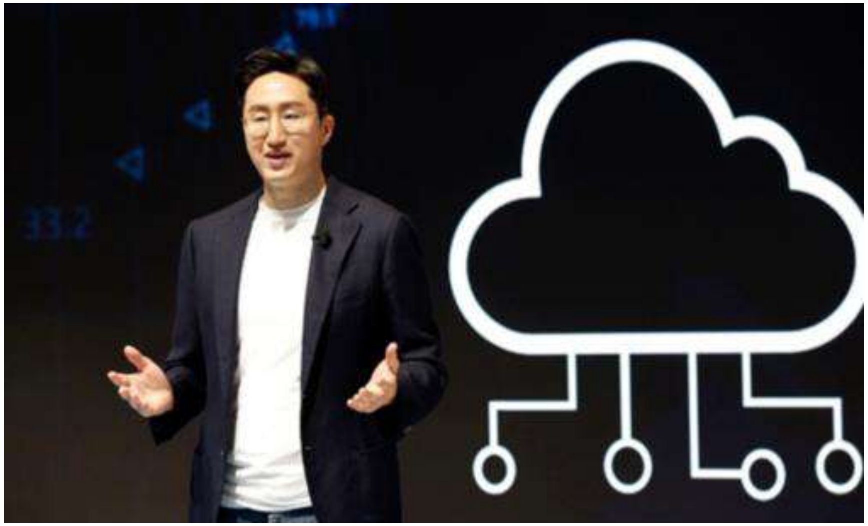
HD Hyundai group (Hyundai Heavy Industry group)



- HD KSOE : Sub-holding company of the Group's shipbuilding & offshore businesses
- Leading company specialized in R&D and engineering for marine business area

HD KOREA SHIPBUILDING & OFFSHORE ENGINEERING

HD Korea Shipbuilding & Offshore Engineering (HD KSOE)

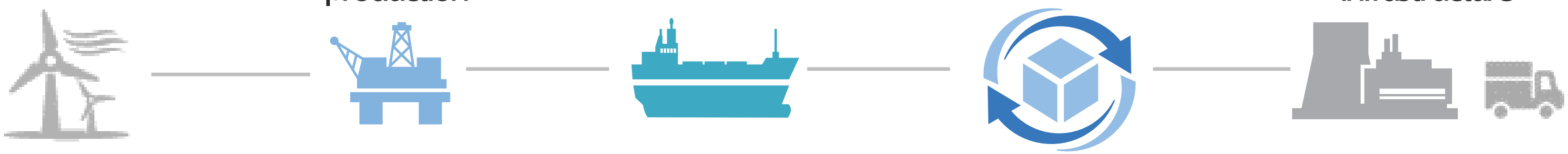


[CES 2022] HD Hyundai Group sets vision to become "future builder" - Hydrogen vision 2030

- Hydrogen business value chain from upstream to downstream
- Leading future global maritime green hydrogen market

Shipbuilding & offshore engineering → **HD Hyundai group**

Offshore power generation — Hydrogen production — Transportation — Storage — Utilization & Infrastructure



Renewable energy & power generation infrastructure	Green hydrogen production infrastructure	Hydrogen transportation infrastructure
HD KOREA SHIPBUILDING & OFFSHORE ENGINEERING HD HYUNDAI HEAVY INDUSTRIES HD HYUNDAI ELECTRIC	HD KOREA SHIPBUILDING & OFFSHORE ENGINEERING HD HYUNDAI HEAVY INDUSTRIES HD HYUNDAI ELECTRIC HD HYUNDAI OILBANK	HD KOREA SHIPBUILDING & OFFSHORE ENGINEERING HD HYUNDAI HEAVY INDUSTRIES HYUNDAI MIPO DOCKYARD HYUNDAI SAMHO HEAVY INDUSTRIES

Engineering for Carbon Neutrality : Our endeavor

HD KOREA SHIPBUILDING & OFFSHORE ENGINEERING

Hydrogen production : HYUNDAI nearshore green hydrogen production platform

Innovative idea for more economical green hydrogen production

Green hydrogen production platform with viable technologies minimizing development time and cost

- HYUNDAI green hydrogen production platform, enabling low-cost green hydrogen by reducing CAPEX/OPEX.
  - The concept of 'Nearshore floating green hydrogen & e-fuel production platform' (Approval in Principal from ABS, May 2022)
  - Unveiled LH2 carrier at GASTECH exhibition.('22.09)
  - Aiming of commercializing with 100MW capacity of electrolyzer for the first time in the world ('27)
  - This concept can produce low-cost green hydrogen by reducing CAPEX/OPEX

[Comparison between the location of the production platform]

	Offshore	Near-shore	Onshore
Construction Period	○ (Works in factory, Pipe/Cable works)	◎ (Works in factory)	△ (civil engineering)
Construction Cost	X (Pipe/Cable double investment)	◎ (No civil engineering)	△ (Land cost, civil engineering, etc.)
Operation difficulty	X (Hard to access)	○	○
Acceptance	◎	○	△ (Hazard Facility)
Regulation	△ (Offshore rule)	◎ (Marine rule)	○ (Local regulation)

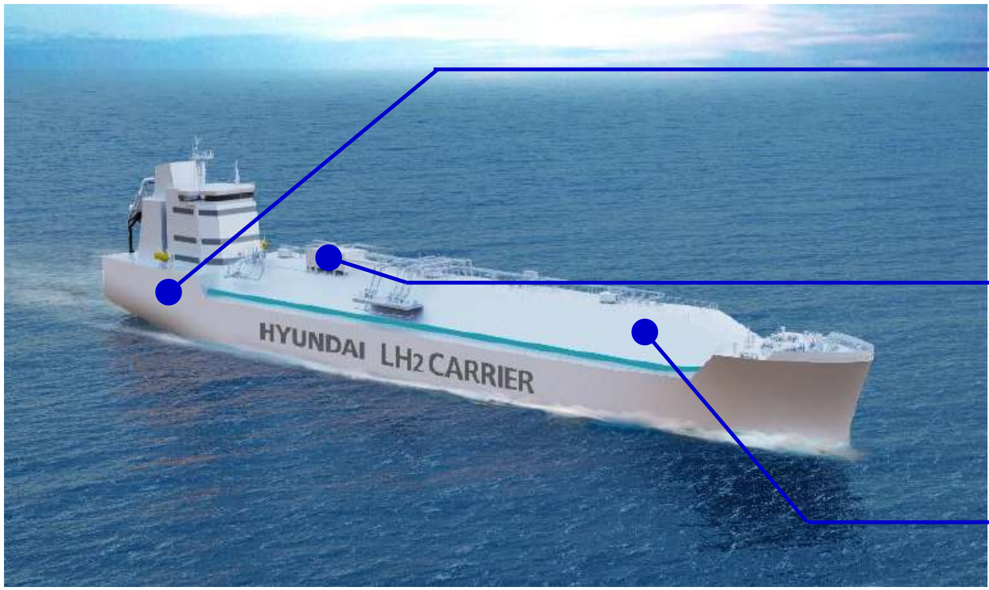
[Concept for nearshore green hydrogen platform of HD Hyundai group]

Hydrogen transportation : HYUNDAI LH2 Carrier

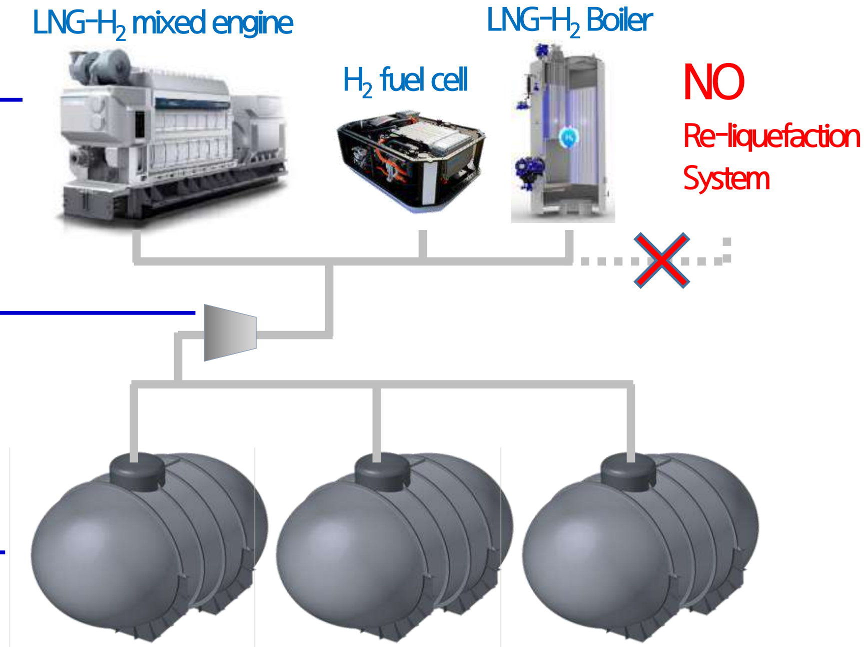
Innovative idea for more economical green hydrogen transportation & utilization

LH_2 carrier with viable technologies minimizing development time and cost

- HD HYUNDAI LH_2 Carrier, enabling ZERO hydrogen cargo waste during voyage
  - the concept of 'Zero H_2 Cargo Loss' without hydrogen loss during ship operation
  - Unveiled LH_2 carrier concept at GASTECH exhibition.('21.09)
  - Aiming of commercializing 20,000m3 LH_2 carriers for the first time in the world ('27)



[Concept drawing for LH2 carrier of HHI group]



Transformation into a Zero Carbon Society

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GHG Regulation in Maritime Industry

Stricter GHG regulation in Maritime industry to Net Zero GHG

IMO INTERNATIONAL MARITIME ORGANIZATION

Target : CO_2 70%, GHG 50% reduction* by 2050

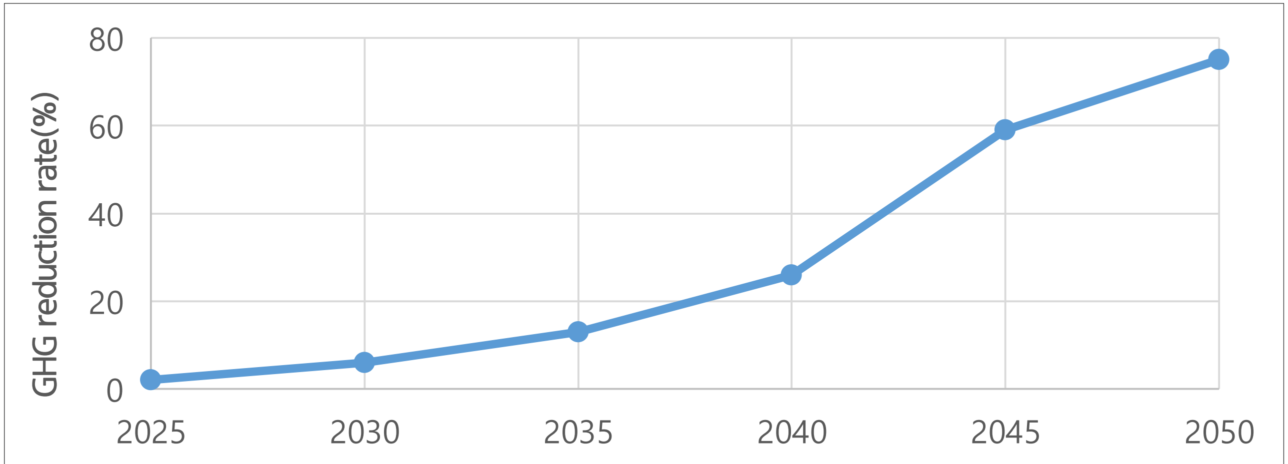
- New vessel CO_2 regulation, EEDI('13)
- Existing vessel CO_2 regulation, EEXI('23) CII('23~'26)
- Well-to-Wake standard is to be applied

European Union

Target : Net Zero GHG by 2050

- Introduction of GHG emission reduction policy **'FIT for 55'**('21)
  - 55% reduction by '30 (w.r.t '90)
- **Stricter Well-to-Wake emission regulation** and ETS scheme extended to maritime transport

Transition to Zero Carbon fuel accelerates**



* : Change of IMO's target to Net Zero GHG by 2050 is under discussion

** : Biofuels(Diesel, Methanol, Gas), e-fuel(Green hydrogen, Green ammonia, Green Methanol)

- EEDI : Energy Efficiency Design Index
- EEXI : Energy Efficiency Existing Ship Index
- CII : Carbon Intensity Indicator
- ETS : Emissions Trading System
- AMP : Alternative Maritime Power

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Fuel Transition Outlook by Type of Mid/Large Size Ships

Due to stricter environmental regulations, LNG fuel use is reaching technical limitations

- In accordance with IMO/EU regulations, maritime fuel transition is expected as follows

Diesel → Low Carbon Fuel* → Low Carbon + Carbon-free*/Zero Carbon Fuel mix → Zero Carbon Fuel

- Fuel transition will be differentiated by type of ship (Cargo fuel use first)

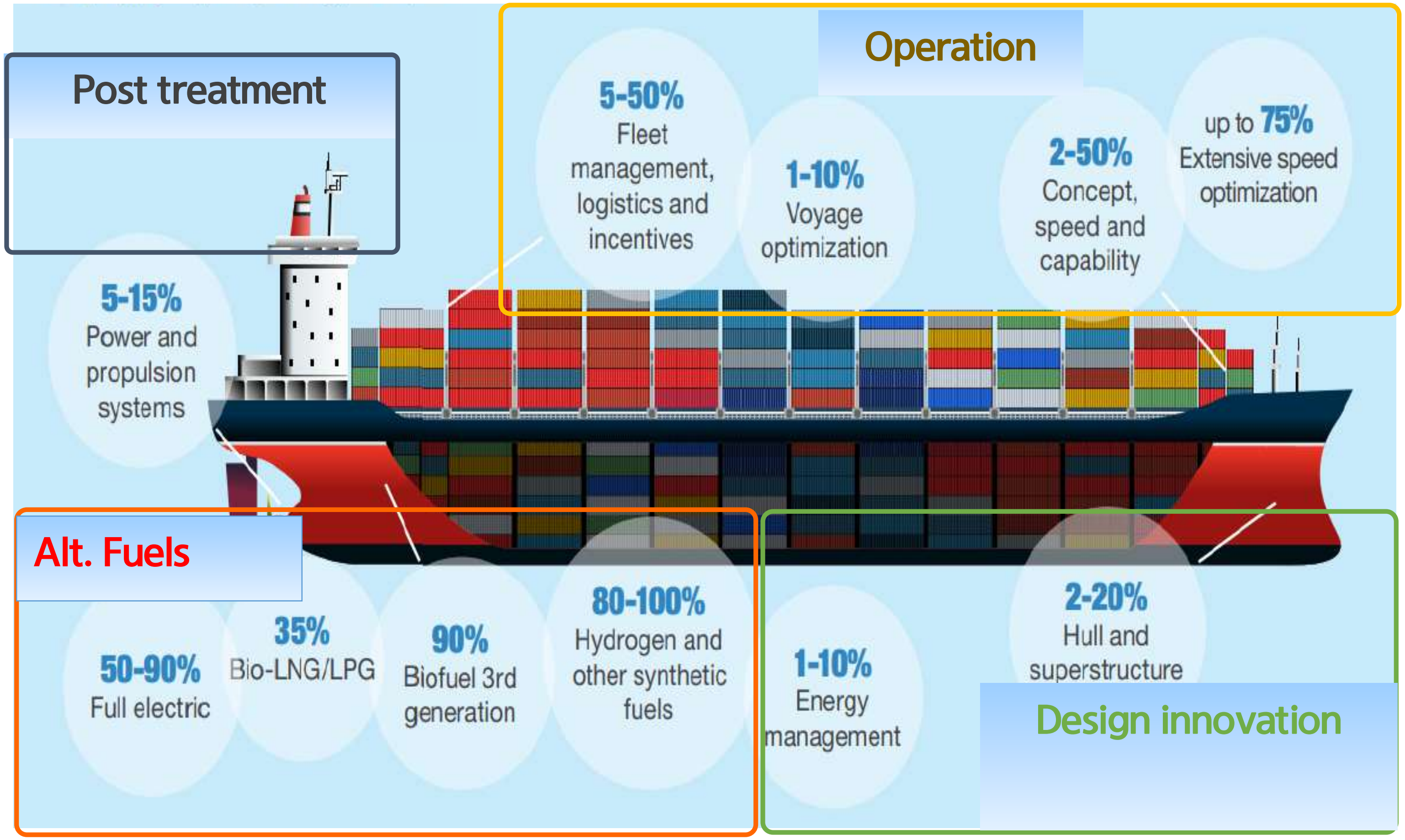
years	2020	2022	2025	2030	2040	2050 ~
EEDI Phase (reduction rate)	II(20%)	III(30%)		IV(40%)	V(50%)	VI(70%)
LNGC	LNG DF				LNG DF (LNG+Zero Carbon Fuel)	**Zero Carbon Fuel**
LPGC	Diesel	LPG DF		LPG DF(LPG+Zero Carbon Fuel)		
Container	Diesel				LNG DF (LNG+Zero Carbon Fuel)	
Bulker	LNG DF				LNG DF (LNG+Zero Carbon Fuel)	
Hydrogen Carrier			LNG DF (NG+ Hydrogen)		**Hydrogen**	
Midsize Ships (Bulker, Tanker, Container - call & sail @ EU)	Diesel				**Ammonia or Hydrogen**	

* : Low Carbon fuel : LNG, LPG, · Zero Carbon fuel : Ammonia, Hydrogen

GHG Reduction Technologies : Viable Solution for Emission Regulations

Due to stricter environmental regulations, alternative fuel technology must be developed

- It is difficult to achieve IMO's GHG reduction target by energy-saving technology only
- To meet the CO_2 abatement goal, "Alternative fuel" plays a key role of GHG reduction strategy in ship design perspective



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Transformation into a Zero Carbon Society : Change in ship fuel selection

Changes in ship fuel have already begun, and commercialization of decarbonized fuel is expected after 2030

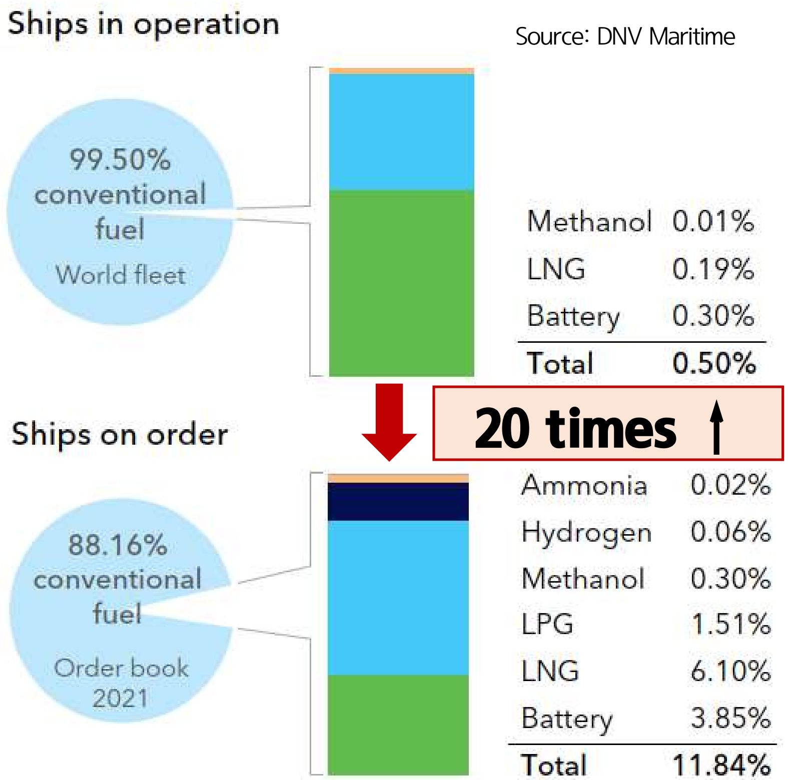
More than 15% of vessel ship age is over 20 years

- Within 10 years almost 30%(Over 20, 15years) of existing vessel might be replaced by alternative fueled vessel
- Bulk Carrier and Container Ship have large proportion of old age among all ship type

Conversion of ship fuel

- Increasing the application of alternative fuel for new-order
- Alternative fuel ship construction rate : abt. 12%, More than 20 times the ship in service (0.5%).
- Methanol, LNG, Battery, LPG, Hydrogen, Ammonia

Source: DNV Maritime



Methanol	0.01%
LNG	0.19%
Battery	0.30%
Total	**0.50%**

Ammonia	0.02%
Hydrogen	0.06%
Methanol	0.30%
LPG	1.51%
LNG	6.10%
Battery	3.85%
Total	**11.84%**

[Percentage of global ships by fuel('21.06)]

Gearing up for Alternative Fueled Ships

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Viable Solution Complying with Emission Regulations

LNG in the short term, to alternative fuel (biofuel, ammonia/hydrogen) in medium/long term

Characteristics of alternative Fuels

Low carbon fuel

LNG
LPG

- Infrastructure
- Global Availability
- Long Term Solution
- Safe to handle
- High CAPEX
- Methane slip

Carbon Neutral

Bio Fuels
Green-Methanol

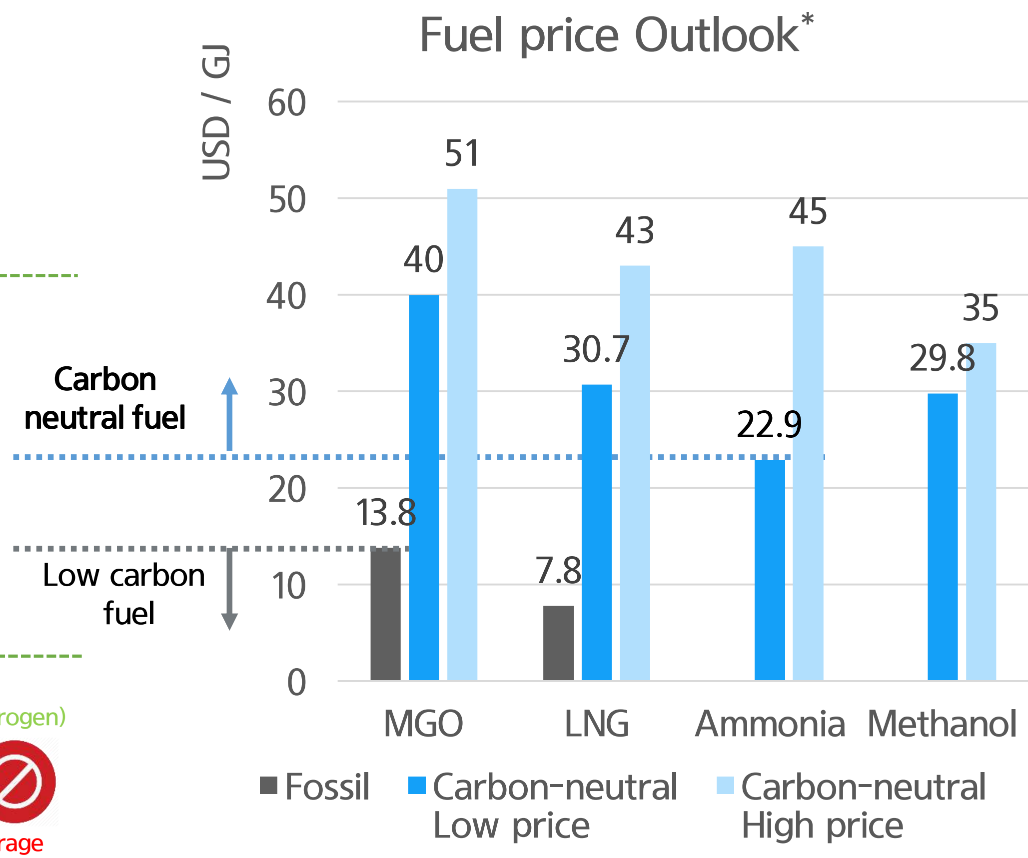
- Carbon Neutral
- High OPEX
- Sustainable Scaling up needed
- Limited bunkering

Zero Carbon

Ammonia
Hydrogen

- Long Term Solution
- Zero carbon
- High CAPEX
- High OPEX
- Limited bunkering
- Ammonia: Toxic to handle
- (hydrogen): Storage challenge; Flammable to handle

Alternative Fuels price outlook



* DNV, Maritime Forecast to 2050, 2021

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HD Hyundai group's solution for Zero Emission Fuel Solutions

Zero emission fuel carrier/fuel propulsion vessel based on the world's best gas carrier technology

HD Hyundai group's solution for Zero Carbon Fueled Ship

- Proven technological our competitive edge by contract from the world first methanol fueled vessel
- Leading next generation green fuel maritime market by developing ammonia, hydrogen fueled vessel

Methanol Fueled

World First Methanol DF

Contract Record-Maersk

- 2021, 9 Container Ship
- 2022, 4 Container Ship

Ammonia Fueled

■ Leading Ammonia Marine Application

- Ammonia Fueled Engine Development
- Zero Leak Safety System Development
- "Class" Approval : All Type of Vessel

Hydrogen Fueled

■ Preparing Hydrogen Era

- Hydrogen Engine Development
- Large Scale Tank Product Development
- Tank Vaccum Insulation (-253 ℃)

	2021	2022	2023	2024	…
Ammonia	Ammonia DF Concept Design	Zero Leak Safety Design	Major Equipment Design	Ammonia DF Engine & Ship Design Ready	
Hydrogen	Hydrogen Carrier Concept Design	LNG-Hydrogen Propulsion System	20K Hydrogen Carrier design	Large Scale(~160K) Hydrogen Carrier Design	

Trends of methanol fueled vessel

Transition to zero carbon fueled vessel : green-fuel in medium/long term

Pros and Cons of Green Methanol fueled ship

- Pros : High Technical Readiness Level, Well established Infrastructure, Easy Handling
- Cons : Limited renewable energy, biomass energy

Maersk's vision : Achieve Net Zero till 2040

- Strong Green Methanol Supply Chain Build-up

[Shipping giant Maersk to become major green hydrogen consumer as it embraces methanol fuel]

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What's next ? – future collaboration option

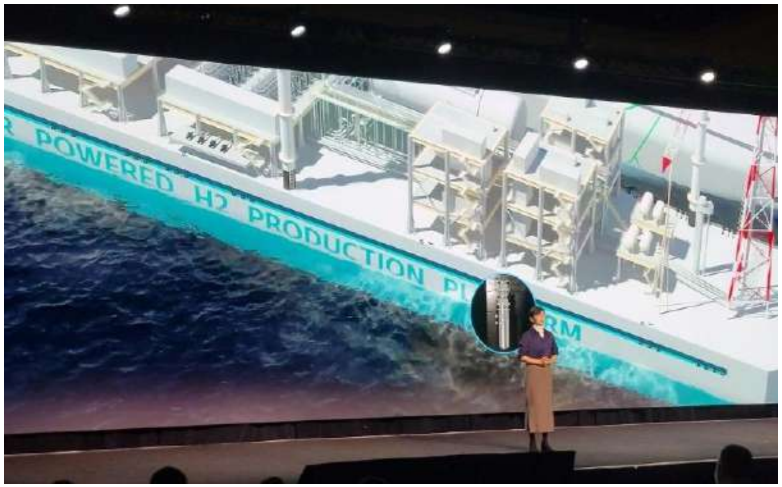
Engineering for Carbon Neutrality : Our endeavor and future collaboration option


Korea Shipbuilding opens European R&D center in Germany

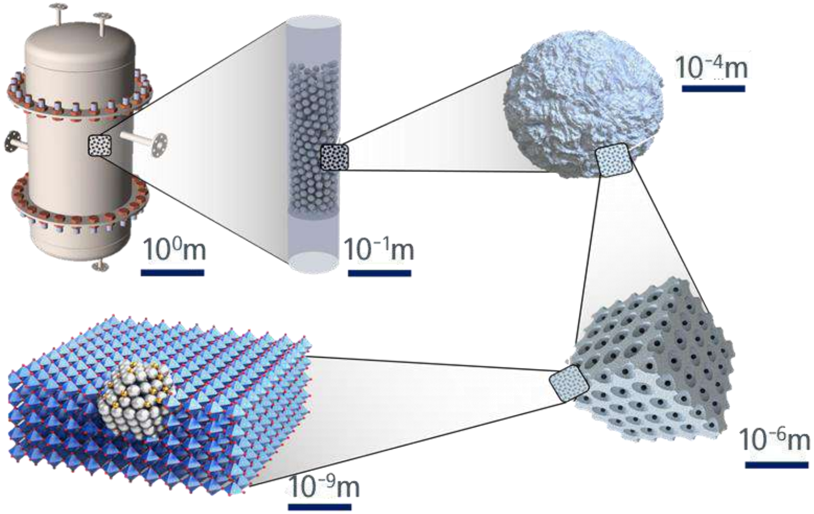
The opening ceremony for Korea Shipbuilding & Offshore Engineering's European research and development center in Dusseldorf, Germany, is seen in this April 12 photo provided by the company. Yonhap

[HD KSOE global R&D center in Germany]

[Location of HD KSOE global R&D center in Germany]



[CES2023 presentation]



[Development scale of computational catalyst design]

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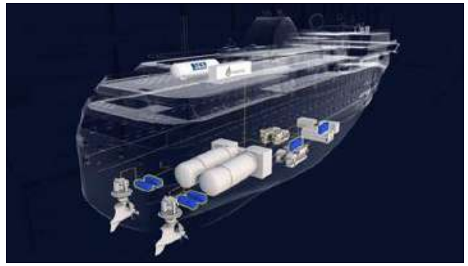
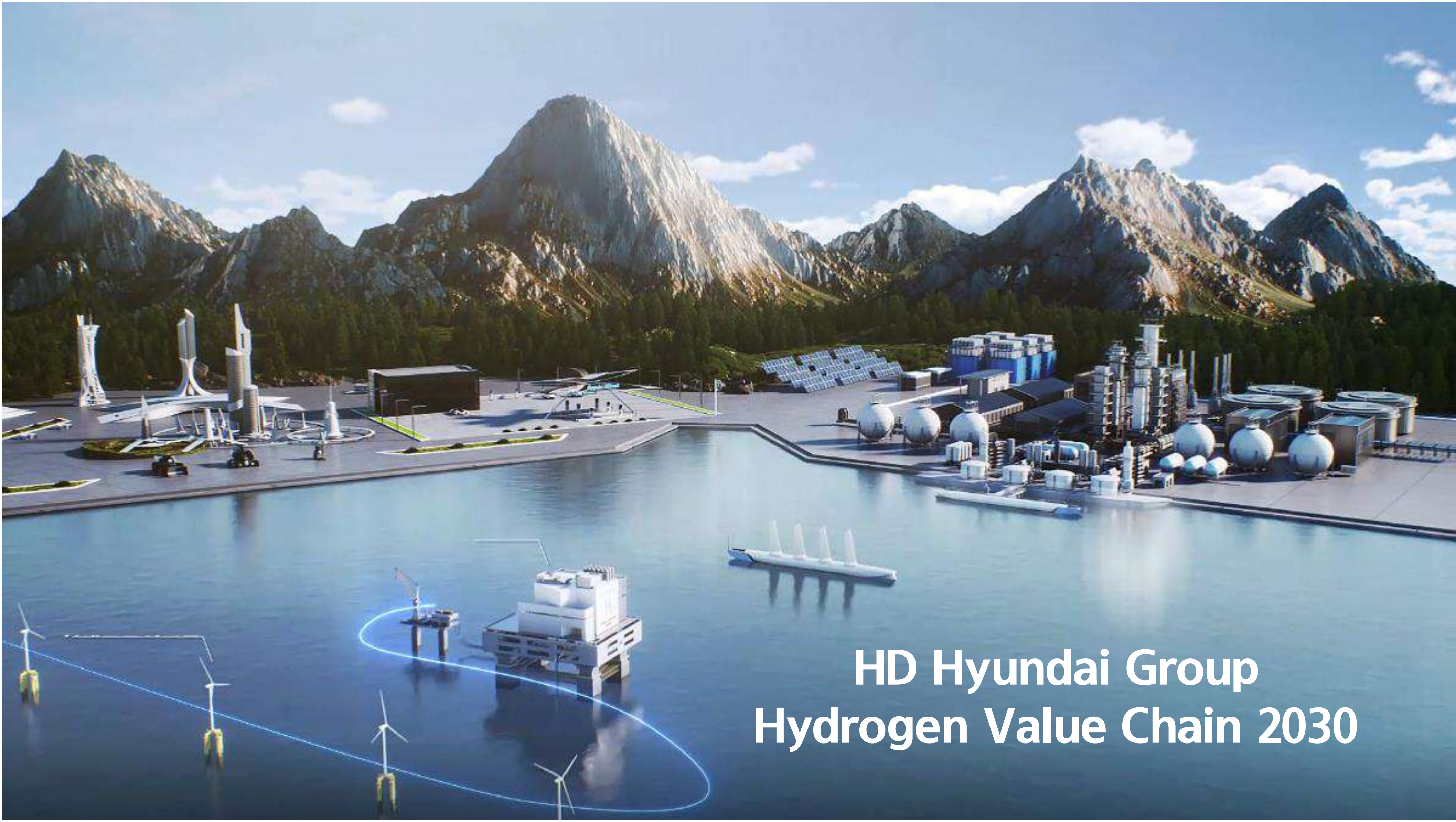
Future green hydrogen value chain in the marine sector

Gearing up for Alternative Fueled Ships : possible green hydrogen value chain of HD Hyundai Group

Hydrogen value chain (zero carbon)

Offshore Wind Power Generation	Hydrogen Production Infrastructure & Plant	Marine Transportation & Storage	Utilization
		 	
•AIP for 10MW offshore wind turbine floater ('21) •Renewable energy generation through offshore wind power generation (~'23) •200 MW offshore wind power plant (~'25)	•AIP for nearshore green hydrogen production plant ('22) •High performance offshore water electrolysis (~'26) •100 MW offshore green hydrogen production plant from offshore wind power (~'28)	•AIP for 20K liquid hydrogen carrier ('21) •AIP for 91K ammonia carrier ('21) •20K liquid hydrogen carrier (~'24)	•Development of a hydrogen fuel cell system package using PEMFC (~'23) •Electric hybrid Ship (~'24)


HD Hyundai Group
Hydrogen Value Chain 2030

“Promoting Green Hydrogen Economy in Central Germany”

Tobias Richter
HYPOS

Germany

Promoting Green Hydrogen Economy in Central Germany

Tobias Richter

HYPOS

Gefördert durch:
Die Bundesregierung
aufgrund eines Beschlusses des Deutschen Bundestages

SACHSEN-ANHALT
Ministerium für Wirtschaft, Tourismus, Landwirtschaft und Forsten

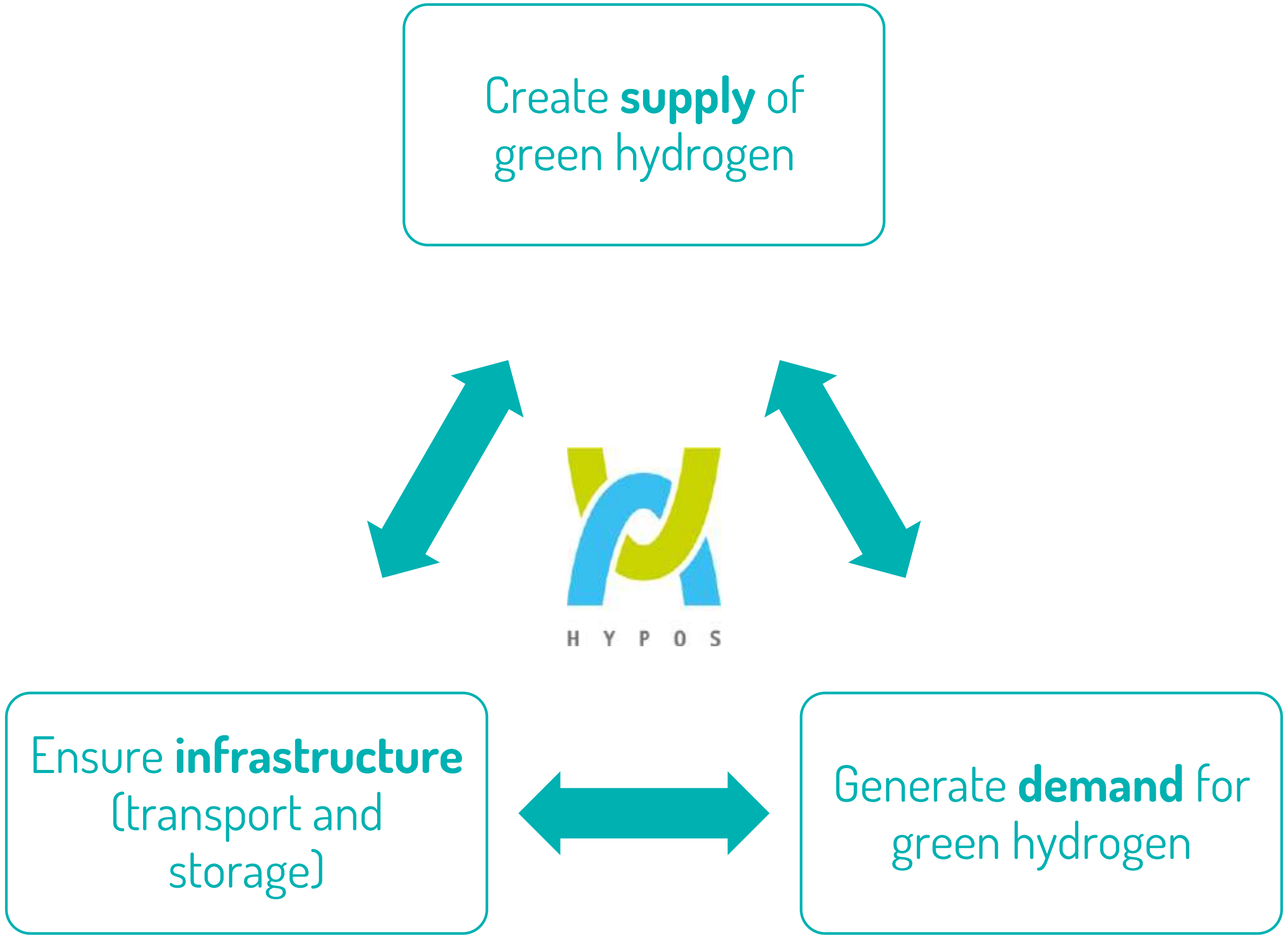
H Y P O S HYDROGEN POWER STORAGE & SOLUTIONS

HYPOS network – our Members

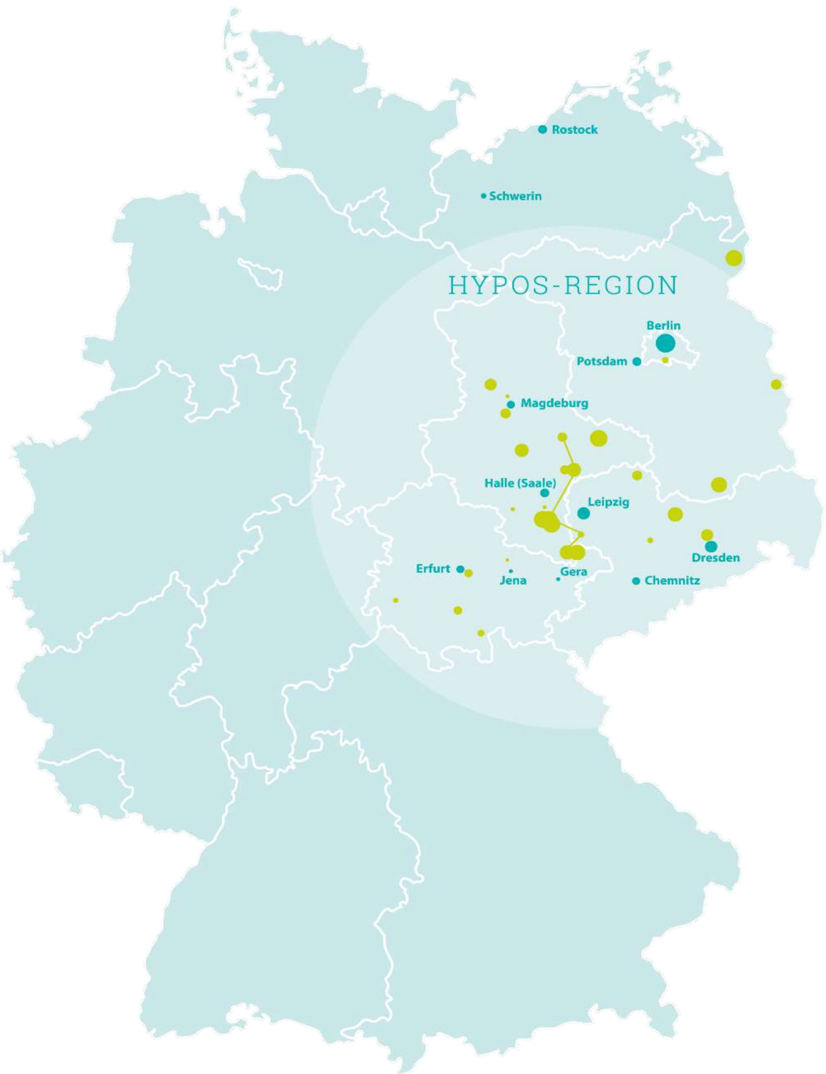
➢ **more than 170**

Status: September 2022, Source: HYPOS e.V.

HYPOS – Challenge

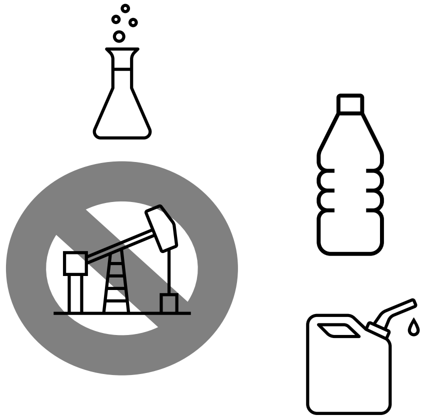


Hydrogen **demand** in Germany

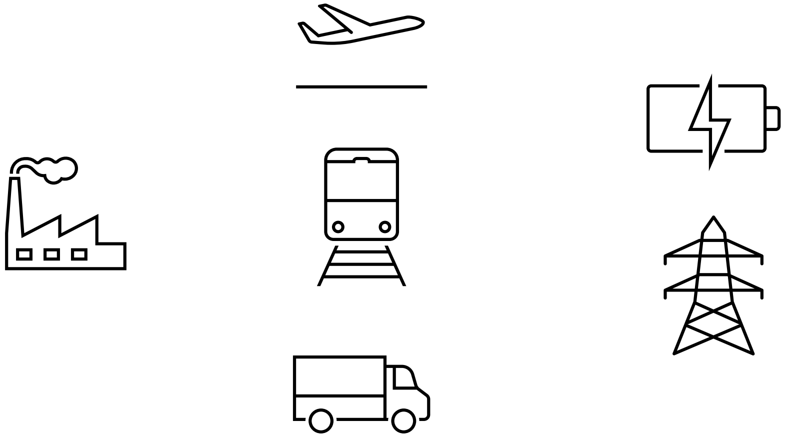


Now → **Future**

Consistent hydrogen revenue for years: around **50 TWh**

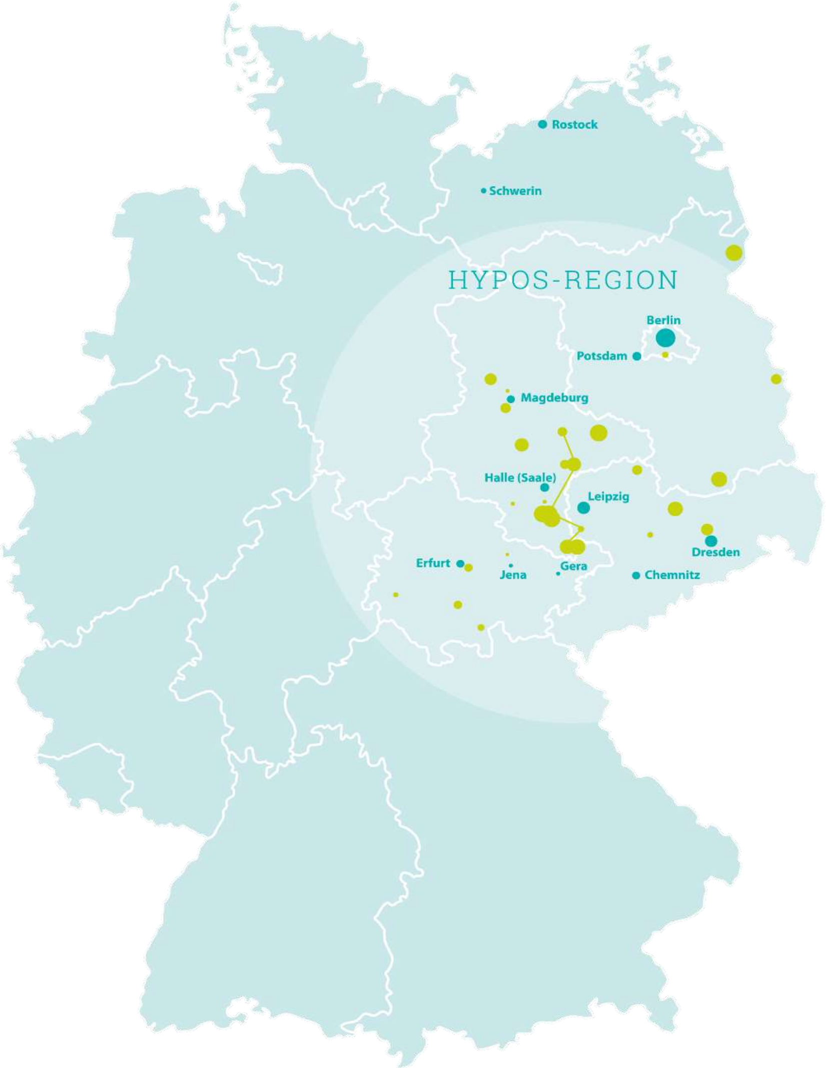


Growing hydrogen demand



HYPOS

Hydrogen **demand** in Germany



Now → **Future**

Consistent hydrogen consumption for years:

- Germany: around **50 TWh**
- Central Germany: **14,3 TWh**

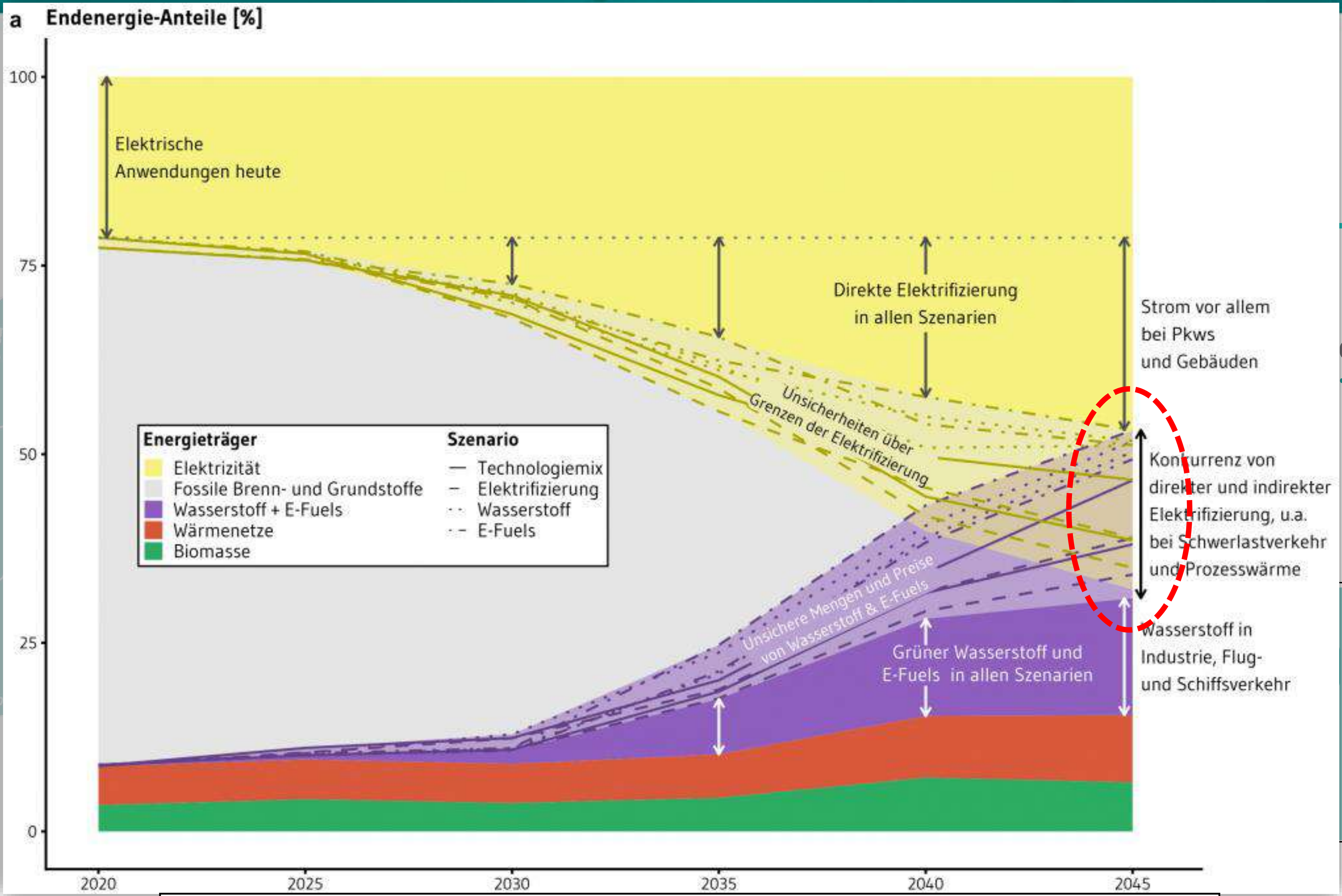
Estimated hydrogen demand

- 2045: **125 – 800 TWh/a**

Depending on the

- level of electrification
- economic growth
- ambition of climate protection

HYPOS



→ **Future**

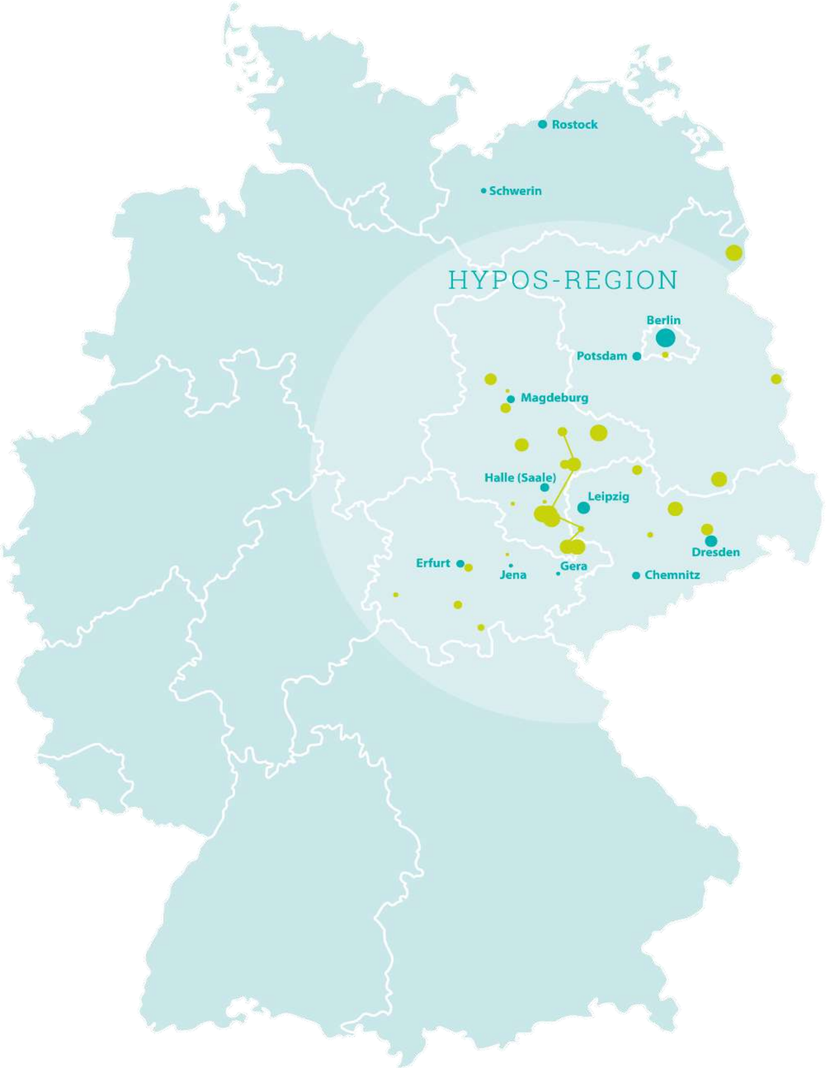
emand

TWh/a

[2021, Ariadne, *Kurzdossier: Durchstarten trotz Unsicherheiten – Eckpunkte einer anpassungsfähigen Wasserstoffstrategie* , https://ariadneprojekt.de/publikation/eckpunkte-einer-anpassungsfaehigen-wasserstoffstrategie/]

H Y P O S

Hydrogen **demand** in Germany



Now → **Future**

Consistent hydrogen consumption for years:

- Germany: around **50 TWh**
- Central Germany: **14,3 TWh**

Growing hydrogen demand

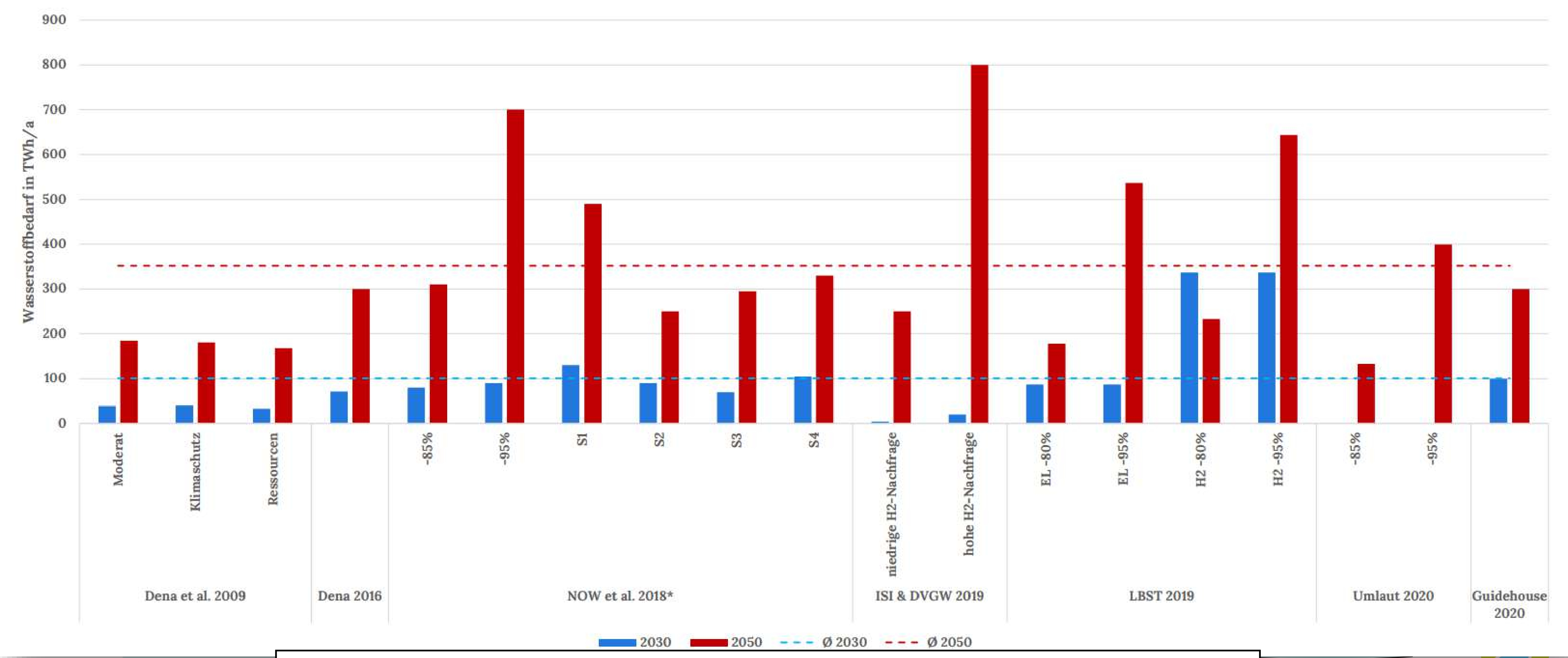
- 2050: **125 – 800 TWh/a**

Depending on the

- level of electrification
- economic growth
- ambition of climate protection

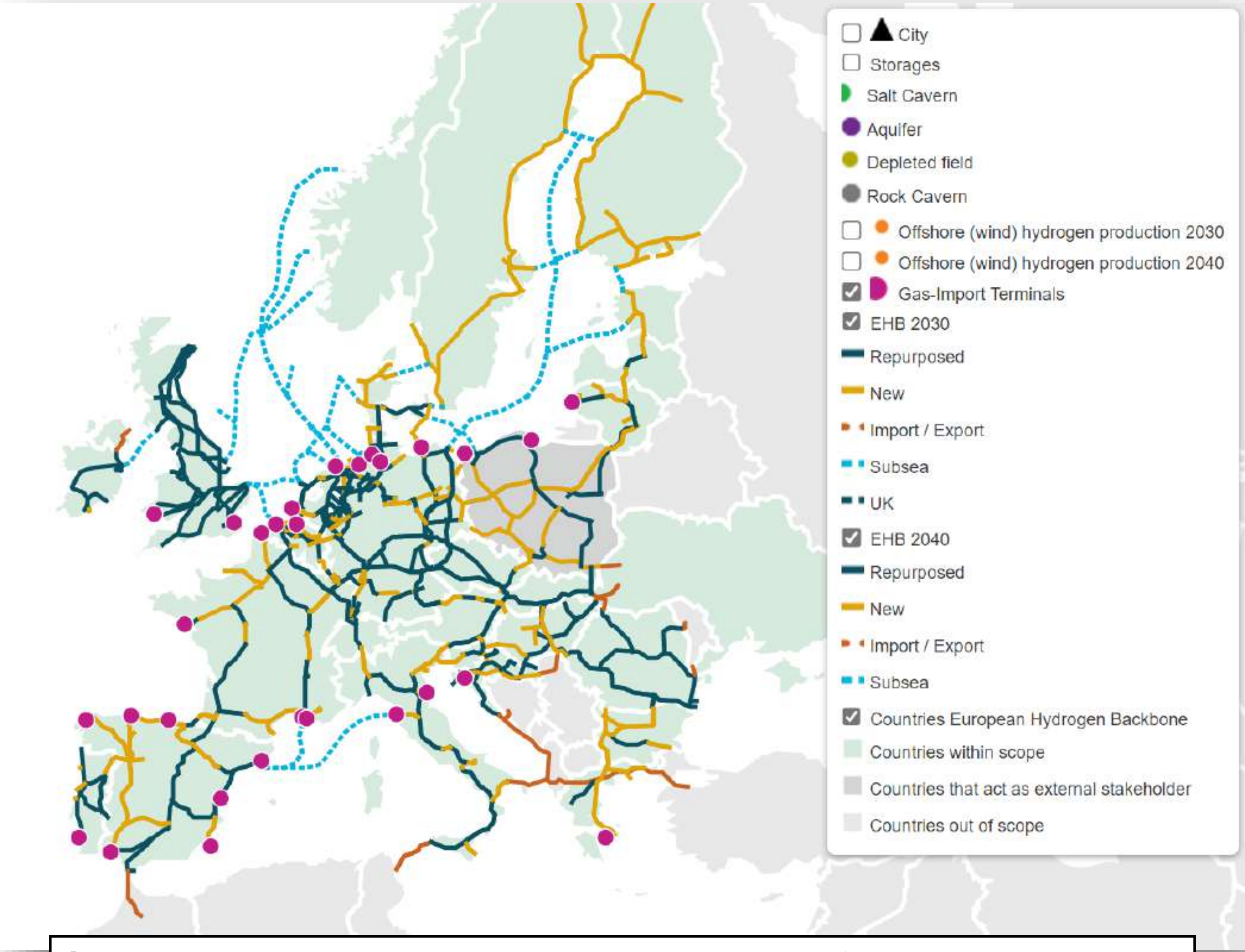
HYPOS

Hydrogen **demand** in Germany

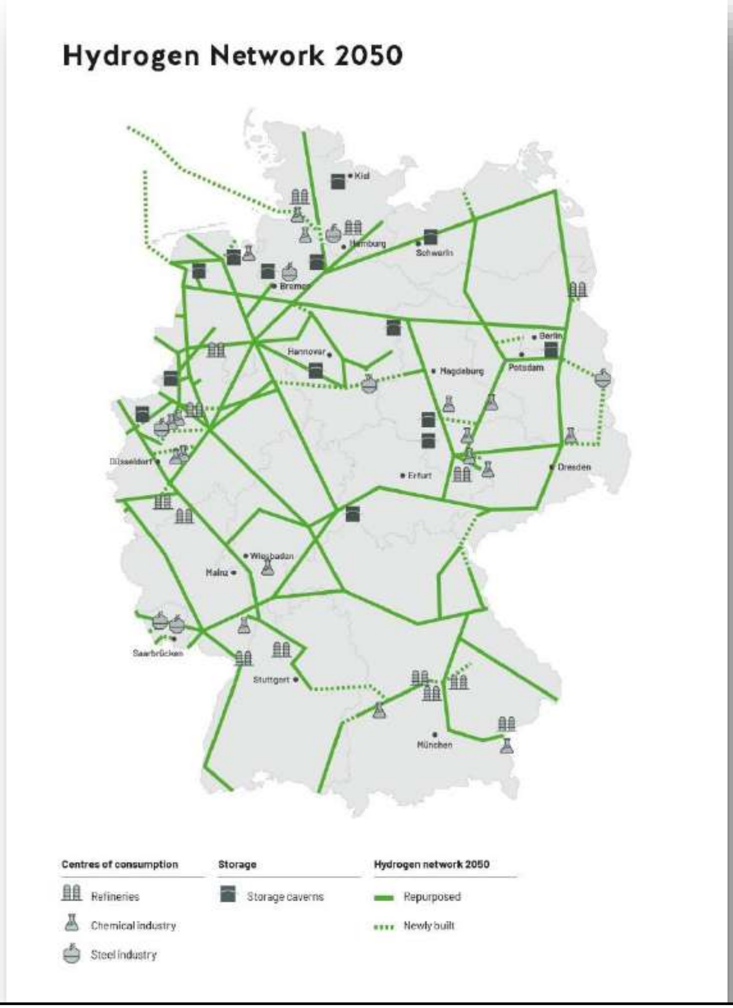


[2021, Ariadne, *Kurzdossier: Durchstarten trotz Unsicherheiten – Eckpunkte einer anpassungsfähigen Wasserstoffstrategie* , https://ariadneprojekt.de/publikation/eckpunkte-einer-anpassungsfaehigen-wasserstoffstrategie/]

Hydrogen **infrastructure** in Europe and Germany

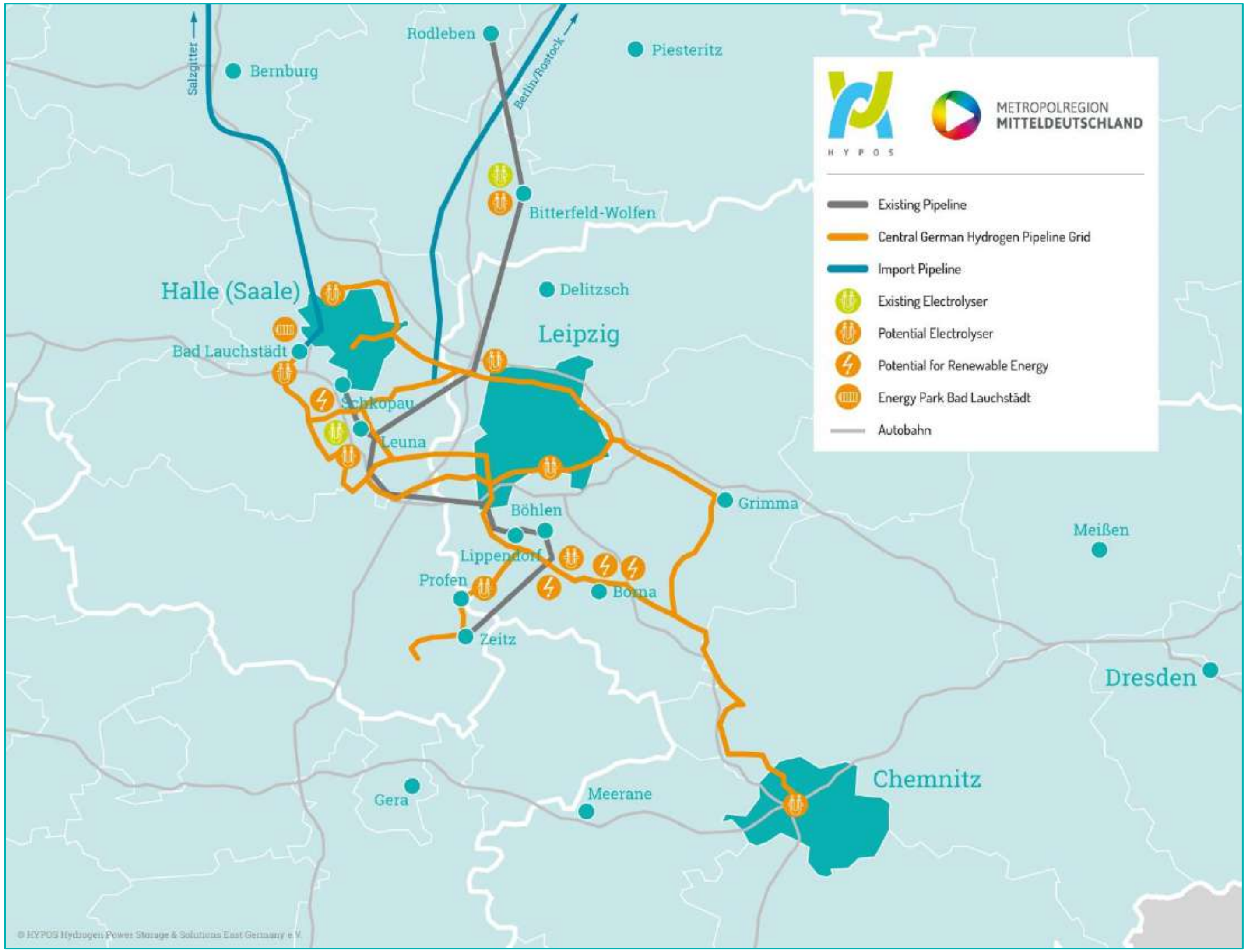


[European Hydrogen Backbone, European Hydrogen Backbone Maps | EHB European Hydrogen Backbone]



[FNB GAS, H2-Netz 2050, Wasserstoffnetz 2050: für ein klimaneutrales Deutschland - FNB GAS (fnb-gas.de)]

HYPOS – Central Germany Hydrogen Pipeline Grid



Final results

- total length: 339 km (40% conversion; 60% construction)
- pipeline segments: 13
- total investment: 422-610 Mio €
- regional H_2-demand by 2030: **20 TWh/a**
- regional H_2-supply by 2030: 2,5 TWh/a
- **import infrastructure** via Rotterdam and Rostock

HYPOS

Conclusion

Challenges

- **Infrastructure**: from planning into practice
- sufficient hydrogen **supply**
- competitive hydrogen **costs**

Our local benefits

- Existing hydrogen demand
- 150 km of hydrogen pipeline

Milestones

- Expansion of renewable energies
- Initial implementation in infrastructure
- Scale up in hydrogen production technologies
- Secure imports

HYPOS

THANK YOU FOR YOUR ATTENTION

Tobias Richter

Feel welcome to contact me at richter@hypos-eastgermany.de

Gefördert durch:
Die Bundesregierung
aufgrund eines Beschlusses des Deutschen Bundestages

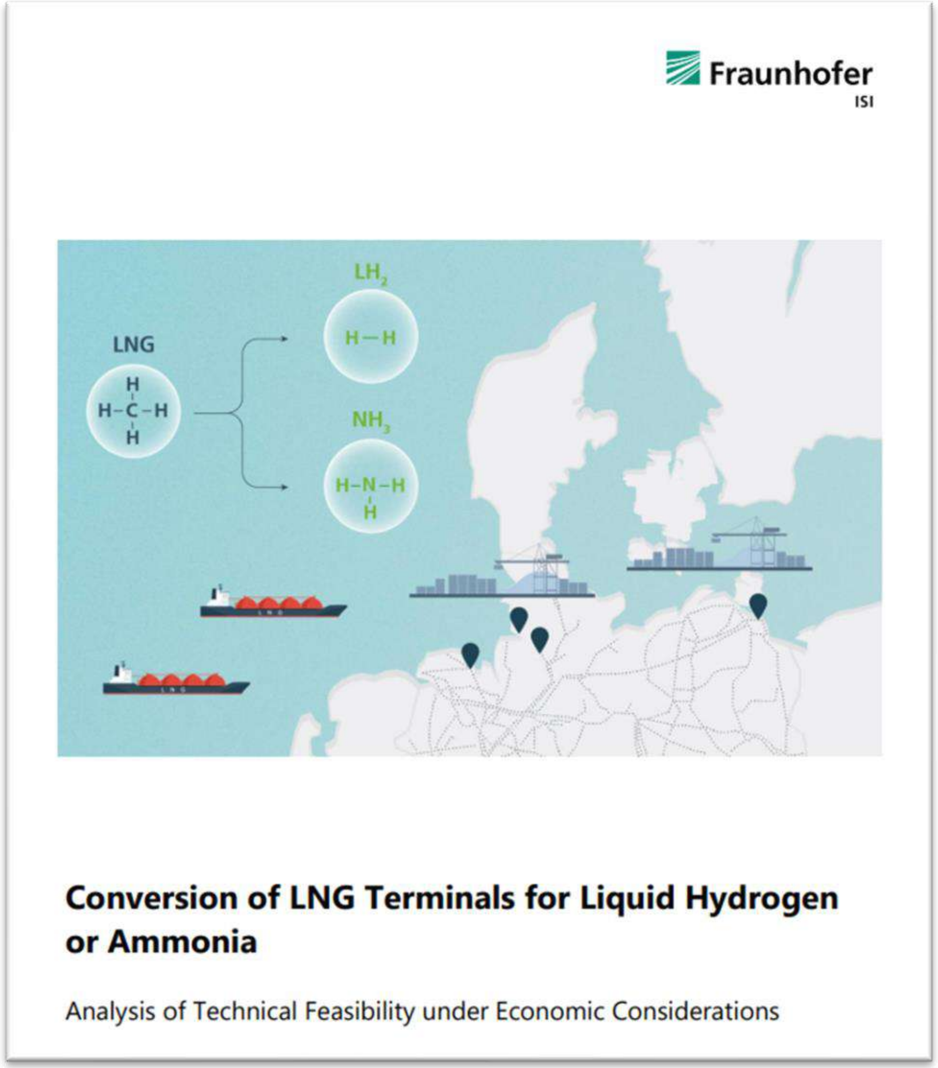
SACHSEN-ANHALT
Ministerium für Wirtschaft, Tourismus, Landwirtschaft und Forsten

H Y P O S HYDROGEN POWER STORAGE & SOLUTIONS

LNG-Terminals

Conversion to hydrogen-ready terminals

- Conversion feasible but associated with further **costs** and **effort**
- At the moment **not ready** for hydrogen or ammonia



[Riemer, M.; Schreiner, F.; Wachsmuth., J. (2022): Conversion of LNG Terminals for Liquid Hydrogen or Ammonia. Analysis of Technical Feasibility und Economic Considerations. Karlsruhe: Fraunhofer Institute for Systems and Innovation Research ISI.]

HYPOS

“Metallic Materials Compatibility For Safe Green Hydrogen Applications”

Dr.-Ing. Thomas Böllinghaus
BAM
Dr. Zivayi Chiguvare
UNAM

Germany / Namibia

Sicherheit in Technik und Chemie

May 2023

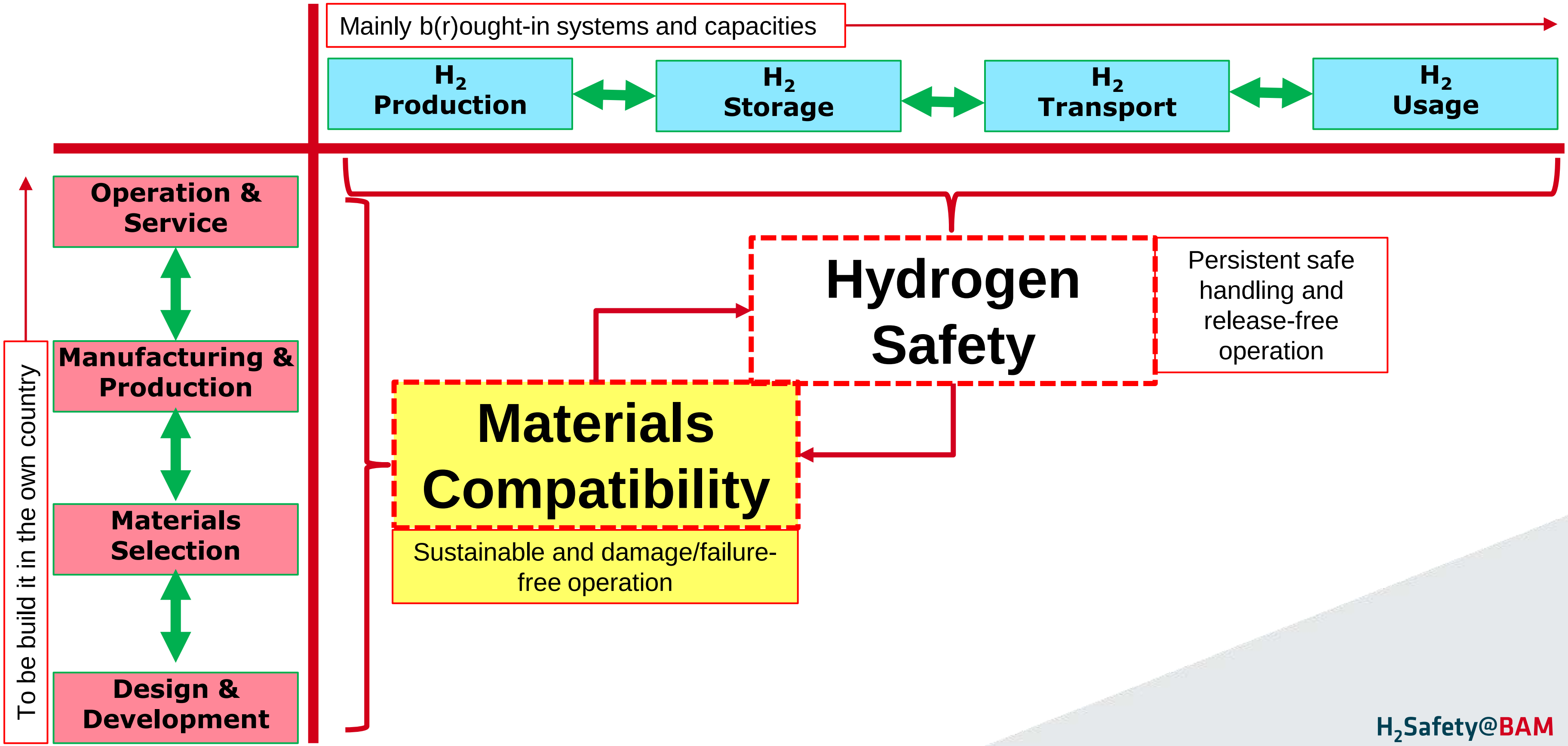
METALLIC MATERIALS COMPATIBILITY FOR SAFE GREEN HYDROGEN APPLICATIONS

Thomas Böllinghaus,
HoD Component Safety @ BAM, GH_2 Advisor and Hon.-Prof. @ UNam
Zivayi Chiguvare, Acting Dir NGHRI, UNam
Eike Krafft, MD, Cleanergy

1. Introduction (Hydrogen Metal Interactions)
2. MatCom for Hydrogen Transport and Piping
3. Research Project for Capacity Building (Edu & Labs)
4. Conclusions

www.bam.de

Value Chains Associated to GH_2T



BAM

Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

DEEP DIVE: HYDROGEN IS NOT AN INERT MEDIUM !

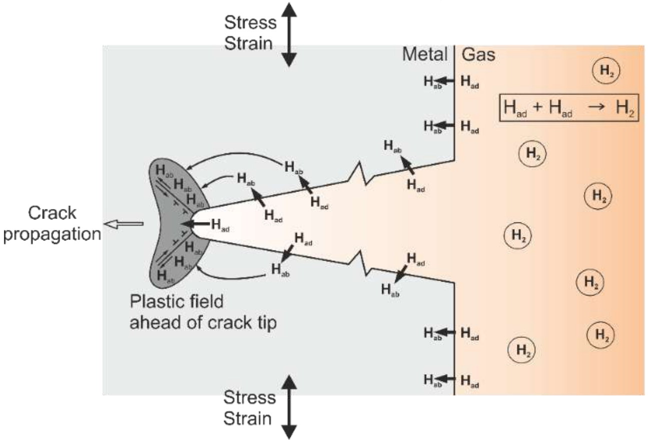
HYDROGEN METAL INTERACTIONS (HMIs)

www.bam.de

HMIs I: Hydrogen might enter containment materials !

Types of hydrogen uptake: Combinations are possible !

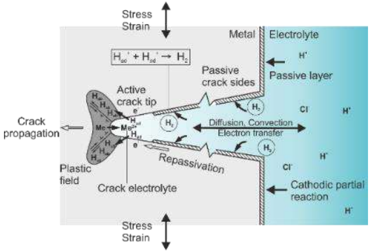
Pressurized hydrogen



- → GH_2 Applications
- → Dependent on p and T
- → Dependent on purity !
- → Lower concentrations
- → Deeper trapped

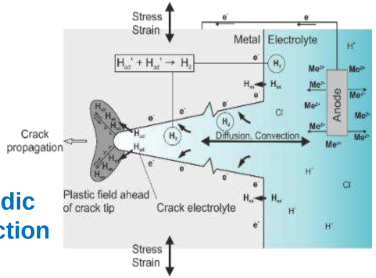
Risk for pressurized hydrogen assisted cracking (PHAC)

Electrolychemical (aqueous) environments – No dissociation



Free corrosion

Cathodic protection



Risk for hydrogen assisted Stress corrosion cracking (HASCC)

Risk for hydrogen assisted corrosion fatigue (HACF)

Th. Boellinghaus et al.: Materials Science and Engineering, K. H. Grote, E. K. Anderson (Eds.): Handbook of Mechanical Engineering, 2nd Ed. Springer, New York, USA (2020), Part B3

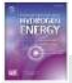
New formula:

Assessment of the absorbed H concentration dependent on p and T considering microstructural trapping sites, fugacity and multiaxial stress

$$c_H = K_0(T)\sqrt{f}\exp\left(-\frac{\Delta H_S - \sigma_H V_H}{RT}\right)$$

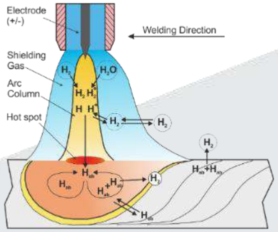
Enhanced gaseous hydrogen solubility in ferritic and martensitic steels at low temperatures

Andreas Drexler, Florian Konert, Oded Sobol, Michael Rhode, Josef Domitner, Christof Sommitsch, Thomas Böllinghaus



Welding:

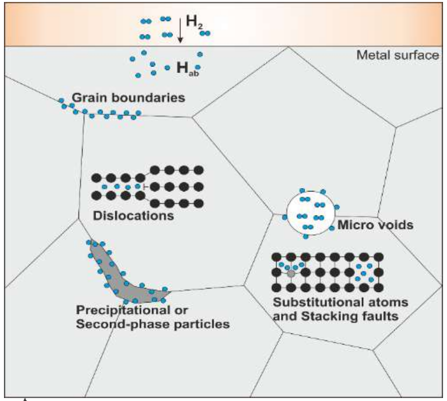
Risk for hydrogen assisted cold cracking (HACC)



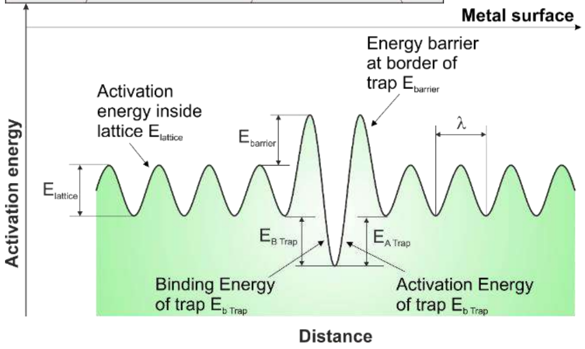
H2Safety@BAM

HMIs II: Hydrogen will move in metallic materials !

Trapping and Enhanced diffusion: Combinations are possible !

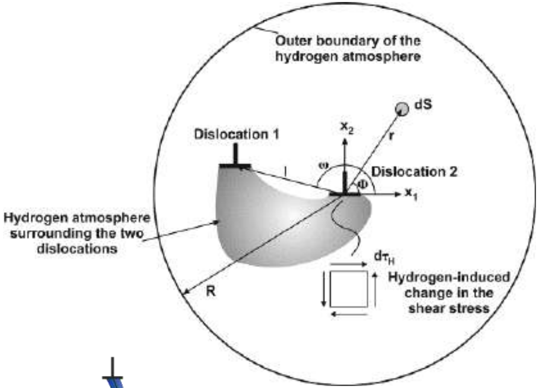


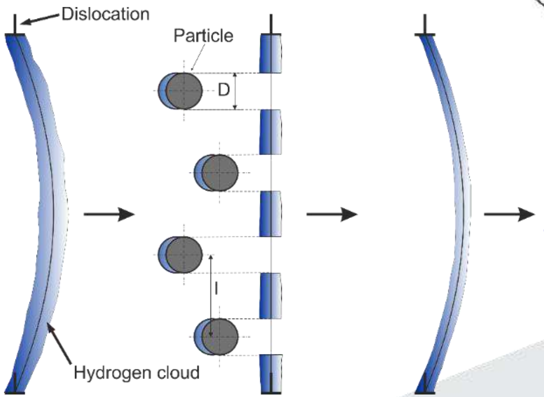
Hydrogen trapping at various microstructural imperfections



Reversible trapping

Enhanced hydrogen transport in the strain field of dislocations



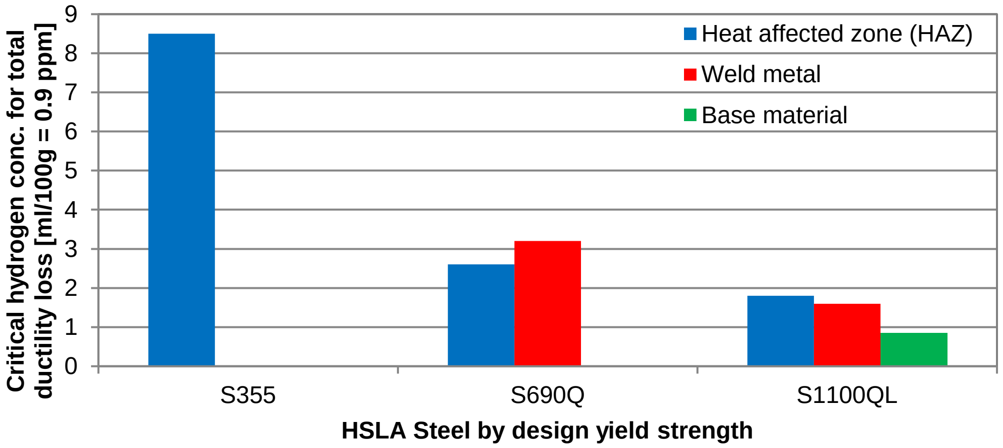


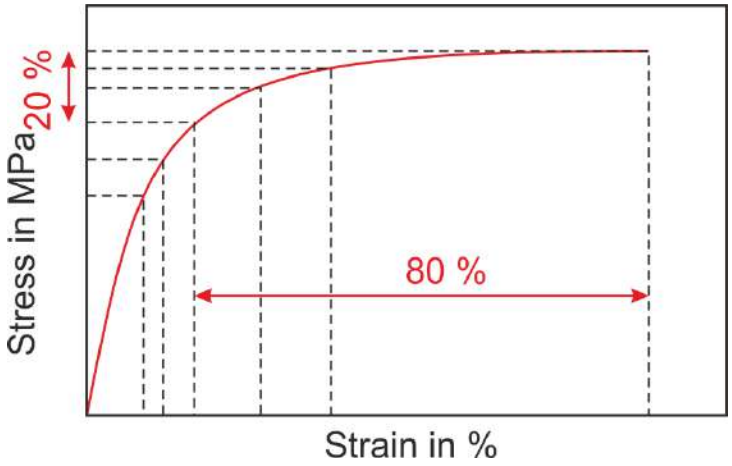
Enhanced hydrogen transport and sweeping at dislocations

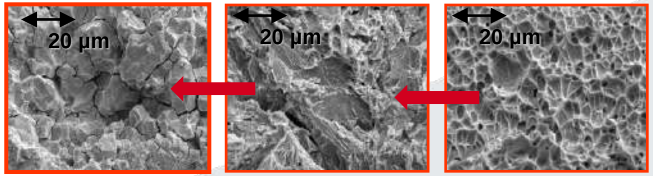
HMIs III: Hydrogen will change material properties!

Hydrogen degradation mainly in terms of ductility reduction!

→ Hydrogen might reduce the ductility reserves of a material even below the design yield strength
→ Ductility reductions may cause sudden brittle cracking and fracture







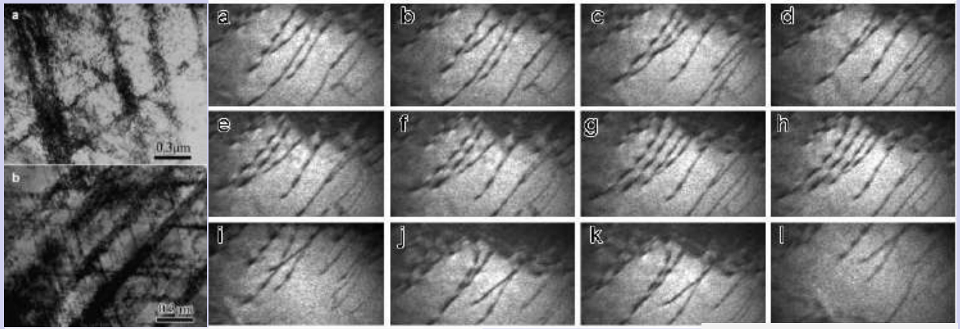
HMIs IV: Hydrogen might cause brittle cracking!

HELP & HEDE – Combinations are possible !

→ Phenomena well known > 150 years
→ Real metallurgical mechanisms never clarified

→ General agreement: Not a single mechanism
→ Combination between HELP and HEDE

Hydrogen Enhanced Localized Plasticity

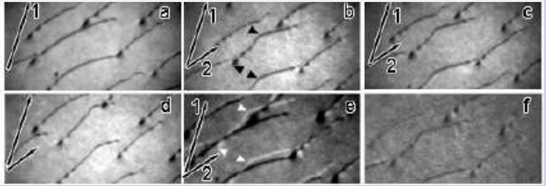


Dislocation distribution at a crack tip without and with hydrogen

Hydrogen enhanced dislocation movement

[Zhao et al.: JMST 30 (2014), pp. 1155 – 1159]
[http://robertson.matse.illinois.edu]

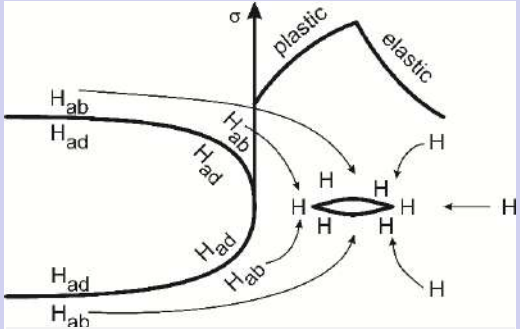
Dislocation arrest due to hydrogen



Softening: Increased dislocation activity (velocity and activation)
→ Hydrogen enhanced deformation
Hardening: Reduced dislocation velocity by formation of Cottrell clouds or blocking of dislocations
→ Hydrogen retarded deformation

+

Hydrogen Enhanced DEcohesion



[Wendler-Kalsch.: Wasserstoff und Korrosion, D. Kuron (Ed.), 1986, pp. 8-47]

Hydrogen diffuses in areas of high strains and stresses (hydrostatic) as for instance ahead of notches or crack tips
→ Hydrogen decreases atomic bonding forces by transfer of electron to 3D shell of iron atoms

Sicherheit in Technik und Chemie

UNAM

UNIVERSITY OF NAMIBIA

BAM

Bundesanstalt für Materialforschung und -prüfung

CLEANERGY SOLUTIONS NAMIBIA

O&L

NeXentury

CREATING A FUTURE. ENHANCING LIFE

METALLIC MATERIALS COMPATIBILITY FOR HYDROGEN TRANSPORT LINES AND FUELING STATION PIPINGS

www.bam.de

Hydrogen transport lines and fueling station pipings

Extremely high knowledge gains in both directions

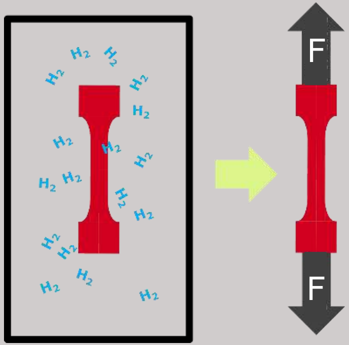
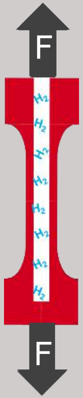
Africa (Namibia)

- New components and systems
- Above ground (easy accessible)
- Harsher environments (marine desert climate)
- Application of innovative materials
- Testing concentrated on new materials

Europe (Germany)

- Mainly old CNG grits and systems used
- Below ground (less accessible)
- More mild environments (mostly coated or covered)
- New materials only where replaced
- Testing concentrated on used materials

Small scale test procedures

Ex-situ charging followed by tensile tests	In-situ mechanical tests [...]der H_2 at[...]res	In-situ mechanical tests under H_2 atmospheres
	 [1] MPA Stuttgart	

Applicable only to materials with low hydrogen fugacity (ASS)

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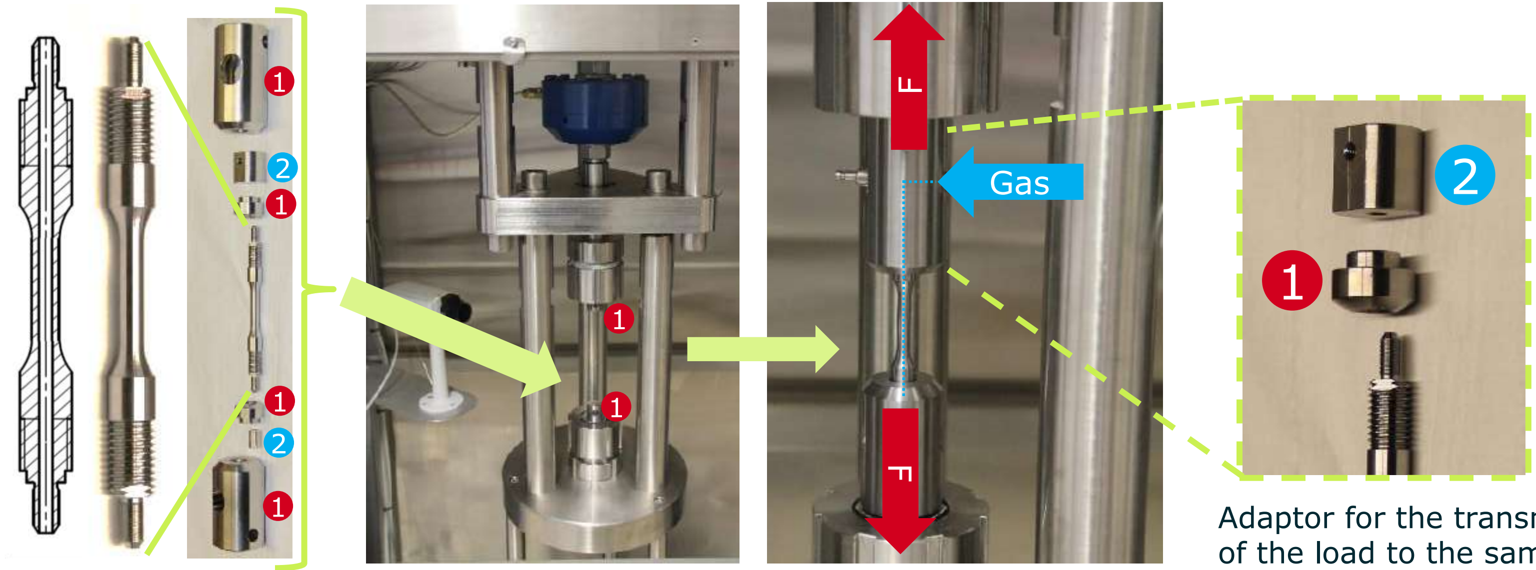
Principle – can be applied in any materials lab



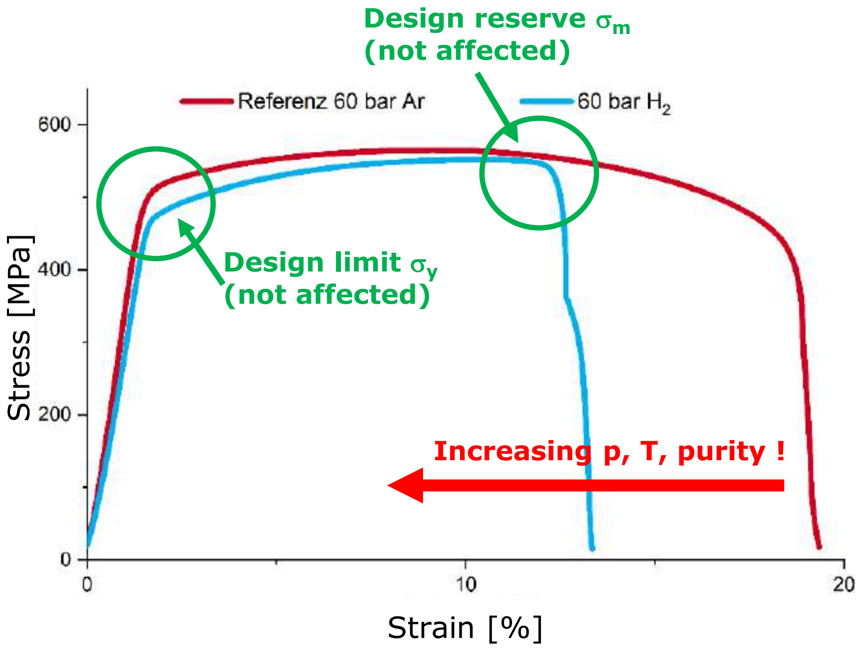
Adaptor for the transmission of the load to the sample 1 and the gas connection 2

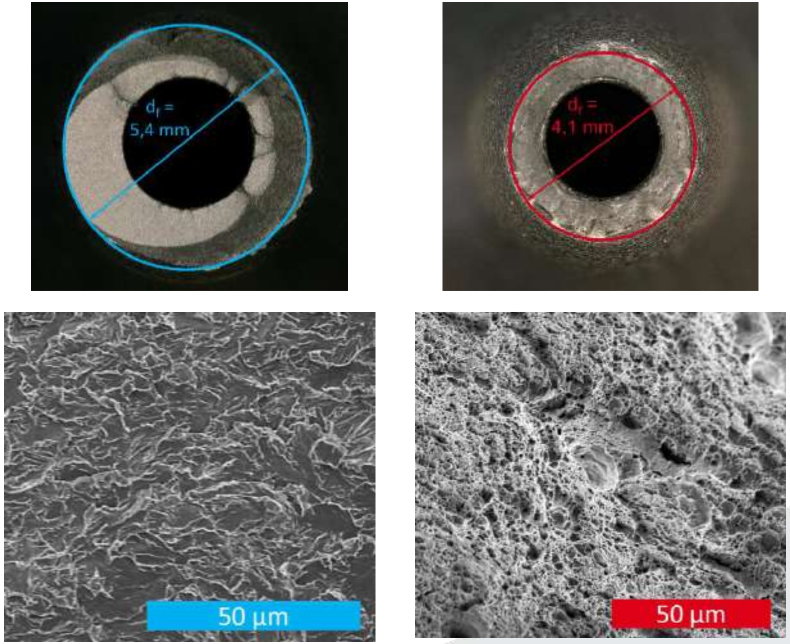
…..convert the specimen itself to an autoclave (pressurized from inside)

Ohlthaver&List Group Cleanergy

UNAM

Exemplary results – X65 for hydrogen transport lines

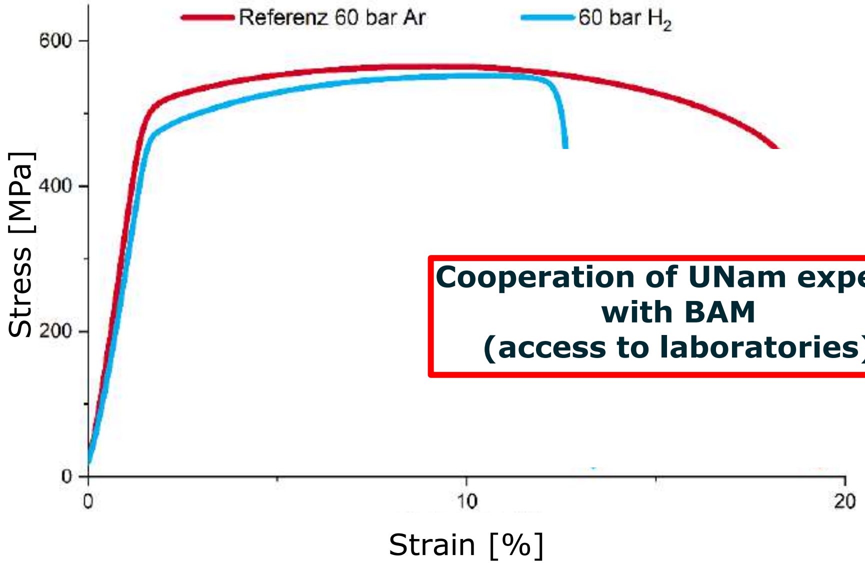




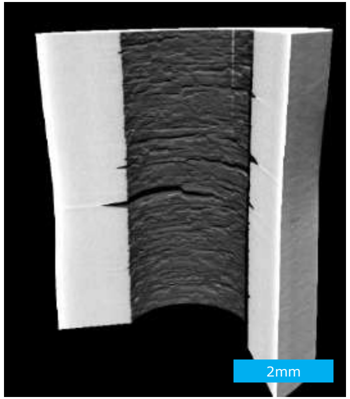
Effect of the H_2-atmosphere on ductility becomes visible

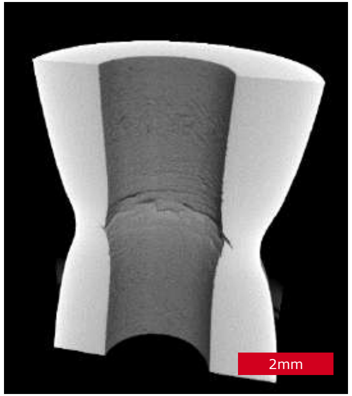
Safe conditions (p, T, purity) and alternative materials can now be determined

Detailed fracture investigation via X-ray tomography



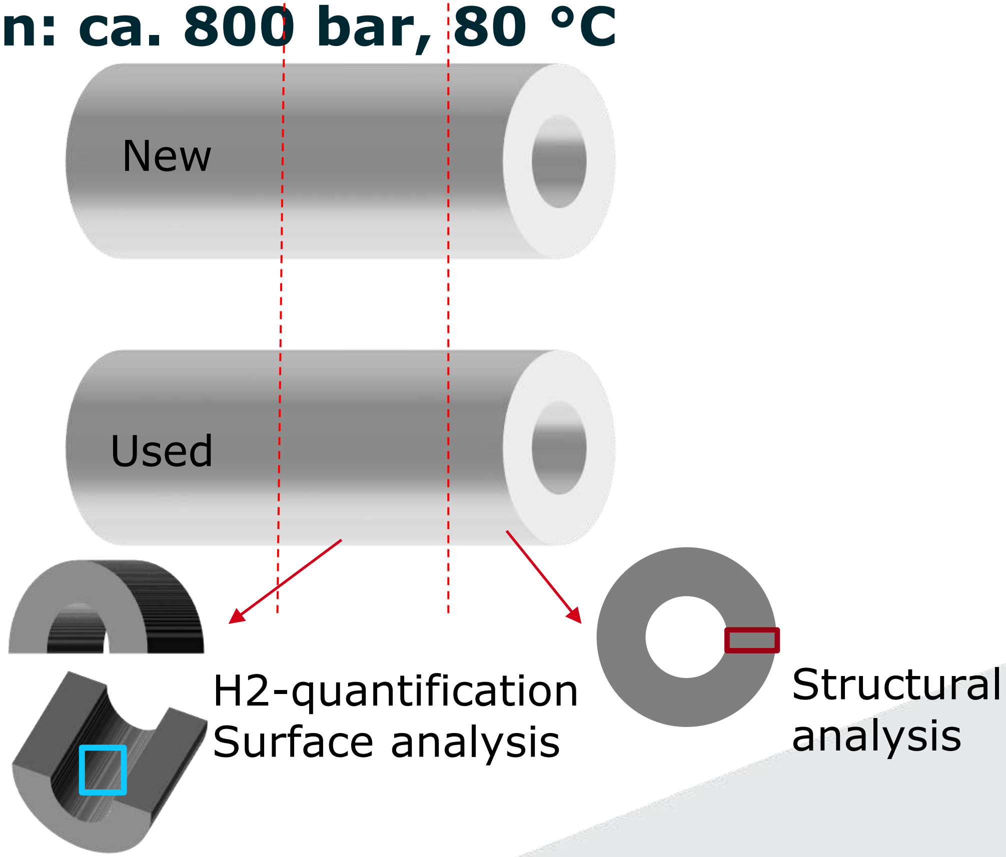
Cooperation of UNam experts with BAM (access to laboratories)





Influence of H_2-atmospheres in earlier stages can be observed (finding the answers about microstructural behaviour and mechanisms)

Exemplary results: 316 L in a pressurized hydrogen fueling station: ca. 800 bar, 80 °C



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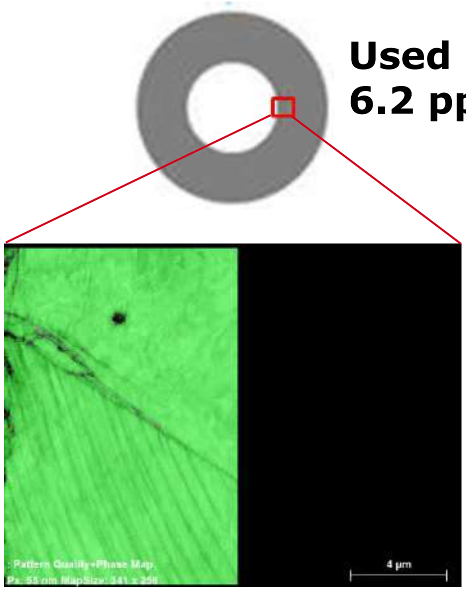
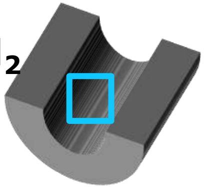
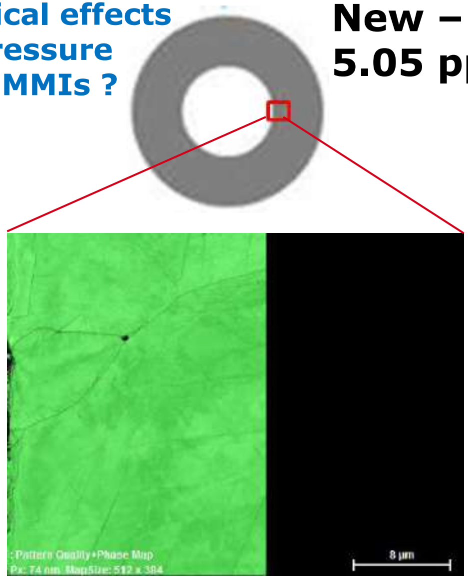


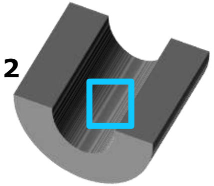
Used – 6.2 ppm H_2

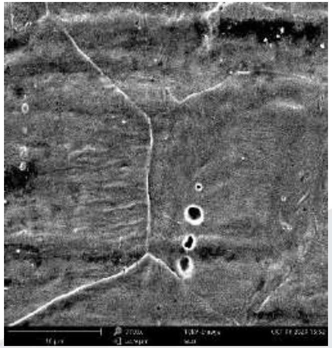


Mechanical effects of pressure vs. HMMIs ?



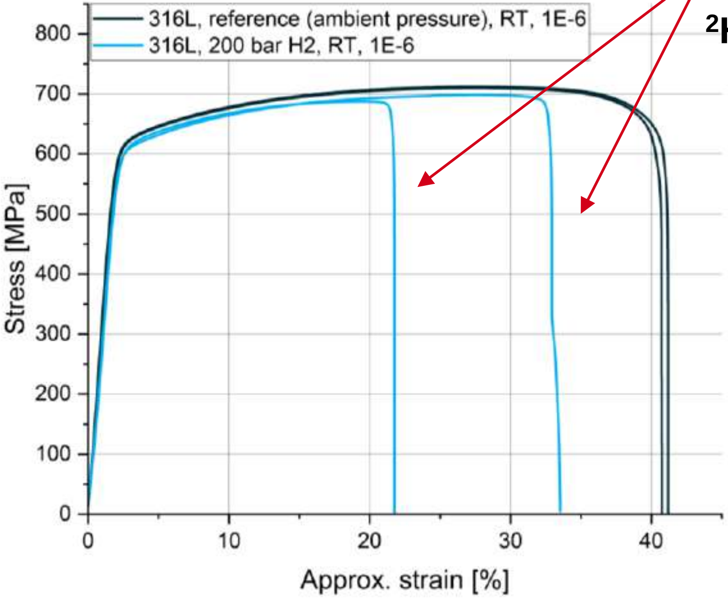
New – 5.05 ppm H_2



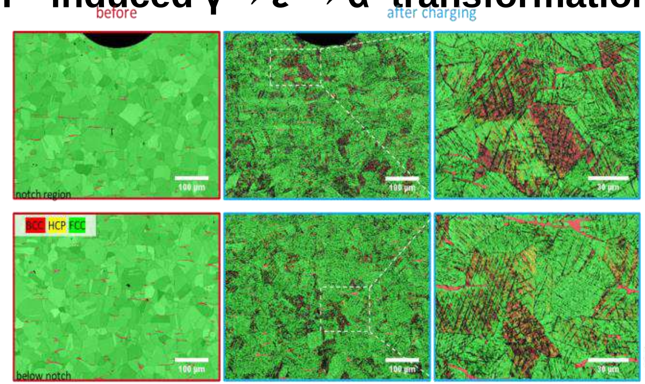


First SSRT-HTS results with ASS

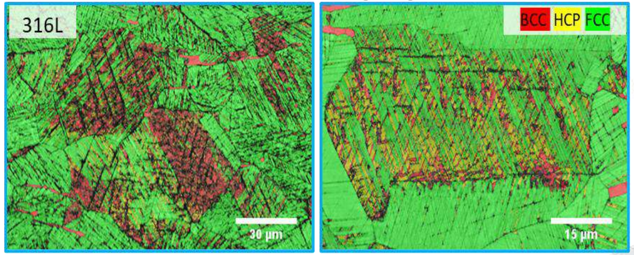
Influence of hydrogen transformation or mechanical pressure or both (deformation or hydrogen induced martensite ?)

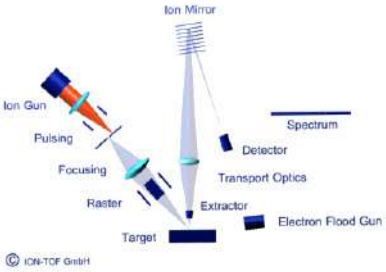


^{2}H – induced γ→ ε → α‘ transformation



AISI **316L** after EM charging for 120h

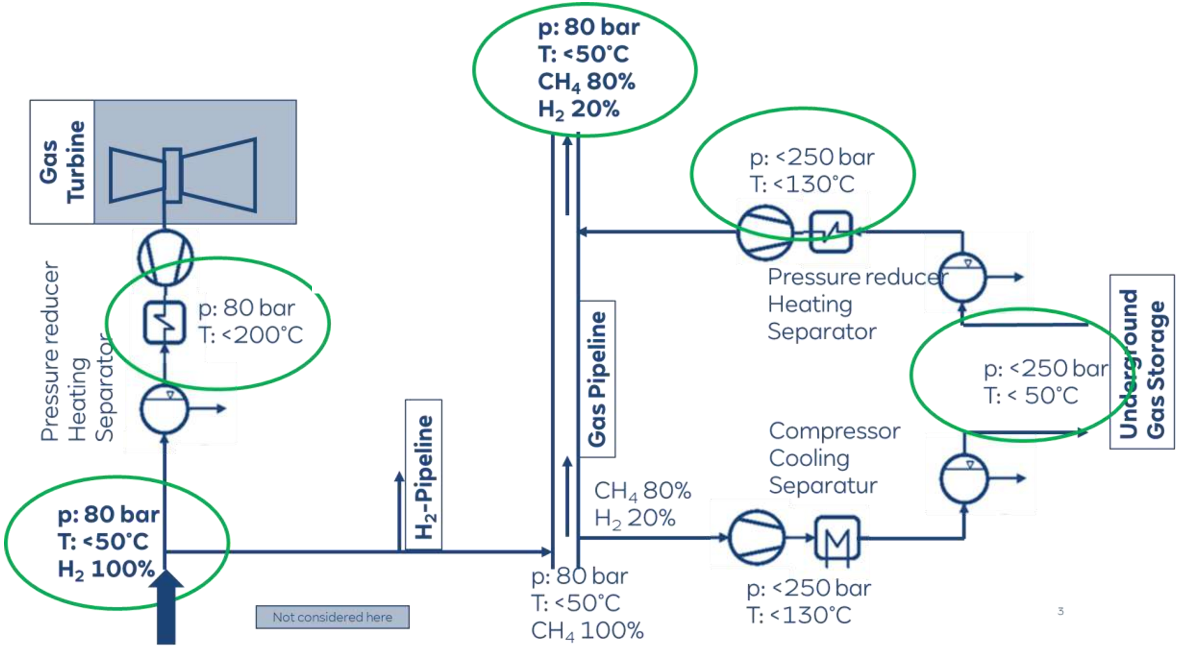




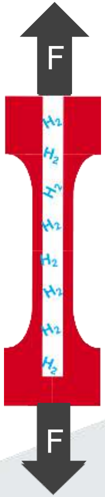
Pure hydrogen-induced transformation into martensite has been evidenced –
Here: Likely an effect of the combination of hydrogen and large deformation

ALTERNATIVE MATERIALS !?

Test only the critical regions in the systems – Transfer of the approach from old systems in Germany to NEW facilities in Namibia !



Associated research to pilot plant projects is essential !



2. Pilot Projects & Research

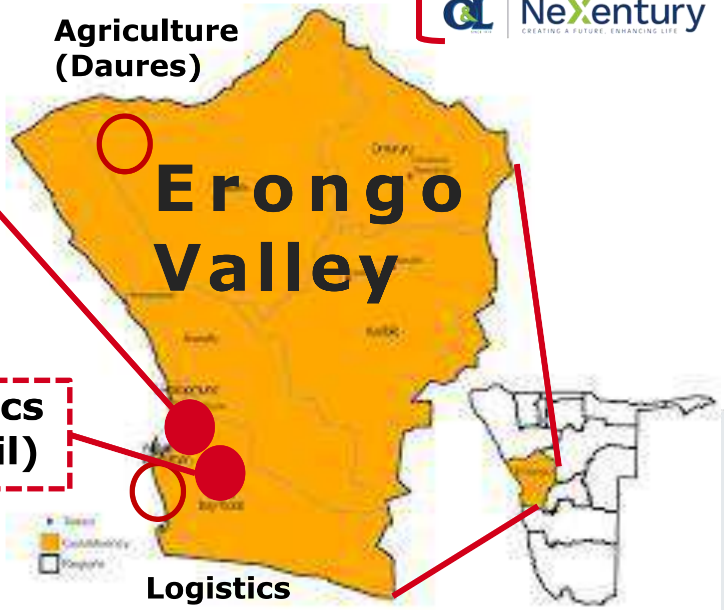
SASSCAL/BMBF Joint Call of Interest 2

- 03/22: Call launched
- 08/22: Selection of 4 (out of 21) projects in Central Namibia for detailed proposals
- 11/22: BAM selected as partner in 2 projects
- 01/23: Preparatory experiments
- 03/23: Proposal submission
- 04/23: >Granting<
- 07/23: Project start

BAM, UNAM, CLEANERGY SOLUTIONS NAMIBIA, O&L NeXentury

Cleanergy
H_2 Production & Refueling Plant

Logistics (HyRail)



2. Associated Research

Cleanergy – H_2-Production and Refueling Plant

Materials Compatibility (Steels and their Welds)

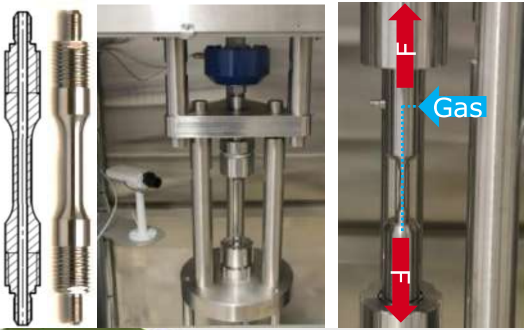
Focus: Potentials of new facilities in Namibia:
Weldable innovative steels with a better H_2-compatibility than those for CNG-grits in Europe

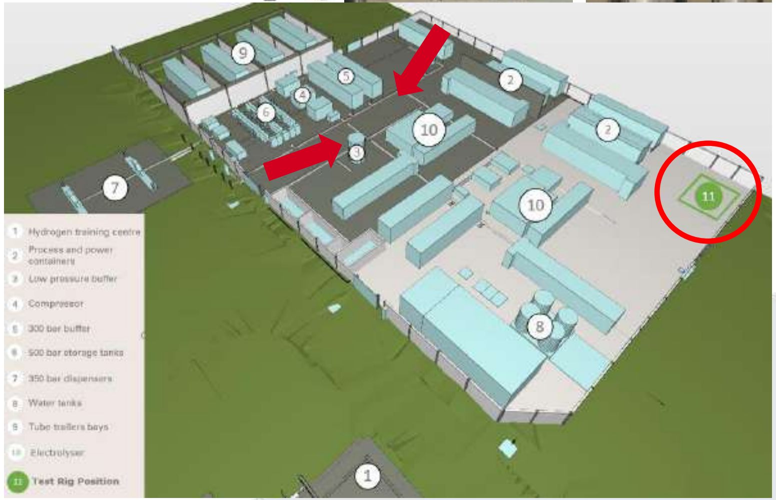
2 Modules:
- Low alloyed steels for hydrogen storage and transport
- High alloyed steels for piping and NH_3 production

Knowledge gains:
- Sustainable and lighter H_2-resistant materials
- Transferability of SSRT-HST to real applications
- Effects of the harsher climate on long-term usage
- Materials for upscaling the H_2 and NH_3 production

Capacity building:
- Four Namibian doctoral students (IWE´s for UNam)
- Laboratory start-up for NGHRI

Slow Strain Rate Testing with Hollow Specimen Technique (SSRT-HST)

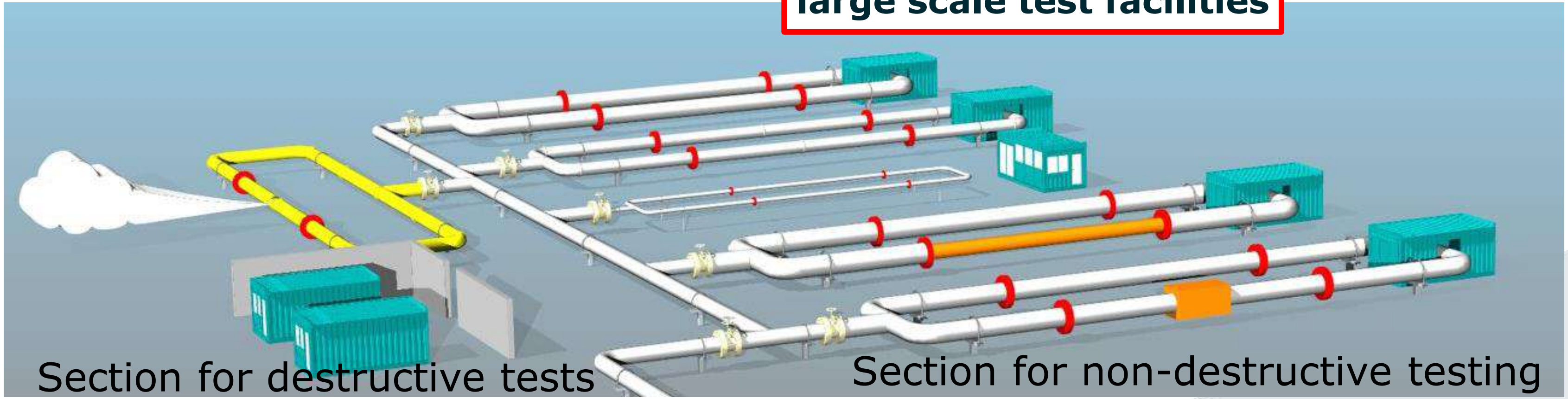




Outlook: Comparison of results to large/full scale testing : Flow-loop H_2

1. New pipeline materials
2. Release scenarios incl. ignition and impact assessments
3. Components of pipeline systems (compressors, flanges etc.)
4. Purity tests

Cooperation within pilot plant project: BAM will provide access to Namibian experts to large scale test facilities



Conclusions

1. BAM builds trust in GH_2T in Namibia by technical safety increase and capacity building. BAM is not a showstopper, but prevents showstoppers.
2. Current focus: Smart and easy materials compatibility testing that can be applied in labs in Namibia.
3. Top-down capacity building, starting with education of educators will lead to a faster knowledge transfer and dissemination in Namibia than bottom-up education.
4. The fact that up to now there is no (!) lab capacity in Namibia currently hampers the development of GH_2T in Namibia, especially along vertical value chains.
5. NGHRI@UNam has to be developed into a research and testing institute allocated between academia and industry.
6. The BMBF/SASSCAL project of the Cleanergy Hydrogen Pilot Plant not only immensely supports knowledge transfer in both directions. It also represents a start-up for the further development of the NGHRI@UNam.

7. Establishment of an internationally recognized welding education and training program under the IIW guidelines is essential that Namibian citizens participate and especially can be employed for establishment of GH_2T in their own country.

Thank you

1. H_2Safety@BAM – MatCom 1: Dr.-Ing. Oded Sobol and the complete team

2. BMBF and PTJ: Mrs. Kerstin Annassi for the continuous support during application and to Till Mansmann for granting the Cleanergy Pilot Plant Project.

3. UNam and NGHRI: Prof. Kenneth Matengu, UNam-VC, as well as Dr. Zivayi Chiguvare and Dr. Natangue Shafudah for the close cooperation regarding all GH_2T in Namibia.

4. Cleanergy: Mr. Eike Krafft, MD Cleanergy, and Mrs. Anna N. Kankondi, O&L Group, for the continuous support and great interest in the research needs for the pilot plant.

CHAPTER 5. INVOLVING AFRICAN LOCAL ECONOMY AND SOCIETY IN THE GREEN HYDROGEN VALUE CHAIN

“Green Hydrogen Value Chain in Namibia”

Dr. Zivayi Chiguvare
Namibia Green Hydrogen Research Institute
UNAM

Namibia

NGHRI
Namibia Green Hydrogen Research Institute

https://www.nghri.com/

UNAM
UNIVERSITY OF NAMIBIA

Green Hydrogen Value Chain in Namibia

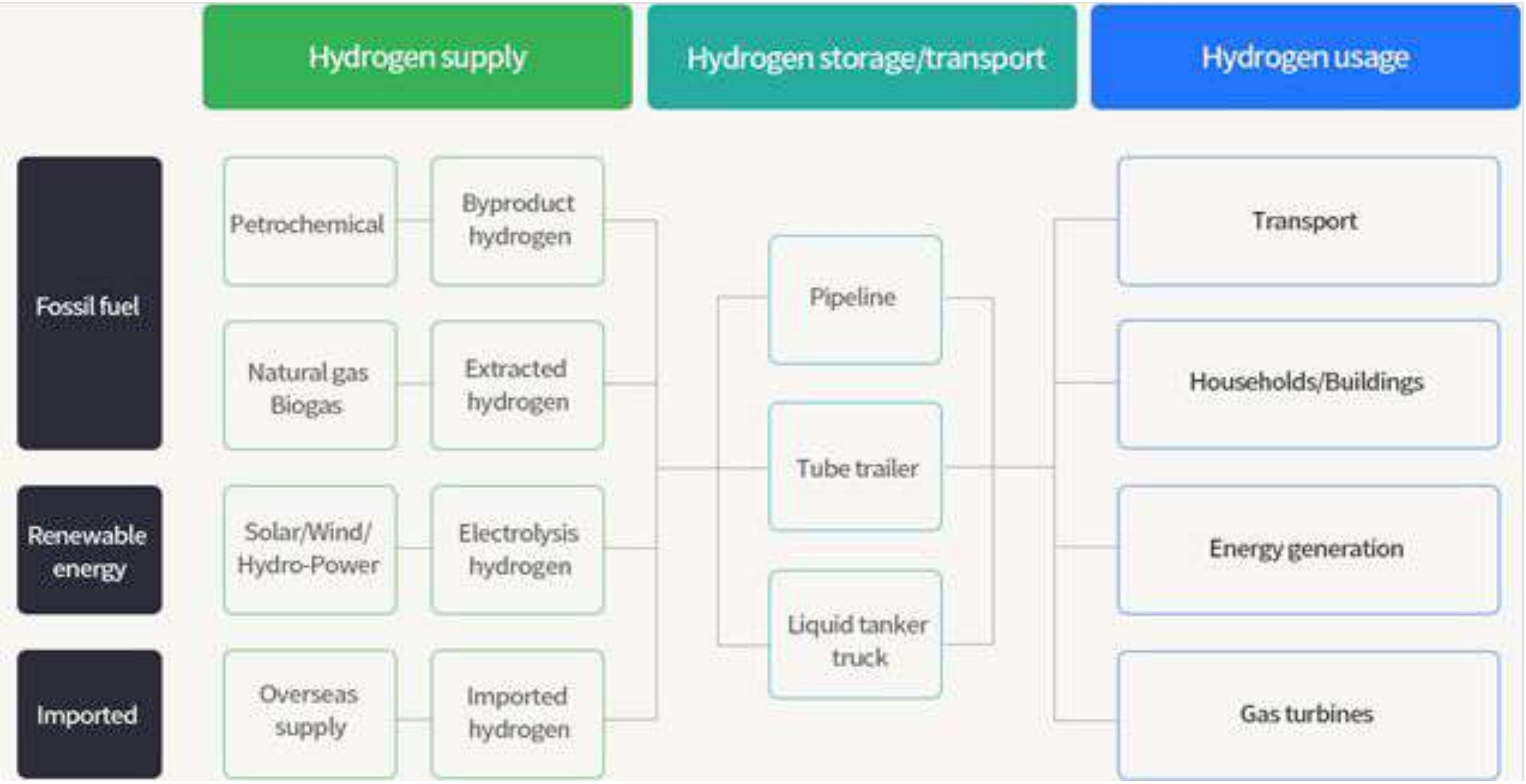
University of Namibia
Research, Innovation and Development

Namibia Green Hydrogen Research Institute

Dr Zivayi Chiguvare
Acting Director (NGHRI)

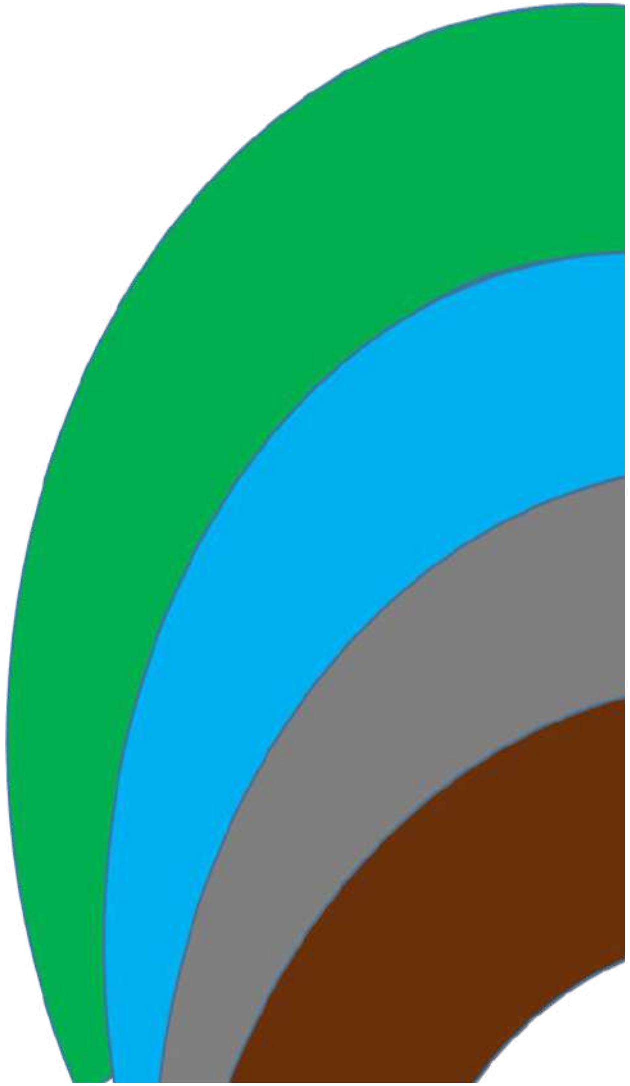
The Hydrogen Energy System

Anytime hydrogen is separated out of a water molecule, it takes a lot of energy, whether using electrolysis or natural gas reforming types of reactions.



Direct conversion to electricity, … indirect via fuel cells, … store then convert as needed

The Hydrogen Rainbow



Green Hydrogen
Made from renewable energy
No CO_2 is emitted

Zero Carbon

Blue Hydrogen
Made from CH_4
CO_2 is captured and stored

Low Carbon

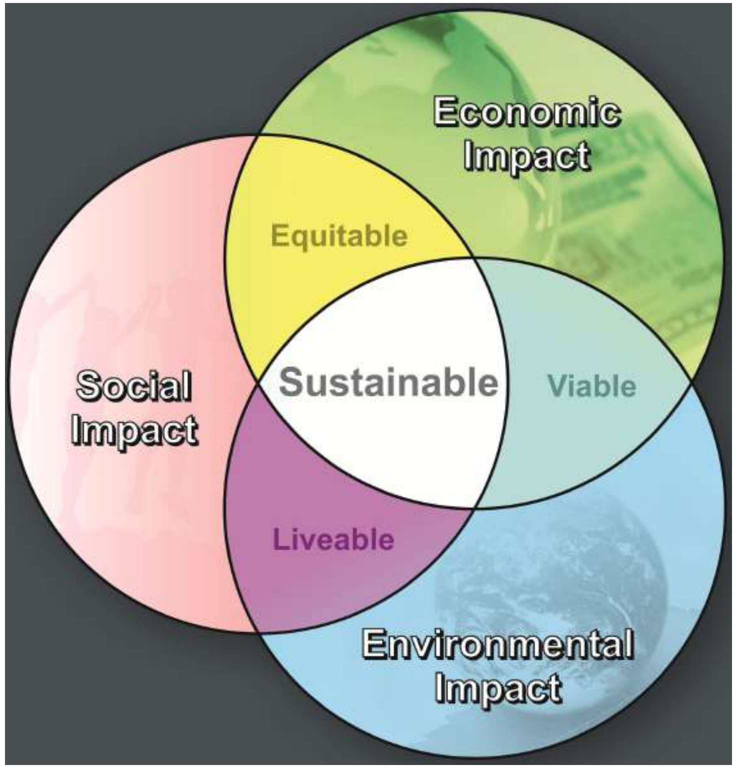
Grey Hydrogen
Made from CH_4
CO_2 is emitted into the atmosphere

High Carbon

Brown Hydrogen
Made from coal
CO_2 is emitted into the atmosphere

High Carbon

Hydrogen production methods



Sustainability is key

National Context

- Namibia's Harambee Prosperity Plan II (HPPII) lists as priority Goal 3: "the development of complementary engines of growth," with two activities that promote the initiation of research and development into the green and blue economy:

Activity 1	Develop an implementation plan to attract private sector investment into the Green and Blue Economy.
Activity 2	Investigate the feasibility of Green Hydrogen and Ammonia as a transformative strategic industry.

- The HPP II further outlines actions to be carried out to unlock the potential of the green economy including the research and development of hydrogen as an energy source, culminating in the establishment of hydrogen production, storage, delivery, and usage infrastructure.

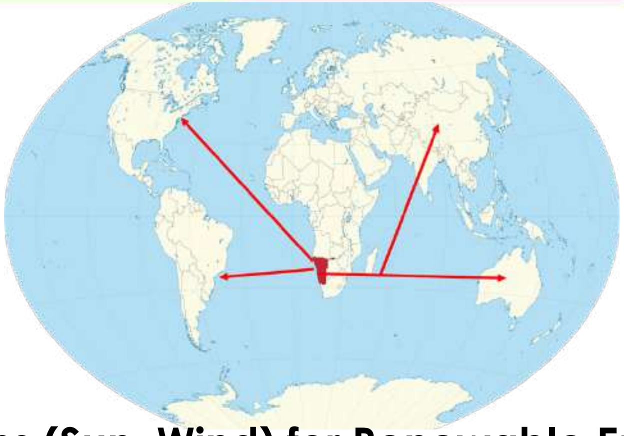
- One such action is to establish an Inter-Ministerial National Green Hydrogen Council.

National Context

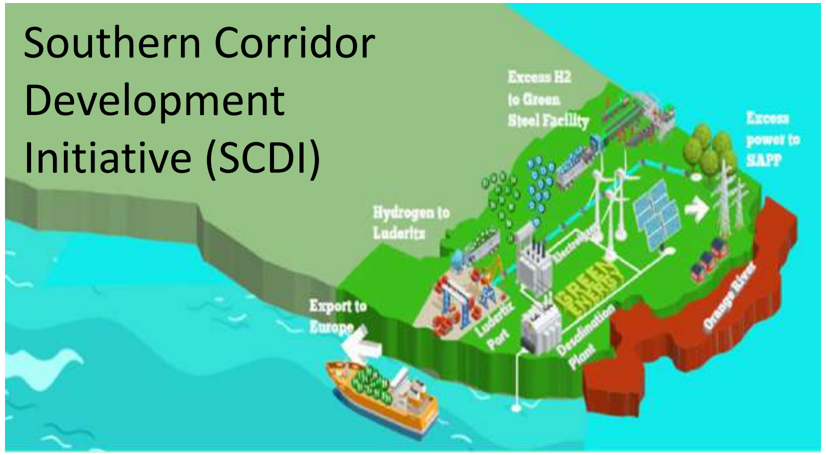
UNAM as a public university that responds to:

- National development priorities (NDP)
- Growth at Home Strategy
- Namibia Industrial Policy
- HPPII – SCDI, Green hydrogen, Blue Kelp, digital health, etc.
- Food security, health, education, indigenous knowledge, environment, policies, engineering and technology (AI in Agriculture incubator)
- HESS telescopes

Why Namibia?



✔ **Suitable conditions (Sun, Wind) for Renewable Energy**
✔ **Distribution across the world is easy**



- Climate change, mitigation and adaptation research as strategic goal

Overview of UNAM

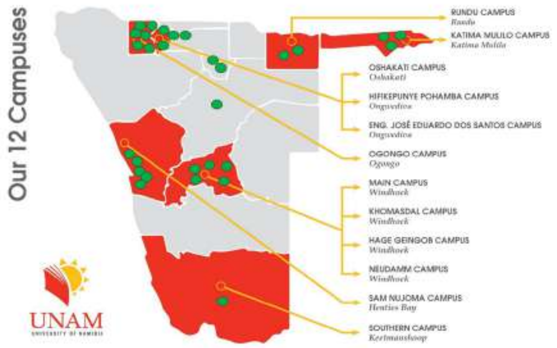
NGHRI – Namibia Green Hydrogen Research Institute

UNAM – UNIVERSITY OF NAMIBIA

- +/- 30,000 students
- +/- 1600 academic staff
- +/- 2500 total staff
- 4 faculties
- 3 research centres
- 1 Commercial arm
- 12 campuses
- Multiple parcels of land country-wide

4 faculties:

- Agriculture, Engineering & Natural Sciences – 4 schools
- Commerce, Management & Law – 4 schools
- Education & Human Sciences – 2 schools
- Health Sciences & Veterinary Medicine – 6 schools



NGHRI Structure

Namibia Green Hydrogen Research Institute (NGHRI)

- Centre for clean Hydrogen Production
- Centre for Hydrogen Storage, New Materials, and Delivery
- Centre for Hydrogen Fuel Cell Technology, and Mobility Applications
- Centre for Hydrogen Energy Use, Economics, Law, Environment and Society
- Centre for Hydrogen Capacity Building, Competence, and Standards
- Centre for Hydrogen Digital and Emerging Technologies

Formulation of enabling policies, end use and environmental sustainability options for widespread hydrogen energy usage

Collaboration with government and private sector partners, International academic and research institutes, identified as key for success

Green Hydrogen in Namibia

The Namibia Green Hydrogen Research Institute is committed to solving important energy challenges:

- Turning raw technology into practical solutions that create exceptional value in the global marketplace.
- Developing new technologies, technical insight, and training to produce, store, deliver, and utilize green hydrogen energy in a variety of applications.
- A future featuring greater levels of energy security, environmental progress, and economic prosperity.
- Industry leadership, while minimizing environmental impact.

NGHRI will provide a variety of services such as applied and basic research, consultancies, commissioned research, capacity building, incubation services and piloting, technology transfer and commercialization.

NGHRI envisages a Science and Technology Park in the form of a self-contained mini-campus with state-of-the-art infrastructure, that will comprise of fully equipped laboratories, R&D experimental stations, private sector and government representative offices and experiment stations, an entrepreneurship and start-up incubation centre, a training centre and wellness facilities.

NGHRI
Namibia Green Hydrogen Research Institute

Sample research projects

UNAM
UNIVERSITY OF NAMIBIA

1	GREEN HYDROGEN PRODUCTION TECHNOLOGIES AND THE HYDROGEN VALUE CHAIN
2	SEAWATER DESALINATION
3	SOLAR AND WIND POWER (for desalination of sea water)
4	ELECTROCHEMICAL WATER SPLITTING FOR HYDROGEN GENERATION (WATER ELECTROLYSIS)
5	CATALYSIS: ROUTE TOWARDS GREEN HYDROGEN
6	DEVELOPMENT OF HYDROGEN FUEL CELLS
7	COMBINING HYDROGEN STORAGE, AMMONIA AND LIQUID HYDROGEN ORGANIC CARRIER
8	NEW MATERIALS DEVELOPMENT
9	PHOTOVOLTAIC AND WIND ELECTRICITY GENERATION AND STORAGE IN HYDROGEN
10	WATER RESOURCE MANAGEMENT
11	REGULATORY FRAMEWORK, POLICY FORMULATION AND ETHICS
12	STRATEGIC ENVIRONMENTAL ASSESSMENT, AND ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENTS
13	SKILLING, RESKILLING AND UPSKILLING THE WORKFORCE FOR A GREEN HYDROGEN FUTURE
14	EMERGING TECHNOLOGIES AND DIGITAL SOLUTIONS

Research Engagements

- NGHRI participated in the submission of pilot project proposal bids to the Joint Communique of Intent advertised by SASSCAL, and 2 of the pilot projects selected included the NGHRI as a consortium member. Pilot projects have associated research projects, which will be led by NGHRI. The selected projects will be funded by the BMBF through SASSCAL.

Namibia National Green Hydrogen Conference

17-18 May 2022

- The NGHRI will ensure that identified research projects, and pilot projects on green hydrogen production and usage are properly implemented, and that the population is educated on the opportunities available to them, in this regard.

Pilot projects: Gh2 Port Applications

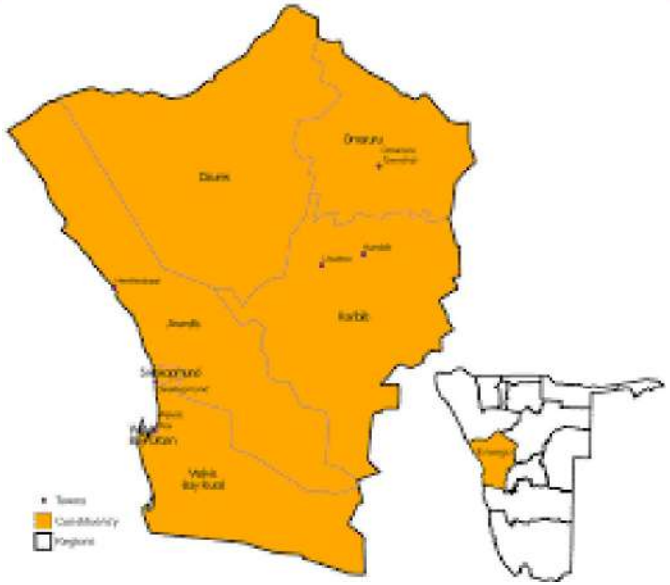
Project Name: **Green Hydrogen Applications in the Port Environment**

Location: Walvis Bay Port

Project Size: 5 MW Electrolyser and H_2 mobile refueler (945 kg at 500 bar)

Project Value: 5.66 million EUROS

Project Partners: Cleanergy Solutions Namibia, CMB Germany GmbH & Co. KG, and Namport, UNAM



Strategic targets of this project:

- To convert an existing tugboat to operate on hydrogen dual fuel technology
- To convert existing port equipment to operate on hydrogen dual fuel technology
- To develop green hydrogen bunkering and refueling infrastructure at the port
- To develop safety and operation procedures for use of hydrogen at ports
- To elevate the Germany-Namibia partnership, covering the whole value chain for green hydrogen and to promote the technological solutions proposed

Pilot projects: H_2 Refueling Station

Project Name: **H_2 Pilot Plant / Refueling Station in Walvis Bay**

Location: Walvis Bay

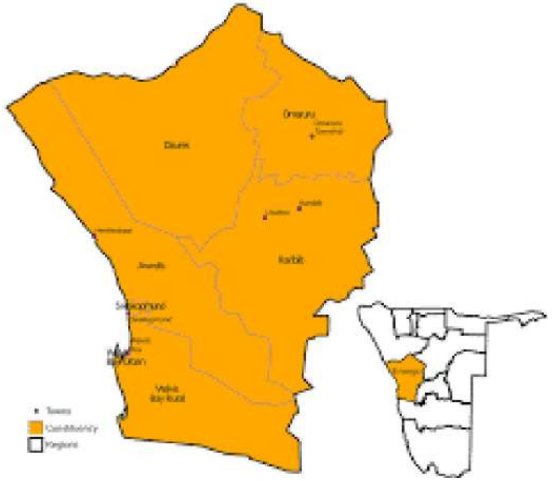
Project Size: 5 MW Electrolyser, and a and a H2-refuelling station.

Project Value: 25 million EURO

Project Partners: CMB.TECH, Ohlthaver & List Group (JV = Cleanergy Solutions Namibia)

Strategic targets of this project:

- to test technologies,
- to develop offtake applications within the transport sector, mining sector and port activities and
- to facilitate technology transfer and skills development into Namibia.
- Building upon the lessons learned with the pilot plant, a second phase with a
- bigger commercial plant including ammonia production is planned.



Pilot projects: H_2 Diesel Dual Fuel Locomotives

Project Name: **Hydrogen Diesel Dual Fuel Locomotive for Namibia with Supporting Research Projects**

Location: Walvis Bay to Kranzberg corridor in Namibia, through TransNamib

Project Size: 50 locomotive fleet conversion to GH2 dual fuel

Project Value: 7.63 million EURO

Project Partners: CMB.TECH, UNAM, Hyphen Technical, TransNamib , NGHRI, Nicholas Holding Solutions Namibia)

Strategic targets of this project:

- 1x Locomotive converted for the use of H2 as fuel, through repowering of the locomotive with a new rail engine that is H2 ready.
- 2x H2 Valve Bank close to each locomotive engine with control valves, actuators, gauges, sensors, relief values and cut off valves
- 1x H2 fuel tender car, a modified flat bed container wagon for transporting the 40ft, half height H2 fuel skids.
- 2x 40ft half height tube skids, with 8x Type 1 steel cylinder searchable to storeH2 as compressed gas at >200 bar.

Pilot projects: Daure Agriculture Project

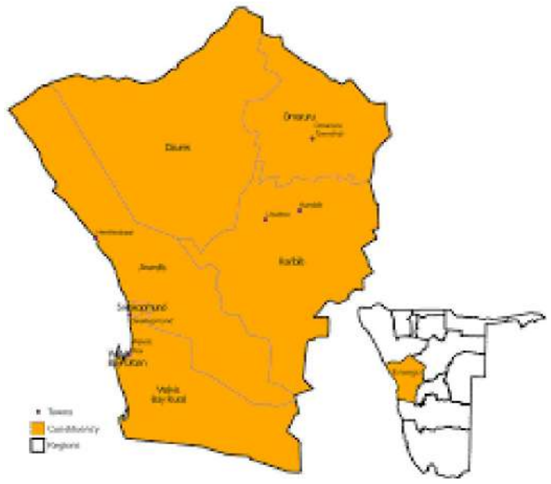
Project Name: **Daure Green Hydrogen Proposal**

Location: Erongo Region, Daures Constituency

Project Size: 1.5 GW (Current Phase 508 kg Green ammonia/day

Project Value: 15,1 million EURO

Project Partners: NGHRI, University of Stutgard , Enapter , Windwise , Enersense Nam

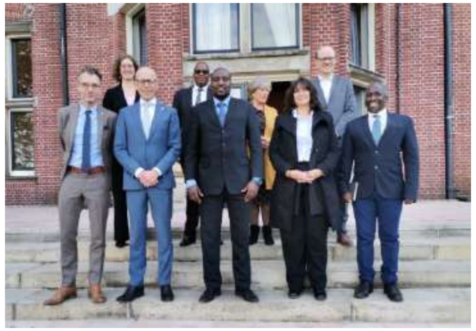


Strategic targets of this project:

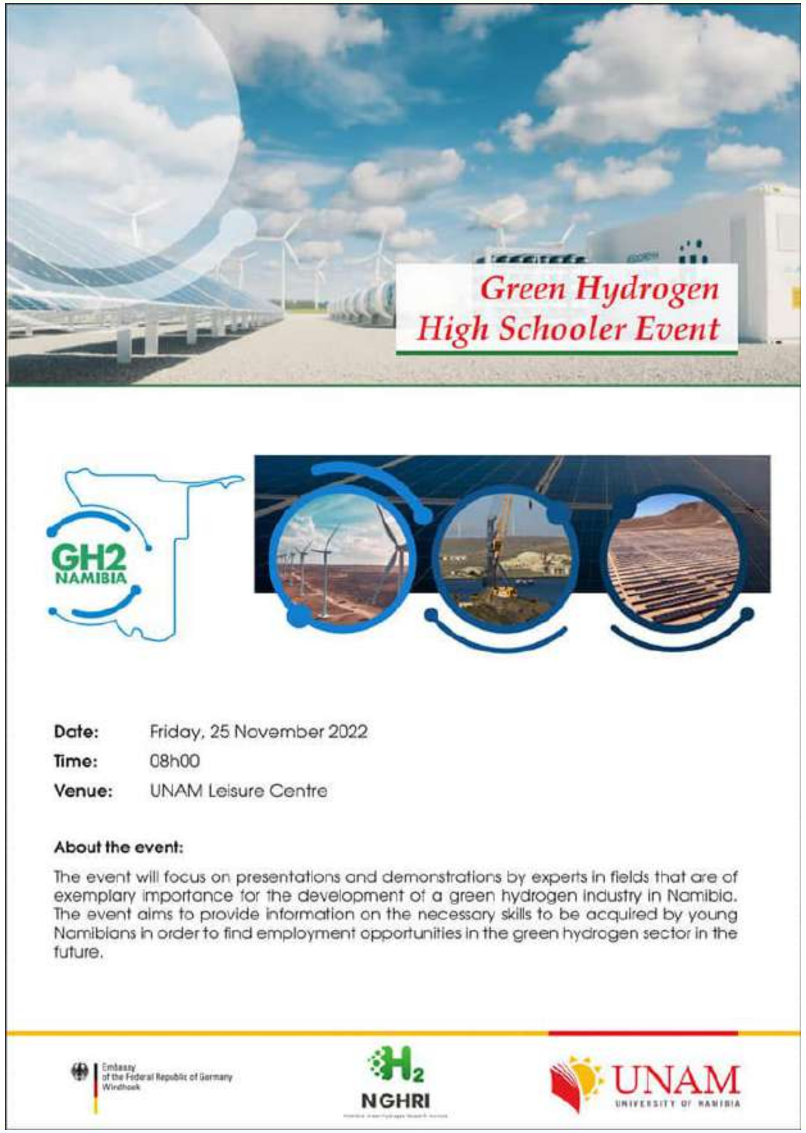
- Sustainable production of green hydrogen based on renewable energies,
- Establish of green scheme program for ammonia nitrate crops
- Storage and transport of green hydrogen, ammonia and related derivates,
- Integrated application technologies for utilization of green hydrogen in
- agriculture , ammonia nitrate and cleaning detergents
- Fuel Cell operated Centre pivots, boreholes and houses

Research Engagements

- The study visits by UNAM delegation (Prof K. Matengu, Vice Chancellor; Prof. A. Peters – Pro Vice Chancellor -Research, Innovation and Development, Dr. M. Kudumo – Director -International; and Dr. Z. Chiguvare – Acting Director – NGHRI) - Engagements with German, the Netherlands and Belgium Institutions, and the discussions thereof, including participation in the EU H2 Week, where 4 meetings were held with various institutions (Oct 2022).
- Participation at COP-27 – Prof A. Peters and Dr. N. Shafudah attended and represented UNAM and the NGHRI at Cop 27.
- Dr. N. Shafudah is in Germany – Aachen for a one week study on Green Hydrogen (23-27 Jan 2023).



Research Engagements



Masterclass on Green Hydrogen

- 01 and 02 December 2022

- 60+ candidates offered Masters' degree scholarships
- 40 candidates offered TVET scholarships
- BMBF/SASSCAL

Research Engagements

German Vice Chancellor Habeck' s visit to Namibia - 04 - 05 December 2022, where University of Namibia and University of Anhalt leaders signed an MOU, in his presence.

Conclusion

Stakeholder Engagements

To date, the University of Namibia has signed Memoranda of Understanding with close to thirty international Institutions, on collaboration in Green Hydrogen Research and Development. The NGHRI will be at the forefront of ensuring the operationalisation of those MOUs. In 2022 the Institute has received, and hosted, a number of international researchers including academics and postgraduate students.

Research Engagements

NGHRI participated in the submission of pilot project proposal bids to the Joint Communique of Intent advertised by SASSCAL and UNAM will participate in all 4 pilot projects selected as a consortium member. Pilot projects have associated research projects, which will be led by NGHRI. The selected projects will be funded by the BMBF through SASSCAL.

NGHRI participated in an introductory training session on the Bloomberg Terminal, in September 2022.

The NGHRI will ensure that identified research projects, and pilot projects on green hydrogen production and usage are properly implemented, and that the population is educated on the opportunities available to them, in this regard.

Outreach Activities

NGHRI in collaboration with UNAM and NUST successfully hosted the First International Conference on Hydrogen-Based Energy Systems, on 14 and 15 October 2022, at the Windhoek Country Club Resort.

Outlook

Stakeholder Engagements

- Ensure the operationalisation of the signed Memoranda of Understanding with close to thirty international Institutions, on collaboration in Green Hydrogen Research and Development.

- Identify and engage with new national and international partners.

- Receive, and host, international researchers including academics and postgraduate students.

Research Engagements

- Establish state of the art laboratories along the whole value chain
- Perform the research in relation to the pilot projects already awarded
- Identify new research lines
- Publish research results in renowned journals

Outreach Activities

- Host the International Conferences on Hydrogen-Based Energy Systems,
- Host masterclasses on Green Hydrogen Value Chain for identified audiences
- Seek certification and / or accreditation for developed short courses and training programmes

THANK YOU

“Exploring the Socio-Economic Impact of Green Hydrogen Production on Local Communities in Namibia”

Toni Beukes
HYPHEN

Namibia

Click here for video presentation

“Anhalt University - Skill Set Opportunities for International Students”

Dr. Lothar Koppers
Anhalt University

Germany

HOCHSCHULE ANHALT University of Applied Sciences

Anhalt University - Skill Set Opportunities for International Students

German-African Green Hydrogen Forum

Forge for knowledge with strong ties to practice

Anhalt University's clear approach is convincing because it consistently brings together science and innovation. In **Bernburg, Dessau**, and **Köthen**, we provide innovative research and teaching at an international level. In addition, we offer a high quality of life and studies for **7,500 students**, 2,500 of whom out of more than 110 countries contribute to the University's international flair.

The Bachelor's and Master's programs in **seven departments** have one thing in common - besides teaching expert knowledge, they prepare students for a successful start to their career.

Mission statement

DEVELOPMENT OF PERSONALITIES

PRACTICE-ORIENTED TEACHING AND FURTHER EDUCATION

APPLICATION-ORIENTED RESEARCH AND RESEARCH TRANSFER

INTERNATIONALIZATION

THIRD MISSION

SUSTAINABILITY

DEVELOPMENT OF THE UNIVERSITY

RETAINING TIES WITH GRADUATES

DIVERSITY AND EQUALITY

HEALTH PROMOTION

Campuses

Green (nature and money) Bernburg

- Economics, Law and Business studies
- Environmental orientated programmes of study

Bauhaus-ian Dessau

- creative branches of study (architecture and design)
- along the lines of the Bauhaus tradition

STEM Köthen

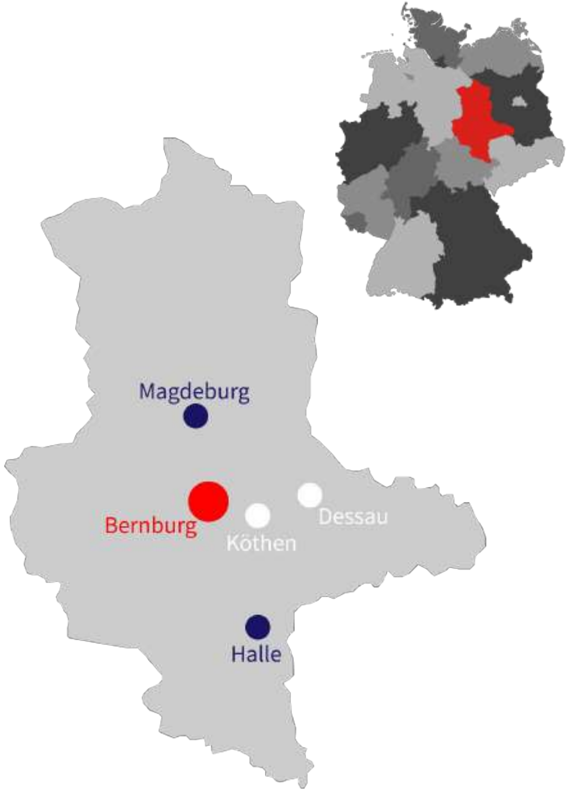
- Engineering and computer sciences
- Since 1891 education in engineering

HOCHSCHULE ANHALT University of Applied Sciences

Bernburg

Department 1
Agriculture, Ecotrophology, and Landscape Development

Department 2
Economics and commercial law

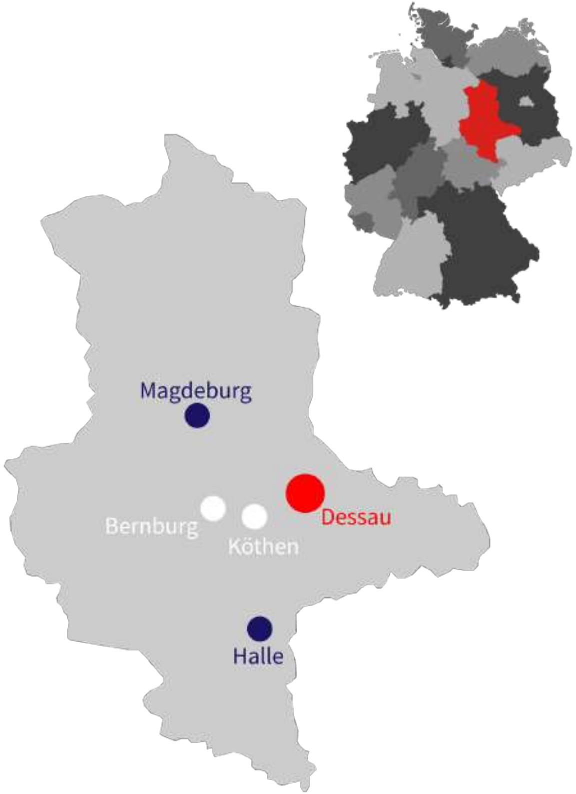


HOCHSCHULE ANHALT University of Applied Sciences

Dessau

Department 3
Architecture, Facility Management and Geoinformation

Department 4
Design



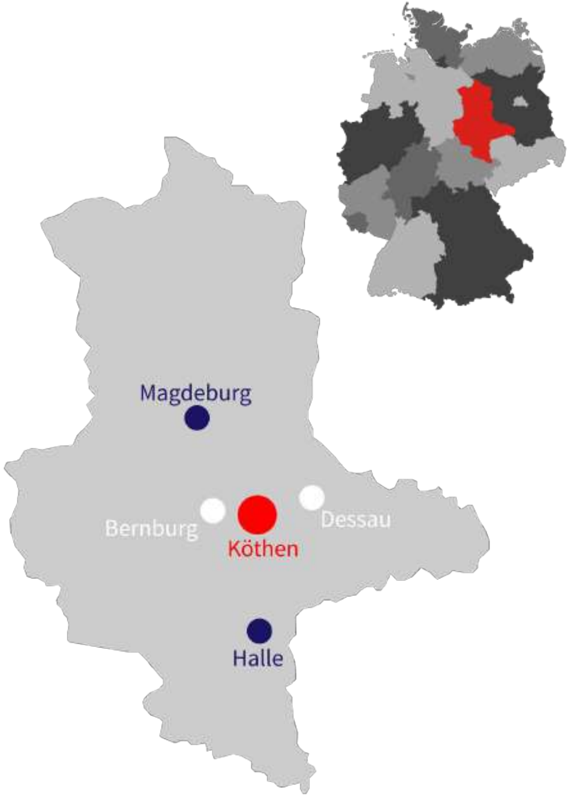
HOCHSCHULE ANHALT University of Applied Sciences

Köthen

Department 5
Department of Computer Science and Languages

Department 6
Electrical Engineering, Mechanical Engineering and Engineering Management

Department 7
Applied Biosciences and Process Engineering



HOCHSCHULE ANHALT University of Applied Sciences

Anhalt University - important figures

- 1st place in the areas of foreign students and foreign graduates in Germany, **award for excellent support** from the Federal Foreign Office
- 2nd place of German medium-sized universities in the area of **start-ups** in 2018; since 2015: 51 spin-offs.
- Research volume per professor in STEM fields at twice the national average, own **doctoral law** since 2021 (engineering, life sciences, architecture/design and social sciences, health and business)
- **Innovative universities** since 2018

HRK
Alexander von Humboldt Stiftung/Foundation
DAAD
Bundesrepublik Deutschland Auswärtiges Amt
STIFTERVERBAND
DZHW Deutsches Zentrum für Hochschul- und Wissenschaftsforschung
Bundesministerium für Bildung und Forschung

German Bachelor courses (full-time) for international students

- 1 Year Preparatory school (Studienkolleg) required for international students
- Requirements for application at Studienkolleg
    - TestDaF B-Level in German Language
    - University entrance level in your own county
- Entrance test: www.hs-anhalt.de/international/vorbereitende-programme-fuer-ein-studium/studienkolleg/aufnahmetest-anmeldung.html

- Bachelor courses (after Studienkolleg):

https://www.hs-anhalt.de/nc/studieren/orientierung/studienangebot.html

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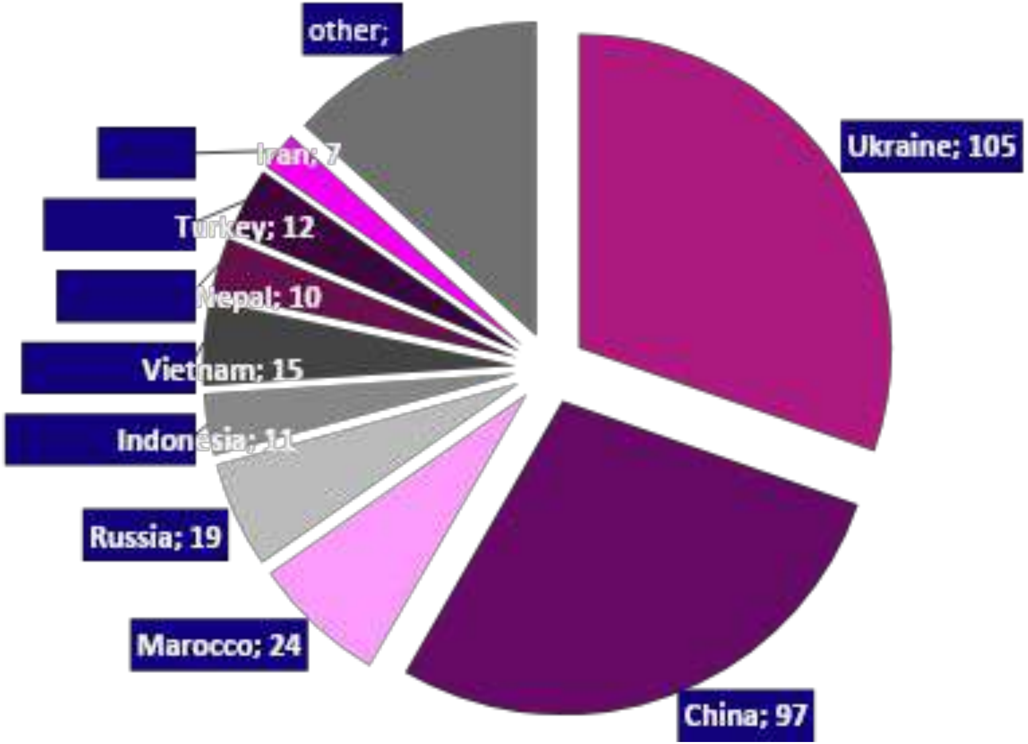
Countries of origin in winter semester 22/23 at preparatory school



Preparatory school

- Direct application
- Duration: 2 semesters
- Courses free of charge
- Recognised nationwide
- Starting: February and August

HOCHSCHULE ANHALT University of Applied Sciences

English Master courses (full-time)

- Architecture
- Architectural and Cultural Heritage
- Design Research
- Integrated Design
- Landscape Architecture

- Biomedical Engineering
- Molecular Biotechnology
- Food Science, Technology and Business

- Electrical and Computer Engineering
- Photovoltaic Engineering Sciences

Enrollment period for the winter semester:
https://www.hs-anhalt.de/nc/en/study/orientation/study-guide.html

Enrollment period for the summer semester:
https://www.hs-anhalt.de/nc/en/study/orientation/study-guide.html

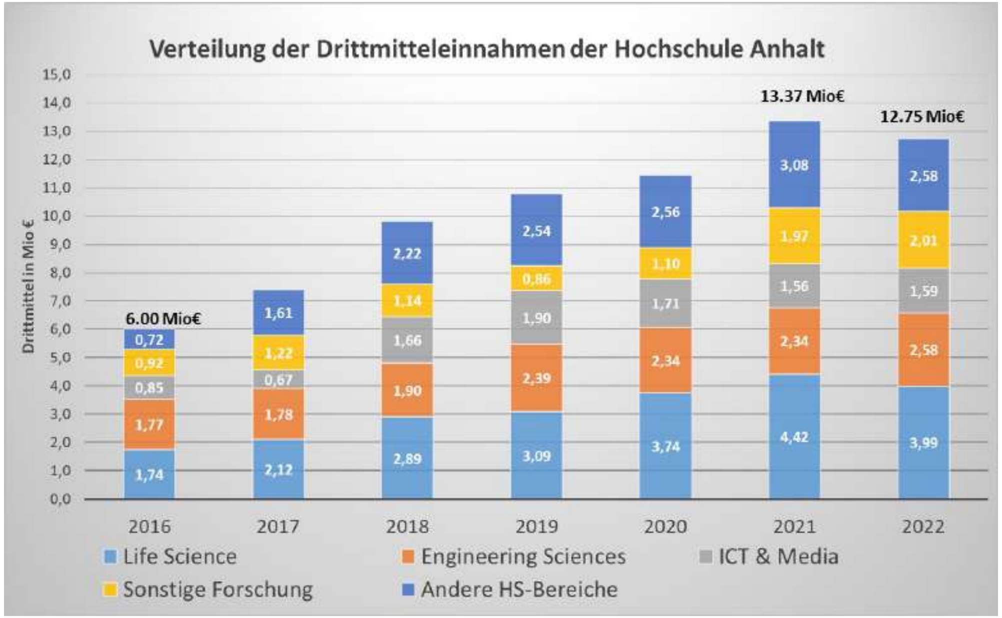
HOCHSCHULE ANHALT University of Applied Sciences

International cooperation

- International student exchange programs
- Double degree programs
- Joint research projects

HOCHSCHULE ANHALT University of Applied Sciences

Research – third party funding and public grants



Engineering Sciences

Life Science

ICT & Media

upcoming:
New European Bauhaus

https://www.hrk.de/themen/forschung/forschungslandkarte/

HOCHSCHULE ANHALT University of Applied Sciences

Green Hydrogen Activities

International and national Projects on

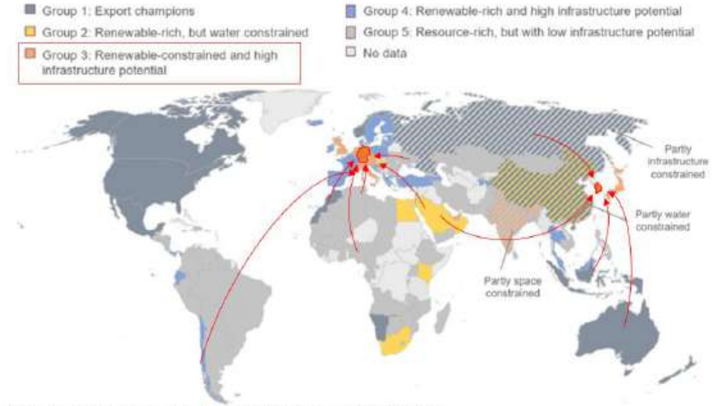
- development of life-cycle analysis Plants and
- logistics and transport issues of green hydrogen

Projects

- South Korea: Concept for the sustainable supply of industrialized countries with "green hydrogen" (H_2) from external producer regions
- Brazil: Development of a life-cycle analysis of green hydrogen plants
- Namibia: Academic Training for green hydrogen
- Germany: Hydrogen used to replace fuel in diesel engines of trains for regional development

Events

- **Today** "1st German-African Green Hydrogen Forum", Bernburg (Germany)
- "4th German-Korea Green hydrogen Forum" 30.10/1.11. Seoul (Korea)



De Blasio N., Pflugmann F. (2020), "Geopolitical and Market Implications of Renewable Hydrogen: New Dependencies in a Low-Carbon Energy World", Environment and Natural Resources Program, Belfer Center for Science and International Affairs, Harvard Kennedy School, Cambridge

UNAM UNIVERSITY OF NAMIBIA
KENTECH Korea Institute of Energy Technology
DAAD
Fraunhofer
KINGS
SPONSORED BY THE Federal Ministry of Education and Research

Conclusio

- Hydrogen and how to use it is a cross-cutting issue
- Hydrogen and how to deal with it is an important topic in many courses
- E.g.: YOU WANT TO DEAL WITH ↙ THEN PLEASE ↘ STUDY
  - Plan storage, delivery and citizen adoption (landscape) architecture, mechanical engineering
  - Use of green hydrogen in techn. Environment process engineering, mechanical engineering
  - Generation of green hydrogen process engineering, electrical engineering
  - Calculation and simulation computer science
  - Business and legal ecosystem economics and commercial law
- To think about: Masters in Interdisciplinary Hydrogen Studies

AND ALWAYS THINK ABOUT:

WE ARE YOUR ANHALT UNIVERSITY

STUDY CLOSE²PRACTICE

End of commercial block

CHAPTER 6. FULL PAPERS

Economic and logistics of a transition to a hydrogen economy

by Dipl.-Ök. B.Eng. Sven Ortmann and MSc. Ana Beatriz Barbosa Turiel do Nascimento

Abstract

It's difficult to produce enough green hydrogen for the future needs of Germany in Central Europe. Foreign and likely even overseas suppliers of hydrogen will be needed to maintain the chemical and steel industry of Germany. The transportation of hydrogen can happen by various means, including bound in methanol or ammonia molecules to make transportation easier. There's a substantial demand for methanol and ammonia in German industries.

Major overseas projects for green electricity and green hydrogen production are facing financial and technical uncertainties that impede investment. The intent of the German government is clear, but further legislation may be required to trigger the amount of investment in green hydrogen projects that's needed to compensate the German demand for green hydrogen by 2040.

Keywords: Green Hydrogen; Germany; Logistics.

1. Introduction

Hydrogen has already been in use during the 18th century for ballooning and there have been hopes for a clean hydrogen-fuelled economy since the 1980's. The financial penalties and restrictions imposed on the use of fossil fuels have begun to incentivize businesses for a shift towards a decarbonised economy. Thus hydrogen is becoming one of the pillars of the green economy transition.[1]

It is possible to fuel land, air and seagoing vehicles with hydrogen, and to supply enough hydrogen with negligible carbon dioxide emissions. The central concern isn't the technical feasibility; it's whether using hydrogen is the most economical path towards decarbonised traffic and its effect on performance[2] and on durability.

Another use for hydrogen other than as a fuel is using it as material input in large scale production of carbohydrate chemicals[3], nitrous-hydrogen chemicals and as input in the reduction of iron ore to pure iron in steel production[4]. Again, there are uncertainties regarding the economic competitiveness and in regard to technology.

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1 Cf. Mazloomi & Gomes, (2012).

2 "(…) depending on how the fuel is metered, the maximum output for a hydrogen engine can be either 15% higher or 15% less than that of gasoline if a stoichiometric air/fuel ratio is used." Cf. Office of Energy Efficiency & Renewable Energy, U.S. Government, 2001.

3 The annual production of Methanol in Germany varied between 940,924 and 1,523,239 metric tons in Germany in the 2014...2021 period. Cf. Verband der Chemischen Industrie. 2022, p.16.

4 Germany produced 40.241 million metric tons of steel in 2021. Cf. Wirtschaftsvereinigung Stahl (2022).

Our objective is to discuss the current advances in the use of hydrogen and the necessary points to establish an initial plan to transition into a hydrogen economy. This article will offer an overview of initial costs, incentive situations, global panorama, risks and possible logistical approaches for large scale hydrogen import to Germany.

2. *Hydrogen as a replacement for natural gas*

Hydrogen can be produced with approximate climate neutrality, and its use as fuel is also nearly climate-neutral in most applications.[5] The use of hydrogen as material input can have almost no climate footprint as well. All such processes can merely be approximately climate-neutral.

The climate-friendly production of hydrogen fuel depends on a similarly climate-friendly production of electrical power[6] and on the provision of suitable water. Solar energy, wind power (onshore and more expensively, offshore) and geothermal power are suitable energy sources. Others such as biogas, energy from waste disposal or hydropower cannot be scaled up to meet the future demand in most places.

The list of possible locations to supply climate-friendly power to Germany is restricted by the transportation costs of either electrical power or hydrogen, as well as the inability to create the required climate-friendly power supply in Germany itself. Germany may in the future receive much electrical power from offshore wind power in especially the Danish and Norwegian exclusive economic zones, which can supply much more electrical power than these nations demand.[7]

Northern and Atlantic Africa have advantages especially for photovoltaic power and also opportunities for wind power.[8] Iceland has geothermal[9] and wind power while being a NATO member. More distant locations with high potential for green energy generation such as Chile, Madagascar, Australia and the Arabian peninsula deserve evaluation as well, despite longer sea routes.

Besides the technological improvements to maximize the energy efficiency and lower production costs of green hydrogen, we must also cite the potential versatility in its applications, which are currently focused on transportation, ammonia production and steel manufacturing. The use of hydrogen as fuel in vehicles and machinery for industries has the added benefit of greatly reducing visual and noise pollution, improving air quality in cities and industrial hubs.

Although the use and research of hydrogen energy has now become more intense, the key elements of costs and technical preparation necessary to deploy a cost-effective use in different sectors are

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5 An exception is the formation of climate-relevant contrails at certain atmospheric conditions and altitudes by hydrogen-powered aircraft. Furthermore, turbines and internal combustion engines may burn hydrogen with air at such high temperatures that climate-relevant nitrous oxides can be formed.

6 Cf. Shell Deutschland Oil GmbH. (2017), p. 14.

7 Cf. Royal Haskoning DHV. (2022)

8 Data and resources available on the global wind and solar Atlases: https://globalwindatlas.info/en and https://globalsolaratlas.info/

9 Cf. Ragnarsson, Steingrímsson and Thorhallsson. (2020), p.1

still being investigated and modelled by governments and enterprises.

3. Costs of an approximately climate-neutral hydrogen supply

The costs of industrial supply of „green“ (approximately climate-neutral) hydrogen depend very much on the costs of „green“ electrical power. It's fortunate that the prices of wind power installations and photovoltaic solar power modules per installed kilowatt have been reduced enormously in the past two decades due to technological progress and economies of scale. According to IRENA, solar photovoltaic (PV) has experienced the most rapid cost reductions, with the global weighted average levelised cost of electricity (LCOE)[10] of PV projects declining by 88% between 2010 and 2021, while the LCOE of onshore wind fell 68% by the same period[11].

It’s also important to notice that offshore wind farms, despite having higher costs of initial investment and operation, on the period from 2010 to 2021 the installation costs of this sector fell 41%, from USD 4,876/kW to USD 2,858/kW.

Global weighted average total installed costs, capacity factors and LCOE of newly commissioned utility-scale solar PV, onshore and offshore wind, 2010-2021

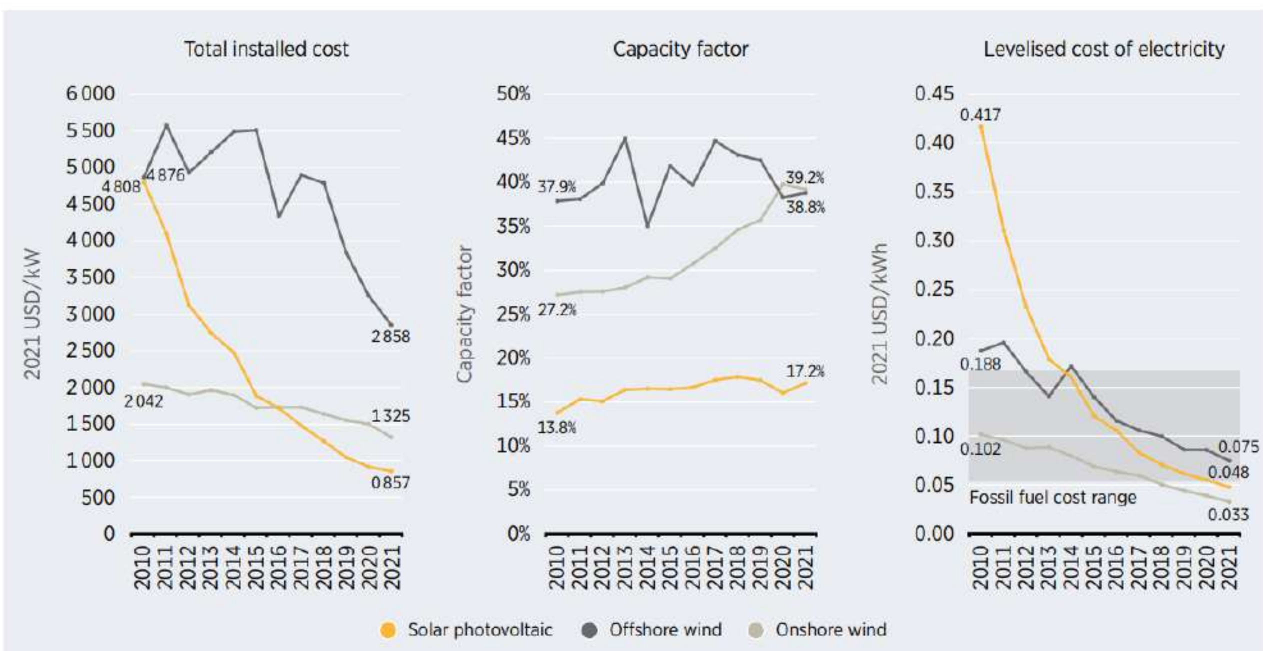

Fig 1: Total installed cost, capacity factor and LCOE of PV solar and wind onshore and offshore, during

[10] The Levelised Cost of Electricity of renewable technologies (solar and wind) varies according to type used, country, and project size. The values obtained by IRENA take into account energy sources, operating capital and energetic performance.

[11] IRENA. (2022 B) p. 26

the period of 2010-2021. Source: IRENA, 2022 B.

There were strong cost reduction trends for renewable energies due to technological advances and economies of scale. The total costs of providing electrical power for the electrolysis of hydrogen from water can not drop this much as the costs for solar modules, as the maintenance, installation, the structural racks, power lines made with much copper and the transformers cannot follow the same cost reduction trajectories. The total costs for wind and photovoltaic power at utility scale have still dropped very much and made these energies very cost-competitive in many locations.

The supply of suitable clean water[12] is a minor cost factor, but still relevant for the location of electrolysis facilities. Some areas of the world are great for green power generation, but lack the groundwater supply needed for the electrolysis reaction and for cooling. Desalination of seawater or processing of waste water are feasible alternatives that could be used to supply water for electrolysis in quantity, but this adds to the total costs.

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[12] "The water consumption rate for electrolysis is $9kgH_2O/kgH_2$ (...)"

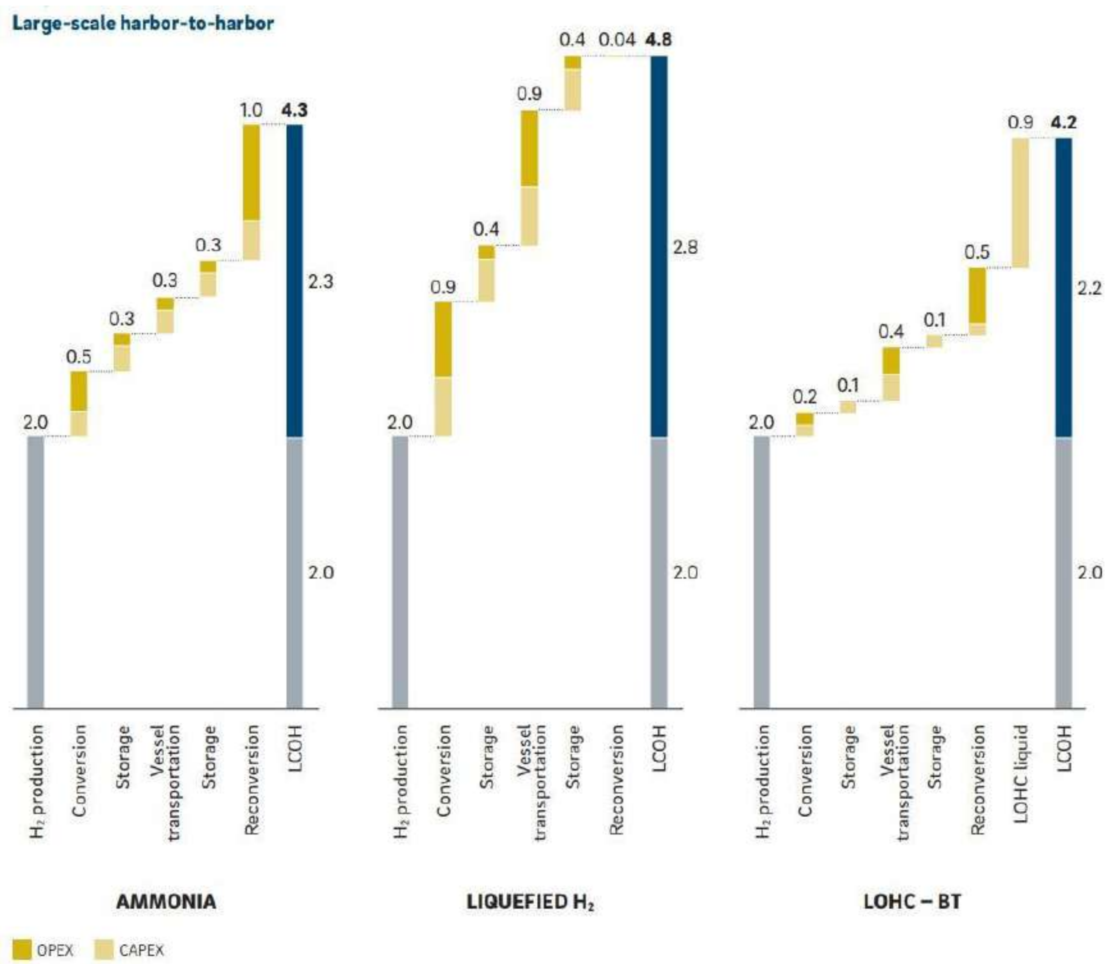

Fig 2: Large Scale harbour-to harbour hydrogen transportation from Persian Gulf to Germany (estimates). Source: Uwe Weichenhain et al, Roland Berger GmbH, 2021

The cost of capital (CoC) to finance utility-scale renewable energy projects is another component that impacts on the future production and supply of green hydrogen. According to the latest data for CoCs[13], from 2019 to 2021 out of 172 countries, the costs of capital to investments in renewable energies were the lowest in Germany, 1.1% p.a. for onshore wind, 2.4% p.a. offshore and 1.4% p.a. for PV. China, that has massively invested in renewable energy technology, has CoCs of 3% p.a. for onshore wind, 2.8% p.a. for offshore wind and 3.9% p.a. for PV. On the other side of the spectrum, Ukraine and South Africa have higher CoCs for wind and PV. Ukraine had 12.2% p.a. for both, and South Africa 7.5% p.a. and 6.9% p.a. respectively.

Project financing depends greatly on legal reliability of the location and on the expectation of long-term revenue stream potential. Renewable energy projects at utility scale often get realised by project developers who sell the finished project, but this requires the same expectation of future revenues. Long-term contracts for the sale of electrical energy (or hydrogen and its derivatives) are thus an

13 Cf. IRENA. (2023).

important legal component in the development of major green hydrogen projects.

The analysis of costs must include studies of solar and wind potential at the site, the costs of capital, government subsidies and personnel costs including the costs or training efforts. All of these can create an pilot plan to support future endeavours and help in the decision-making processes.

4. Investment and decision making of the economic actors

The transition to a hydrogen economy has become a policy in some countries even though few hydrogen-based value added chains are cost-competitive in the current economy. Several governmental efforts to boost the green economy push for large-scale projects. The national programmed budgets for hydrogen policy strategies of France, Germany and Italy starting in 2021 are estimated at 9.175[14] billion, 9.05 billion[15] and 10 billion[16] Euros, respectively. Further commitments are probable.

Europe's high demand for green energy and limited production conditions boost cross-border investment policies, such as the Important Projects of Common European Interest (IPCEIs) already allocated 10.6 billion euros to support the production of hydrogen to member countries. It is expected to gather up to 16 billion euros from private investors[17]. The outlines for a creation of the European Hydrogen Bank, confirmed in March 2023, also indicate the intent to close the gap of cost efficiency between green hydrogen and fossil fuels.

Countries with high technical potential (examples Morocco, West Sahara, Namibia, Chile, Australia) have opportunities to generate green hydrogen for their own needs, and also to export in the upcoming years, and are already gathering investments and bilateral negotiations to fund green hydrogen plants and its supporting structures; Chile has to date seven hydrogen projects that combined are planned to receive 1.181 billion dollars[18] and HYPHEN invests in Namibia to build the first fully vertically integrated GW scale green hydrogen project, valued at 10 billion dollars.[19].

Private businesses usually lack data for a correct and specific calculation of investments in conversion to hydrogen. It's important to create this data and to publish it. Businesses can so far often have to rely on an unusually large share of educated guesses in their investment calculations.

This includes among other things:

- Future demand for hydrogen

[14] Values informed by the French Ministry of Energy Transition in 2021 and 2023 through the 'France 2030' national initiative. See references.
[15] Values informed by Germany's National Hydrogen Strategy. See references.
[16] According to estimated values from the Preliminary Directives of the Hydrogen National Strategy of the Italian government. See references.
[17] Cf. European Commission. (2023).
[18] Associación Chilena de Hidrógeno. (2023).
[19] Cf. HYPHEN. (2022).

- Future costs of investment goods and services
- Political and rule of law reliability of various countries that could host green power and green hydrogen supply installations
- Introduction of legislative requirements that would drive a conversion away from fossil raw materials and their products
- Breakthroughs of technical approaches that compete with hydrogen technologies
- Availability of capacities for electrical power transmission (such as the possibility of exporting electrical power from Morocco to Germany)
- Future development of the price and availability of electricity in the consumer country (in regard to Germany this is especially about winter times of little sunlight and little wind)
- Future development of natural gas prices and availability
- Future development of carbon pricing in Germany and the European Union, especially as the current EU carbon pricing regime is built on auctioning rather than on fixed price controls[20]

The sum of these uncertainties can affect the conversion to a decarbonised hydrogen economy both as incentives and disincentives. It could be a rational business decision to merely prepare for a conversion and postpone or refrain from its execution if one expects a decrease of required investments by economies of scale and technological progress at a later date.

Those same uncertainties may also motivate investments to be made as soon as possible[21], if for example price increases are expected due to rising demand. The set of incentives that influences business decisions may lead to business behaviour that does not match the intents of the government. This in turn may lead to additional legislation to push for the government's aims.

Depending on how the relation between businesses and government is developed, certain countries might need to focus more in areas to improve in order to prepare for the transition. As mentioned before, initial investments and operating costs should also take into account the possibility of need for additional hydrogen infrastructure.

5. The need for additional infrastructure for the supply of enough hydrogen

The provision of green hydrogen as energetic or as material input for the German economy may happen by different means.

The most important options for supply are:

- electrolysis in Central Europe with electrical power from sources in Central Europe
- electrolysis in Central Europe with electrical power from outside Central Europe

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[20] European Commission. (2021)

[21] Example Salzgitter AG, personal talk with Salzgitter AG representatives by Sven Ortmann on 30.5.2022

- electrolysis outside of Central Europe and transportation to Central Europe by ship
- electrolysis outside of Central Europe and transportation to Central Europe by pipeline

The transportation of hydrogen and its derivatives by sea appears to be more costly than the use of pipelines over several thousand kilometres.

The transportation by ship requires either liquefaction or the creation of molecules such as methanol, ammonia or LOHC. All these processes are energy intensive. The energy inputs can in part be recovered later. The transportation of hydrogen in gaseous form requires too much space on a ship. As there are industrial uses for ammonia and methanol, so it's not always necessary to reform those to split off the hydrogen again.

6. Costs of hydrogen transportation

A transportation of hydrogen within Central Europe is always necessary if the hydrogen production is not on-site.[22]

This is possible by

- transportation by pipeline
- transportation in gaseous form by pressurised flasks by lorry, rail or inland water vessel
- transportation in liquefied form by pressurised and possibly cooled containers by lorry, rail or inland water vessel

The storage of hydrogen requires an extensive and suitable infrastructure. Large cooled and pressurised containers are used for storage at ports and logistics hubs, while underground caverns are widely preferred for the storage of large amounts of hydrogen over months. Some of the latter are presently being used to store natural gas in Central Europe.

A liquid storage of hydrogen will experience some evaporation, so either the evaporated hydrogen (gas) gets used as such, or stored in a different pressurised container or liquefied for storage again.

To dispense hydrogen to motor vehicles might require hydrogen-specialised refuelling stations at railway stations, gas stations, logistics hubs, airports and ports.

It is likely that only large customers such as chemical industries and steel factories will justify laying a dedicated hydrogen pipeline, but other consumers might be able to get their own interface along such pipelines. The further development of areas with demand for hydrogen might thus become geographically tied to pipeline routes.

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[22] On-site hydrogen generation by electrolysis is available and often used to create hydrogen fuel stations for lorries. Moreover, industrial consumers are tempted to apply on-site hydrogen generation because there's no supply infrastructure yet. An example for the latter approach is the Salzgitter AG's steel factory.

Existing natural gas pipelines may be used for the transportation of hydrogen as well. This is possibly by mixing natural gas with hydrogen, but this alternative would be of little help for the climate and it's disputed up to which percentage of hydrogen the costs of adapting a pipeline would remain small.

These pipelines may also be used to transport pure hydrogen, with certain adaptions to be made, especially to mitigate the problem of hydrogen embrittlement. Hydrogen is the smallest molecule possible, and an individual hydrogen atom is the smallest atom. Individual atoms may penetrate most types of steel, and two such atoms bonding to a hydrogen molecule inside the steel grid create tension. Austenitic steels avoid this, but they are expensive alloys and the attachment of plastics coatings is mostly an option for the pipeline tubes, not for its parts of more complicated shapes. In conclusion, much of the already existing natural gas infrastructure would require modifications for a conversion to hydrogen transportation.

It is important to optimize safety procedures to prevent leakages, create wide flammability protection and list material restrictions for dealing with hydrogen when modifying or building pipelines and storage containers. Some of the structures already used for natural gas need to be altered, different leak detection sensors (specific to hydrogen) are necessary and tools for inspections may differ.

Considering the different methods of transportation and the yet present uncertainty of accurate and reliable costs, most of the decisions to either transport of locally produced hydrogen will take a ‘case by case’ approach. This ultimately will depend on government subsidies, industry production capacity and end use of this energy.

Decision making by end users

There is insufficient capacity to provide, transport and store hydrogen for a future hydrogen economy so far. This forces a difficult decision on businesses and private persons:
A shift towards using hydrogen may be the preferred path of action in the long term, but in which form shall the hydrogen be provided, and how soon?

Hydrogen can be stored and transported as gas, as liquid or as part of other molecules. It's to date unclear which approach will succeed on the market. Maybe one approach will become a dominant technology. Possible are especially

- pure hydrogen
- liquid organic hydrogen carriers (LOHC)
- methanol
- ammonia
- total electrification instead of hydrogen use

Such decision problems are known from earlier format conflicts such as VHS vs. Betamax, Blue

Ray Disc vs. HD DVD, early battery-electric cars vs. steam cars and early internal combustion engine cars.

It is not necessarily predictable which format will succeed, as the successful one doesn't have to be a superior one. Those who did bet on the wrong format are likely to suffer severe economic disadvantages.

Additionally, the availability of hydrogen or hydrogen carriers depends on the production. Both very large consumers such as steel factories and small businesses such as independent gas stations may opt to produce hydrogen on-site through electrolysis rather than to trust the build-up of a multinational hydrogen infrastructure with its many potential points of failure.

Another uncertainty is the question of what is going to be cheaper; carbon capture and sequestration or the use of green hydrogen? The climate effect is about the same for both options. Regulators may soon reflect this fact in incentives and disincentives.

It's thus understandable that business managers may opt to keep being reliant on fossil fuels for the time being. That might change in the future not only if hydrogen becomes cheaper and energy-efficient, but also if governments make a big effort into making hydrogen one of the main renewable energies available for businesses and society.

7. Government interventions in the markets

The protection of the environment is already a governmental objective with the force of the constitution in Germany.[23] It's necessary to at least seek a net zero emission of carbon dioxide because of its dominant share in the mechanisms of anthropogenic climate change.

This intent is not necessarily present in the decision making of businesses and private persons, though. The effects of their carbon dioxide emissions are not directly felt by them. This is a clear example of an external effect market failure. The orthodox economics research answer is that the external costs need to become internalised; the emitters of carbon dioxide need to suffer the downsides of these emissions themselves.

The European Union did set up an emissions trade regime with limited carbon dioxide emission rights to this end. However, this applies to large emitter businesses only. Germany added a national carbon dioxide emissions trading regime that includes additional commercial parties to internalise the costs of a greater share of the carbon dioxide emissions in Germany. The effect of such disincentives stems from a combination of the prices of emission rights, the ever tighter limitation of the total emission

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[23] Article 20a of the German Basic Law says “Mindful also of its responsibility towards future generations, the state shall protect the natural foundations of life and animals by legislation and, in accordance with law and justice, by executive and judicial action, all within the framework of the constitutional order.” See references.

rights and uncertainty. Said uncertainty about future pricing leads risk-averse actors to fear very high prices.

Such Pigou taxes for the internalisation of external costs are not the only potential measures available to legislators to pursue the governmental objective of protecting the climate and to pursue a secure and renewable supply of energy to the nation.

Some more possible measures include:

- regulatory mandates (such as the requirement that new liquid natural gas port terminals need to be adaptable to hydrogen).[24]
- governmental investment, especially in infrastructure
- subsidies
- research & development grants to make decarbonised business models competitive sooner

There's also the possibility that neighbouring countries will strengthen the hydrogen supply to Germany by investing into importing infrastructure themselves. The Dutch port of Rotterdam and the Belgian port of Antwerp may become very important for a maritime transportation of hydrogen or carrier substances thereof to Central Europe, for example.

[24] Cf. German Federal Ministry of Justice (2022).

References:

IRENA. (2023). "*The cost of financing renewable power*". International Renewable Energy Agency, Abu Dhabi. Retrieved on 14.06.2023 from: https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/May/IRENA_Cost_of_financing_renewable_power_2023.pdf?rev=6b95edc23fa5468190745975681a71cc

IRENA. (2022 A). "*Geopolitics of the Energy Transformation: The Hydrogen Factor*", International Renewable Energy Agency, Abu Dhabi. ISBN: 978-92-9260-370-0. Retrieved on 14.06.2023 from: https://www.irena.org/Publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen

IRENA. (2022 B) "*Renewable Power Generation Costs in 2021".*, International Renewable Energy Agency, Abu Dhabi. ISBN 978-92-9260-452-3. Retrieved on 31.05.2023 from: https://www.irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021

German Federal Ministry of Justice. (2022). "*Act to Accelerate the Use of Liquefied Natural Gas (LNG Acceleration Act – LNGG)*". Retrieved on 11.07.2023 from: https://www.gesetze-im-internet.de/lngg/BJNR080200022.html

Basic Law for the Federal Republic of Germany. Art. 20a. Retrieved on 11.07.2023 from: https://www.gesetze-im-internet.de/englisch_gg/englisch_gg.html#p0116

Mazloomi, K.; Gomes, C. (2012). "*Hydrogen as an energy carrier: Prospects and challenges*". Renewable and Sustainable Energy Reviews, Volume 16, Issue 5, Pages 3024-3033. ISSN 1364-0321. Retrieved 31.05.2023 from https://doi.org/10.1016/j.rser.2012.02.028

Hosseini, S. E.; Butler, B. (2020). "*An overview of development and challenges in hydrogen powered vehicles*". International Journal of Green Energy, 17:1, 13-37. Retrieved on 23.05.2023 from: 10.1080/15435075.2019.1685999

Ragnarsson, Á,; Steingrímsson, B.; Thorhallsson, S. (2020). "*Geothermal development in Iceland 2015-2019*." In *Proceedings World Geothermal Congress*, p. 1. Retrieved on 31.05.2023 from: https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01063.pdf

Shell Deutschland Oil GmbH. (2017). "*Energy of the Future: Shell Hydrogen Study: Sustainable Mobility Through Fuel Cells and H2*". p. 14. Retrieved on 22.05.2023 from: https://epub.wupperinst.org/frontdoor/deliver/index/docId/6786/file/6786_Hydrogen_Study.pdf

Office of Energy Efficiency & Renewable Energy, U.S. Government. (2001). "*Hydrogen Use in Internal Combustion Engines. 2001*". Hydrogen Fuel Cells and Related Technologies. Retrieved 12.07.2023 from: https://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdfs/fcm03r0.pdf

Verband der Chemischen Industrie e. V. (VCI). (2022). "*Chemiewirtschaft in Zahlen*". p. 16 Retrieved on 12.07.2023 from: https://www.vci.de/vci/downloads-vci/publikation/chiz-historisch/chemiewirtschaft-in-zahlen-2022.pdf

Wirtschaftsvereinigung Stahl. (2022)."*Rohstahlproduktion in Deutschland Jahresbilanz 2021*". Retrieved on 11.07.2023 from: https://www.stahl-online.de/wp-content/uploads/2022_01_24_PM_Rohstahlerzeugung_Dez-21-1.pdf

Royal Haskoning DHV, (2022). "*Spatial Study North Seas 2030 – offshore wind development*". Retrieved on 30.06.2023 from: https://energy.ec.europa.eu/system/files/2023-01/Final%20Report%20spatial%20studies%20North%20Seas2030.pdf

Gouvermnent de France. (2023) "*175 millions d'Euros supplementaires pour développer la filière de Hydrogène*". Retrieved on 15.06.2023 from: https://www.ecologie.gouv.fr/france-2030-175-millions-deuros-supplementaires-developper-filiere-hydrogene

Bundesministerium für Wirtschaft und Klimaschutz. (2020). "*National Hydrogen Strategy*". Retrieved on 15.06.2023 from: https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6

European Commission. (2023). "*Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions On The European Hydrogen Bank*". Retrieved on 15.06.2023 from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0156&qid=1682349760946

Ministero dello Sviluppo Economico d'Italia. "*Strategia Nazionale Idrogeno, Linee Guida Preliminare*". Retrieved on 15.06.2023 from: https://www.mimit.gov.it/images/stories/documenti/Strategia_Nazionale_Idrogeno_Linee_guida_preliminari_nov20.pdf

Associación Chilena de Hidrógeno. (2023). "*Proyectos*". Retrieved on 15.06.2023 from:

https://h2chile.cl/proyectos/

HYPHEN. (2022). Southern Corridor Development Initiative (SCDI) Namibian Green Hydrogen Project. Retrieved on 11.07. 2023 from: https://hyphenafrica.com/projects/

European Commission. (2021). “Auctioning” Retrieved on 21.07.2023 from: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/auctioning_en

Newborough, M. Graham, C. “Green hydrogen: water use implications and opportunities”. ITM Power PLC. Retrieved on 17.07.2023 from: https://itm-power-assets.s3.eu-west-2.amazonaws.com/Green_Hydrogen_Water_Use_56b96f577d.pdf

Decarbonizing the Ghanaian Economy through Green Hydrogen: A Managerial leadership approach

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Abstract

The development of green hydrogen presents a significant opportunity for African economies to participate in the transition towards a low-carbon economy. However, there is a need to examine the level of awareness about green hydrogen in Ghanaian Institutions and explore the factors that may influence its acceptance. Based on institutional theory, this paper explores the role of managerial leadership in the awareness and acceptance of green hydrogen in Ghana using a mixed method. The study found that although there is a relatively high level of awareness of renewable energy technologies (RET), there exists a considerable lack of information about green hydrogen especially in the public sector. The results further indicated that the perception of cost and lack of technical human resource personnel are the major factors influencing the acceptance of green hydrogen in Ghana. The paper recommends a managerial approach that prioritizes education, training, and strengthening the capacity and technical knowledge of managers and senior-level staff of Ghanaian institutions on green hydrogen.

Introduction

Hydrogen is increasingly being seen as a critical component of the transition towards a low-carbon economy (Ajanovic & Haas, 2021; Field & Derwent, 2021). In recent times, attention has focused on developing green hydrogen in particular because of the recognition that conventional routes for hydrogen production, i.e., from fossil fuels, have negative environmental impacts (Jensterle et al.,2019). Thus, green hydrogen, which is produced using renewable energy sources such as wind and solar power, has become very important in the fight against climate change through decarbonisation (Field & Derwent, 2021). Green hydrogen has the potential to replace fossil fuels in many applications, including transportation, heating, and industrial processes (Oliveira, Beswick, & Yan, 2021). The development of a green hydrogen value chain presents a significant opportunity for African economies to participate in the global transition towards a low-carbon economy (Tian et al., 2022). Green hydrogen has emerged as a key solution for decarbonizing the global energy sector, with a potential demand of 60 million tons annually in the EU alone by 2050 (Saygin & Gielen, 2021).

Green hydrogen is important for African countries for four main reasons. First, while African countries such as Ghana, Nigeria, Cameroon, Egypt, Morocco, South Africa, Ethiopia Djibouti have immense renewable energy sources (RES), such as wind, solar, and hydropower; these resources remain largely untapped (Ibrahim et al., 2021; Amir & Khan, 2022). Secondly, as a result of the availability and abundance of RES, Hydrogen presents an opportunity for Africa to export renewable energy (Mukelabai et al .,2022). Thirdly, green hydrogen presents a sustainable solution to the energy needs of Africa. Many African countries especially those in Sub-Saharan Africa (over 600 million people) do not have access to electricity, while more than 850 million lack clean cooking facilities (International Energy Agency (IEA), 2022). Finally, green hydrogen is important as a means to mitigate the effects of a carbon-fueled economy. While African countries are the least emitters of CO2, they remain the most disproportionately affected by climate change (IEA,2022).

In driving the cause of Renewable Energy Technologies (RETs) such as green hydrogen, researchers have found that understanding the motivations and attitudes of stakeholders such decision makers and consumers is essential for adopting renewable energy sources (Pelau & Pop,2018; IEA, 2015). However, the research into user perspectives of adoption of RET in general and green hydrogen in particular has been lacking especially in developing countries. Further, while there are indications of the importance of national cultures in influencing the adoption of RETs, the literature has yet to fully address the cultural underpinnings involved in switching intentions of citizens. Nonetheless, there are indications that cultural dimensions in a country are important considerations in the acceptance of RETs such as green hydrogen (Leonidou et al, 2013; Lin et al., 2016). Additionally, some studies indicate that in regions where hydrogen energy is underutilized, there exists a public perception of green hydrogen that indicates a lack of understanding regarding its production processes and benefits (Trollip et al., 2022; IEA, 2022). Addressing the low level of awareness is crucial for a successful transition to this energy source (Flynn et al., 2008; Ingaldi & Klimecka-Tatar, 2020; Vallejos-Romero et al., 2023).This paper is based on the premise that national cultures have implications on the adoption of green hydrogen, Thus it is important for researchers to investigate the ways through which culture and managerial leaders affect intuitional awareness and acceptance of RETs (Hofstede, 1980). This paper thus examines the level of awareness about green hydrogen and explores the levels of acceptance of managers in public and private institutions. The questions this paper, therefore, attempts to answer are:

1. What is the current level of awareness about green hydrogen in Ghanaian Institutions?
2. What factors influence the acceptance of green hydrogen in private and public institutions?

Based on these questions, the paper utilizes the antecedents of the institutional theory to identify critical stakeholders in the green hydrogen value chain, and to explore key factors that influence awareness and acceptance of green hydrogen. Additionally, the study examines awareness and obstacles to adoption of green hydrogen. The paper is organized as follows: after this introduction, the next section reviews relevant literature on the key variables and theories underlying the study. This is followed by a description of the methodology employed. The subsequent section presents and discusses the study's findings, while the final section highlights the paper's contribution and offers recommendations.

Literature Review:

Green hydrogen

The concept of green hydrogen has been of interest to both researchers and practitioners in recent past. This is because, from all indications, green hydrogen is a promising renewable energy source that can play a significant role in reducing carbon emissions and achieving a sustainable future. In addition to meeting the global demand for renewable hydrogen, the continent could benefit from early adoption of hydrogen for a variety of end-use applications. The literature indicates that African countries are uniquely situated for switching to green hydrogen (IEA, 2022; Amir & Khan, 2022).

In general, the literature indicates that three factors could account for this. First, Africa's lack of antiquated generation technologies is an advantage, and it provides an opportunity to implement large-scale renewables to produce green hydrogen and tap the continent's renewable energypotential which is 1,590,000 TWh annually (Jensterle et al., 2019) Secondly, there are ongoing partnerships being forged between the European Union (EU) and the African Union (AU) (Bouacida et al., 2022). This partnership may lead to investigating the potential for green hydrogen production from the vast renewable energy sources in the sub-regions (Jensterle et al., 2019). An example is the H2 Atlas-Africa initiative, recently launched by the German Federal Ministry of Education and Research (BMBF) and African partners in the sub-Saharan region (SADC and ECOWAS countries). Finally, there are significant potential socioeconomic benefits associated with green hydrogen, such as job creation (between 300-700 jobs for every 1GWe P2X), tax revenue generation, and emission reduction, first by increasing the electrification rate in green hydrogen production regions and second by serving as an alternative fuel to replace diesel generators and traditional cooking options. These benefits could indirectly address the challenges associated with achieving Sustainable Development Goals 7 and 13 (SDG7 of clean energy; SDG 13 of climate action) (IEA, 2022; UNDP, 2023).Despite these potential benefits, the development of the green hydrogen value chain in Africa faces challenges such as limited involvement of the local economy and society (Noussan et al.,2020; Ibrahim et al 2021).

The current state of green hydrogen in Africa

Japan, Germany, the USA and the EU have led the world in terms of the development and adoption of green hydrogen in particular and decarbonization in general (Scita et al., 2020; Eicke & De Blasio, 2022). While the developed world has taken the lead to decarbonize, recent leadership demonstrated by Japan and Germany has in part pushed the agenda of green hydrogen as a decarbonization strategy to developing regions such as Africa (Bouacida et al., 2022; Lebrouhi et al., 2022). Extant literature has suggested that the green hydrogen value chain in Africa is still in its early stages, but has great potential for socio-economic benefits and climate change mitigation. Hamukoshi (2022) for instance highlights the potential for green hydrogen to revolutionize agriculture and industry in Southern Africa, while Imasiku (2021) identifies policy gaps that need to be addressed to enhance hydrogen energy production and transition from a fossil fuel-based economy to a hydrogen energy-based economy in the region. Ayodele (2019) emphasizes the encouraging renewable energy resources in South Africa for green hydrogen production, and Sadik-Zada (2021) discusses the role of green hydrogen in the transition towards climate-neutral economies and the potential for bridging the energy transition between Europe and Africa. In spite of the fact that the discourse green hydrogen value chain is in its infancy in Africa, a few projects are currently underway. For example, South Africa has set a target to produce 900 MW of green hydrogen by 2030; Morocco has launched a green hydrogen production plant in Benguerir (Roos, 2021; Azouzoute et al., 2021). Other examples include the Republic of Djibouti, Ethiopia and Egypt which have explored hydrogen production by water electrolysis using wind (Noussan et al., 2020; Osman Awaleh et al., 2021; Ibrahim et al., 2021). It appears these early projects in the aforementioned countries are often led by international companies, and foreign governments (Scita et al 2020; Noussan et al., 2020). The involvement of the local economy and society appears to be limited. This is indicative of potential adoption challenges of green hydrogen by locals.

Awareness and adoption of green hydrogen in Ghana.

The adoption of renewable energy technologies (RETs) has become a global trend in recent years, as the world shifts towards a more sustainable and environmentally friendly energy system (Ritchie & Dowlatabadi, 2015; UNEP, 2019). RETs have the potential to provide clean, affordable and reliable energy while reducing greenhouse gas emissions and mitigating climate change (IEA, 2020). Despite these benefits, the adoption of RETs in developing countries like Ghana, remains low, with renewable energy sources accounting for less than 1% of electricity generation (Energy Commission, 2006).

The low adoption rate of RETs in Ghana has been attributed to a variety of factors, including policy and regulatory barriers, lack of financing and inadequate institutional support (Akudugu et al., 2015; Korboe et al., 2018). In addition, there is limited awareness and knowledge about RETs among the general public, as well as among decision-makers in both the public and private sectors (Adu et al., 2019; Opoku et al., 2020). These present a challenge for Ghana to achieve its target of generating 10% of its electricity from renewable sources by 2030 (Ministry of Energy, 2019). Based on the existing low levels of adoption, it would be interesting to investigate awareness levels about green hydrogen which is a more novel and niche sub-section of the RET (IEA, 2022).

Theoretical Underpinnings

Institutional Theory

Institutional theory is a sociological approach that suggests that organizations are shaped by the social and cultural norms, values and rules that exist within their broader institutional setting (Meyer & Rowan, 1977). The theory posits that organisations conform to these norms, values and rules in order to achieve legitimacy and reduce uncertainty (Scott, 2014). Applying institutional theory to the adoption of renewable energy, we can see that the use of renewable energy is largely driven by institutional pressures. These pressures come from a variety of sources, including government regulations, social norms and stakeholder expectations (Scott, 2014). For example, governments may offer financial incentives to encourage the adoption of renewable energy (Brounen et al., 2014), while social norms may create pressure for organisations to be more environmentally friendly (Lyon & Montgomery, 2015).

In addition, stakeholders such as investors and customers may increasingly expect organisations to prioritise sustainability and renewable energy (Brammer et al., 2012). Organisations that adopt renewable energy can gain legitimacy by demonstrating that they are environmentally responsible and responsive to stakeholder expectations (Deephouse & Carter, 2005). They may also benefit from reduced costs in the long term as renewable energy sources become more cost-effective (Karakosta et al., 2015).

Institutional theory can help explain why some organisations are quicker to adopt renewable energy than others. Organisations that are strongly influenced by their institutional environment are more likely to adopt renewable energy, while those that are less influenced may be slower to adopt (Henisz et al., 2014). Furthermore, research suggests that public and private institutions may have different approaches to the adoption of renewable energy. Private institutions may be more likely to adopt renewable energy due to their focus on innovation and competitiveness, while public institutions may face more challenges due to bureaucratic structures and resource dependency (Kivimaa & Kern, 2016).

Hofstedes Cultural Dimensions

Several factors, including cultural dimensions, influence the acceptability of renewable energy technologies (Li et al., 2018; Morris et al., 2013; Osei-Kyei et al., 2017). Hofstede's cultural dimensions theory (Hofstede, 1980; Hofstede et al., 2010) provides a useful framework for understanding how culture influences the adoption of new technologies. Hofstede's theory of cultural dimensions explains the 'software' of societies on six dimensions: Power Distance, Individualism vs. Collectivism, Uncertainty Avoidance, Masculinity vs. Femininity, Long-term Orientation vs. Short-term Orientation, and Indulgence vs. Restraint. This discussion however discusses the first five dimensions (Hofstede, 1980; Hofstede et al., 2010).

First, countries with a large power distance may have centralised decision-making processes with minimal input from lower-level employees or stakeholders. This may have an impact on the acceptability of renewable energy technologies, as decision-makers may be less responsive to the needs and concerns of local communities and other stakeholders (Li et al., 2018). In countries with minimal power distance, on the other hand, there may be a greater emphasis on collaboration and consensus building, which may facilitate the adoption of renewable energy technologies (Morris et al., 2013; Huang, 2022).

Secondly, the dimension of Individualism versus Collectivism reflects the degree of individual self-interest ownership and materialism. In individualistic cultures, individuals may place their own demands and interests above those of the collective. Individuals may be less inclined to make sacrifices for the collective benefit, which can hinder the adoption of renewable energy technologies (Osei-Kyei et al., 2017). There may be a greater emphasis on shared responsibility and cooperation in collectivist cultures, which may facilitate the adoption of renewable energy technologies (Li et al., 2018).

Thirdly, countries with a high level of uncertainty avoidance may be more risk-averse and resistant to novel and unproven technologies. This may affect the adoption of renewable energy technologies, as stakeholders may doubt their efficacy or dependability (Li et al., 2018). Countries with low uncertainty avoidance, on the other hand, may be more inclined to take risks. Kaminsky (2016) found that high uncertainty avoidant cultures tended to be resisteant to change and did not easily adopt RETs.

Fourthly, Hofstede discusses masculinity vs. femininity. This dimension refers to the extent to which a culture values traditional masculine traits, such as competitiveness, ambition, and achievement, versus traditional feminine traits, such as nurturance, empathy, and quality of life (Hofstede et al., 2010). Cultures with high levels of masculinity, place a greater emphasis on competitiveness and achievement. This may negatively affect the acceptance of renewable energy technologies, as stakeholders may prioritize economic growth and development over environmental concerns and ignore calls for sustainability (Li et al., 2018; Huang, 2022). In contrast, in cultures with high levels of femininity, there may be a greater emphasis on quality of life and sustainability, which may facilitate the acceptance of renewable energy technologies (Morris et al., 2013).

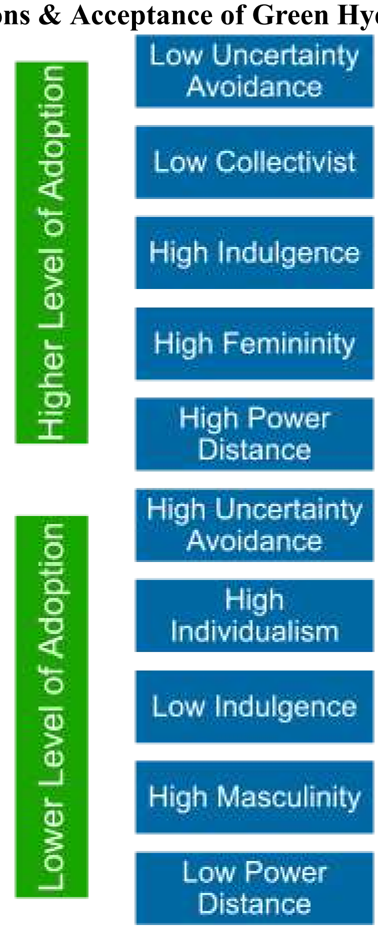
The fifth dimension in Hofstede's cultural dimensions theory is long-term versus short-term orientation. This dimension refers to the extent to which a culture values long-term planning, persistence, and perseverance, versus short-term thinking, immediate gratification, and quick results (Hofstede, 1980; Hofstede et al., 2010). Countries with a long-term orientation may be more willing to invest in long-term solutions that may not yield immediate benefits. This may facilitate the acceptance of renewable energy technologies, positively (Osei-Kyei et al., 2017). In contrast, in countries with a short-term orientation, stakeholders may be more focused on immediate results and gratification, which may make it challenging to promote the adoption of renewable energy technologies (Li et al., 2018).

The sixth and final dimension is indulgence versus moderation. This dimension describes the extent to which a culture permits or restricts the gratification of fundamental human desires associated with appreciating life and having pleasure. There may be a greater emphasis on leisure time, relaxation, and the enjoyment of life's indulgences in cultures with high indulgence. In contrast, cultures with a high level of restraint may place a greater emphasis on self-control, discipline, and the regulation of pleasure.

This dimension is especially important for appreciating the approval of renewable energy technologies that may necessitate lifestyle or consumption changes. Cultures with a high level of indulgence may be more receptive to such changes if they can maintain the same level of life quality and leisure time. In contrast, cultures with a high level of restraint may be more resistant to such changes if they clash with their cultural values of self-control and discipline.

Understanding the distinction between indulgence and restraint can assist policymakers and businesses in developing strategies that are more likely to be accepted and sustainable in various cultural contexts. Taking into consideration cultural norms and values pertaining to gratification and enjoyment enables the development of renewable energy solutions that not only meet energy requirements but are also compatible with the cultural context of the society.

Figure 1:Hofstede Cultural Dimensions & Acceptance of Green Hydrogen



Theoretically it is therefore concluded that when managerial leadership in the Ghanaian economy both public and private, adopt green hydrogen, they are able to identify all the stakeholder, who have the potential of benefiting significantly from the value creating processes associated with managing for stakeholders (Harrison et al., 2015) by conforming to the norms, values and rules in order to achieve legitimacy and reduce uncertainty (Scott, 2014).

Methods

Study site

The study sought to answer the research questions by using persons in managerial positions of institutions to get an understanding of awareness and the current state of green hydrogen using the city of Accra as a case study. Accra is under the Accra Metropolitan Assembly (AMA), which is one of the 261 Metropolitan, Municipal, and District Assemblies (MMDAs) in Ghana. The study site of Accra was selected because of its dominant role as the seat of power and governance, as well as the concentration of institutions and organizations in Ghana (Ghana Statistical Service, 2021).

Four (4) public and three (3) private institutions were selected in Accra. The selected public institutions include Weija Gbawe Municipal Hospital, Ghana Broadcasting Corporation (GBC), Ga Central Municipal Assembly, and Ga North District Assembly. The private institutions included J A Plant Pool Gh Ltd, Landfill Technologies Limited, and Puma Energy Ghana.

Public institutions

Weija Gbawe Municipal Hospital provides primary health services to the natives of Weija Gbawe district and was chosen as a study site due to its important role in providing healthcare services to the community (WGMA, 2022). The hospital was chosen because hospitals are energy-intensive facilities that require a continuous and reliable supply of electricity to power their life-saving equipment, medical devices and lighting systems. Due to their high energy consumption, hospitals are among the largest energy users in the world, accounting for a significant portion of a country's energy consumption (Franco et al., 2017). Their level of knowledge of RETs such as green hydrogen will go a long way in its adoption or otherwise.

Ghana Broadcasting Corporation is a state-owned public service broadcaster, which operates several radio and television stations across Ghana. They were selected for two reasons, first, broadcasting stations typically require a significant amount of electricity to power their broadcasting equipment, including transmitters, antennae, and studio equipment such as cameras, lighting, and audio equipment (Mawhood, 2020; Tolbert et al., 2019). According to a study by Oyekanmi et al. (2021), the energy consumption of broadcasting stations is on the rise due to the increasing demand for digital broadcasting and high-definition (HD) content. Several studies have highlighted the need for energy-efficient broadcasting technologies and practices to reduce the carbon footprint of the media industry (Al-Samarraie et al., 2019; Jiang et al., 2021).Second, they were elected due to their role as a major information provider and

communication channel in the country (GBC, 2020).
Ga Central Municipal Assembly and Ga North District Assembly were selected as study sites due to their significance as local government authorities responsible for governance and provision of services to their respective communities in the Greater Accra Region (GSS, 2018; GNMA, 2018). Thus, knowing their level of awareness of green hydrogen will inform them about the kind of policies they formulate and support and also what and how information related to green hydrogen is disseminated.

Private institutions

Three private institutions were conveniently sampled. The first J A Plant Pool Gh Ltd was selected as a study site due to its leading role in supplying heavy-duty trucks, earthmoving equipment, luxurious buses, lubricants, and car tyres in Ghana and beyond for the past 10 years (J.A. Plant Pool, 2022). The company provides effective after-sales support in terms of repair, maintenance and disposal of its products, sales of genuine spare-parts, and training of drivers, operators, and mechanics. The core business of selling, renting, and leasing heavy-duty trucks, earthmoving, and transport-related equipment requires significant use of energy. The company's machinery and equipment are powered by diesel or gasoline engines, which are significant sources of greenhouse gas emissions (J.A. Plant Pool, 2022).
The second Landfill Technologies Limited was chosen as a study site due to its cutting-edge technology, construction, and engineering expertise in landfill design and construction, research, and construction supervision of landfill engineering projects (Landfill Technologies Limited, 2021). The company also oversees the design and construction of solid waste transfer stations, which could potentially benefit from the adoption of green hydrogen. Finally, Puma Energy Ghana is a major player in the petroleum industry in Ghana, with 83 retail service stations and 80 airports (Ref). Its expertise in supplying aviation fuel especially aside supplying fuel for vehicles in general, could be relevant to the adoption of green hydrogen in the aviation sector among others. The core business of supplying, storing, and distributing petroleum products requires significant energy, including electricity and fossil fuels.

Research Approach

A mixed method approach was utilized in this study. This approach was chosen it allow the researchers to use a variety of methods, combining inductive and deductive thinking, and overcoming the limitations of using exclusively quantitative or qualitative research. Consequently, both quantitative and qualitative research approaches were adopted and questionnaires and interviews utilized as the primary data collection tools.
Population and Sampling
Based on the understanding of the stakeholder as per the institutional theory, the study's population

consisted of management and senior level staff in selected private and public institutions in Ghana. Specifically, public institutions focused on were Weija Gbawe Municipal Hospital, Ghana Broadcasting Corporation (GBC), Ga Central Municipal Assembly, and Ga North District Assembly, along with private enterprises including J A Plant Pool Gh Ltd, Landfill Technologies Limited, Puma Energy, Ghana. These institutions were selected based on their willingness to participate in the study and their prominence in the Ghanaian private and public business sector. Additionally, these industries have been previously studied in renewable energy researches by reputable institutions such as the Deloitte Research Center and the World Bank (World Bank, 2021). Based on the institutional theory, management and senior level staff were included in the study as they were deemed to have the necessary information required to answer the research questions (NBSSI, 2020; Lockwood, 2018; Martin, 2015; Slaughter et al., 2020).

The convenience and snowball sampling techniques were used to select 50 respondents from 7 institutions for the study (see Table 1). The convenience sampling technique was employed to identify respondents who were availability and willingness to participate in the study. In most case electronic platforms were leveraged to reach managers and top executives to gather data, even though in few exceptions questionnaires were hand delivered and collected after two weeks. The snowball sampling technique was used for referrals. Respondents were recruited through referrals from individuals who were already participating in the study who provided contact details of other potential respondents in their respective institutions.

Data Collection

Data was collected in 2022 between the months of June and August. There were two phases; the quantitative data collection followed by a qualitative stage. The first phase ; the quantitative stage utilised questionnaires for a survey. Prior to the data collection, the instruments were pre tested.

The study employed the stability or test-retest approach to ensure reliability of the questionnaire. Seven pre-tests of the questionnaire were administered to selected staff members of various institutions in the selected sectors. These were similar organisations to the eventual 7 institutions used in the actual study. After three weeks, the same participants were given the same questions in a different arrangement to fill out. The correlation between scores at the first test and the second re-test was used to determine the reliability of the questionnaire. To ensure validity, the questionnaire was validated by research experts in Renewable Energy Technologies, and green hydrogen and was based on previously used models and questions (Kuada, 2015; Eshun & Amoako-Tuffour, 2016).

The survey instrument was created to gather information on awareness, influencing factors, challenges, opportunities, and costs related to green hydrogen use in Ghana. The questionnaire was distributed through various online platforms such as LinkedIn, Facebook, and Whatsapp, as well as in-person where possible. Eligible participants were contacted through the snowball sampling technique or online directories.

After conducting the survey, semi-structured interviews were conducted with six respondents from the initial data collection to gain a deeper understanding of some of the issues raised in the survey. As indicated in the literature, the use of interviews after questionnaires helps to reduce self reported bias of respondents (Van de Mortel, 2008; Kvale & Brinkmann, 2009). The aim of these interviews was to explore the factors that affect the acceptance and adoption of green hydrogen, with a specific focus on the themes of cost and cultural aspects.The semi-structured interview format allowed the researcher to probe the respondents further on their attitudes, beliefs, and experiences related to the adoption of green hydrogen. The recorded interviews for each interview, was approximately 15 minutes in length, and were transcribed into MS Word for analysis.

To ensure the validity of the analysis, the transcribed interviews were independently analyzed by two data analysts. The analysis involved comparing participants' responses for similarities and differences, and identifying common themes that emerged from the data. The themes that emerged from the data were retained as the basis for the discussion of the findings.The use of semi-structured interviews is a well-established qualitative research method that allows for a more in-depth exploration of the research questions and enables the researcher to gain a deeper understanding of the respondents' perspectives (Kvale & Brinkmann, 2009). The use of two independent data analysts to analyze the transcribed interviews enhances the validity and reliability of the analysis, and helps to ensure that the findings are grounded in the data. Thematic analysis was used for the interview data.

For the quantitative data, the study utilized descriptive statistics such as frequency and percentage distribution as well as mean value distribution for data analysis. Statistical Package for Social Sciences (SPSS) version 20 was used for the statistical analysis. The responses from the questionnaires were coded with Microsoft Excel and input into SPSS to generate measure tables and figures, which were used for statistical analysis.

Table 1: Population of Management Staff and Sample taken

Institution	**Management**	**Sample Taken**
1. Ga Central Municipal Assembly	10	7
2. Ga North District Assembly	10	7
3. Ghana Broadcasting Corporation, Accra	25	10
4. J A Plant Pool Gh Ltd	8	5
5. Landfill Technologies Limited	6	5
6. Puma Energy- Adenta	5	4
7. Weija-Gbawe Municipal Hospital	15	12
Total	**79**	**50**

Source : Field Data (2022)

Results

Demographic and Employment Profile of Participants

The demographic and employment background of respondents are as indicated in Table 2. The analysis focused on the participants' gender, educational attainment, organization type, department, job position, and years of work experience. The majority of the participants were male (66%), while the remaining 34 per cent were female. In terms of educational attainment, 60 per cent of the participants held Master's degrees, 38 per cent held Bachelor's degrees, and only 2 per cent had obtained a Diploma. The results indicate that the participants were highly educated and well-informed about the research topic, enabling them to provide reliable information.

Table 2: Socio-Demographic Profile of Respondents

Category		**Frequency**	**Percentage (%)**
Gender	Female	17	34.0
	Male	33	66.0
Education	Diploma/HND	1	2.0
	First Degree	19	38.0
	Masters' Degree	30	60.0
Years of Service	Below 2 years	9	18.0
	2 - 4 years	11	22.0
	4 - 6 years	8	16.0
	6 - 8 years	8	16.0
	8 – 10 years	4	8.0
	More than 10 years	10	20.0
Position/Rank	Middle level	11	22.0
	Senior Level	24	30.0
	Management	15	48.0
Department	Administration	11	25.0
	Finance	6	14.0
	Marketing	2	5.0
	Operations	6	14.0
	Procurement	2	5.0
	Technical	16	37.0
	Total	**50**	**100**

Source : Field Data (2022)

The majority of respondents (37%) were part of the technical team, followed by those in administration (25%), finance and operations (14% each), and procurement and marketing (5% each). Most of the respondents interviewed (53%) were at management level, while 33 per cent were at the senior level and 14 per cent were at the junior level. Majority of the respondents (21%) had worked with their respective companies for over 10 years, while 19 per cent had worked for 6-8 years and another 19 per cent had worked for less than two years. The results suggest that respondents had sufficient working experience to provide credible information about their company's use of RETs.

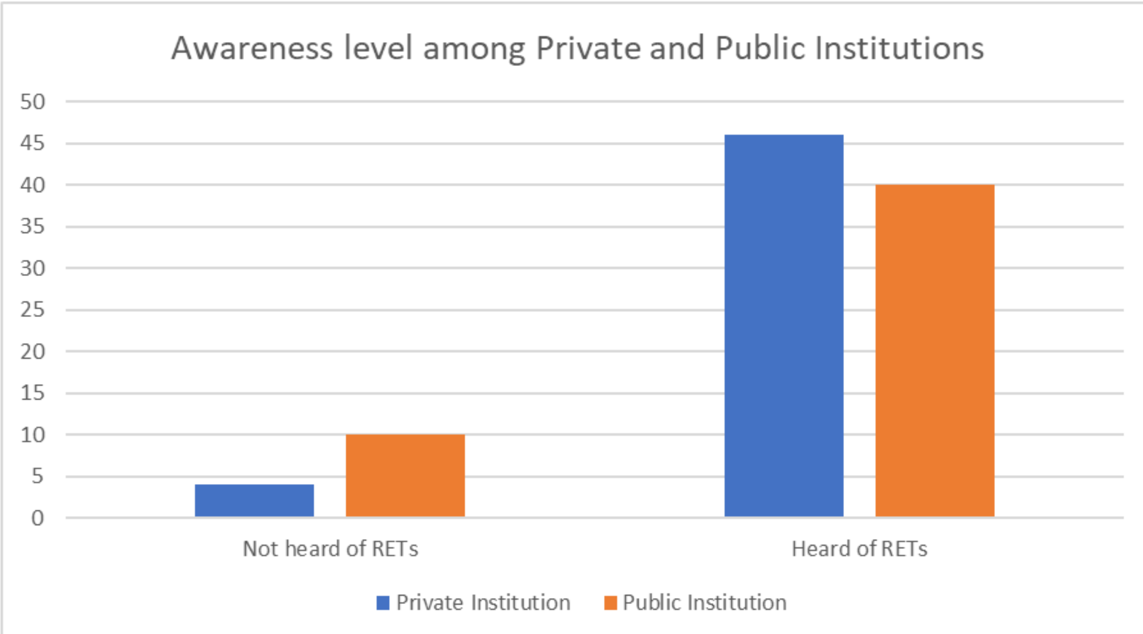
The Level of Awareness About Renewable Energy Technologies and Green Hydrogen

There were different levels of awareness about green hydrogen is shown in figure 1. While most respondents (about 86% of respondents in both public and private institutions) had heard about renewable energy in general they were less aware about green hydrogen in particular. Only two (2) respondents (4.8%) indicated that they were knowledgeable about green hydrogen. Sixty four (64%) of respondent indicated having 'No knowledge' at all (see table 3). Most respondents had sufficient knowledge about solar energy as a renewable source more than any other RET. The level of awareness of green hydrogen among managers was higher in public institutions as opposed to public institutions (see Figure 1).

Table 3: Level of Awareness about Renewable Energy Technologies

Renewable Energy Technologies	**Level of knowledge**			
	No knowledge	Average knowledge	Knowledgeable	Very knowledgeable
1) Solar Photovoltaic Power Plants	4 (9.3%)	15 (34.9%)	21 (48.8%)	3 (7%)
2) Biomass / Biofuel Power Plants	6 (14.3%)	20 (47.6%)	14 (33.3)	2 (4.8%)
3) Wind turbines/energy	14 (30.5%)	16 (37.2%)	12 (27.9%)	1 (2.3%)
4) Geothermal Power Plants	16 (38.1%)	16 (38.1%)	9 (21.4%)	1 (2.4%)
5) Green Hydrogen	27 (64.3%)	13 (31.0%)	1 (2.4%)	1 (2.4%)
6) Hydroelectric power	0	8 (19%)	26 (62%)	8 (19%)

Figure 1: Level of Awareness about Green Hydrogen

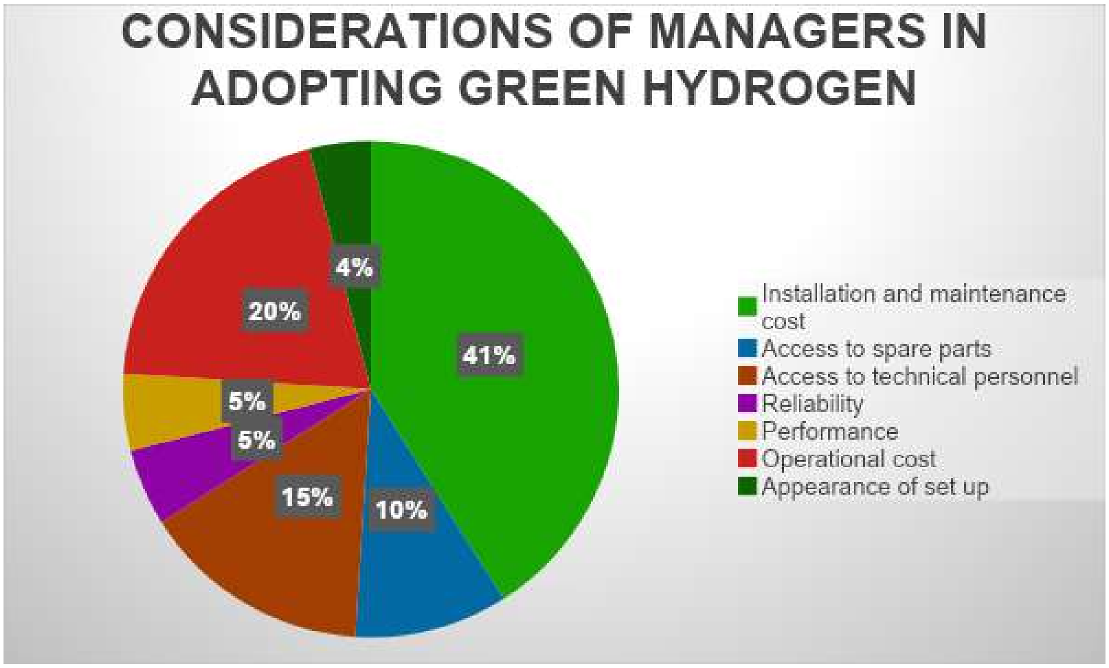


Source : Field Data (2022)

Factors influencing the acceptance of renewable energy technologies.

Respondents were asked to indicate the factors that they consider as important in potentially adopting green hydrogen as a type of renewable energy. The majority of them had concerns bordering on cost (installation, maintenance and operational cost). As indicated by figure 2, 62 per cent of respondents indicated that as primary concern. The perception of high initial capital was seen to be a deterrent. Again, access to the technical know-how was seen to be another area of consideration. Managers in both public and private institutions indicated that they did not believe that their institutions had the technical human resource capacity to adopt green hydrogen.

Figure 2: Consideration Factors in Adopting Green Hydrogen.



Source: Field Study, 2022

The qualitative inquiries through the interview sessions also gathered the following factors as major considerations that drive the adoption and implementation of green hydrogen in their institutions. The main themes that came up were cost ,social norms and expectations. Cost was seen in two main ways. First managers were concerned about cost implications of green hydrogen because they assumed that just like solar energy, the initial set-up would be expensive. On the other hand, current cost of energy for institutions in the private sector had caused them to explore alternatives to the hydroelectric power provided by the Electricity Corporation of Ghana (ECG).

Cost

Cost is an important factor that influences the extent to which managers will adopt a new strategy or not. When asked about what current RETs they had adopted and why , managers indicated the following;

"*This particular [RET] installation has to do with a combination of power plants. Combining the purchase with installation and maintenance cost you will realize that it was a heavy blow for us but we had to do it*" (Technical Manager, 7 years, private sector)

"*Actually, a factor that wanted to deter us was because the technology is not known. It is new to people in the organization. If something is new to people in an organization, making a decision on it becomes difficult*" (Technical Manager, 7 years, private sector)

The were indications that the rise in cost of electricity caused them to switch to RETs;

"*Initial cost was a deterring factor. Looking at the electricity bill we decided to switch*" (Warehouse Manager, 4 years, private sector)

"It was the bills we were paying to ECG that caused us to switch to using solar" (Marketing Manager, 4 years, private sector)

These comments implies that cost is a critical factor taken into consideration in the decision to employ RETs as alternative energy sources. Similar to Faiers and Neame (2017), the cost-benefit issue was an important determinant of usage of renewable energy technologies among the users of RETs. The cost has been found to have a direct and significant relationship with the adoption of RETs (Al-Marri, Al-Habaibeh & Watkins, 2018; Batley et al., 2011).

Social Norms and Expectations

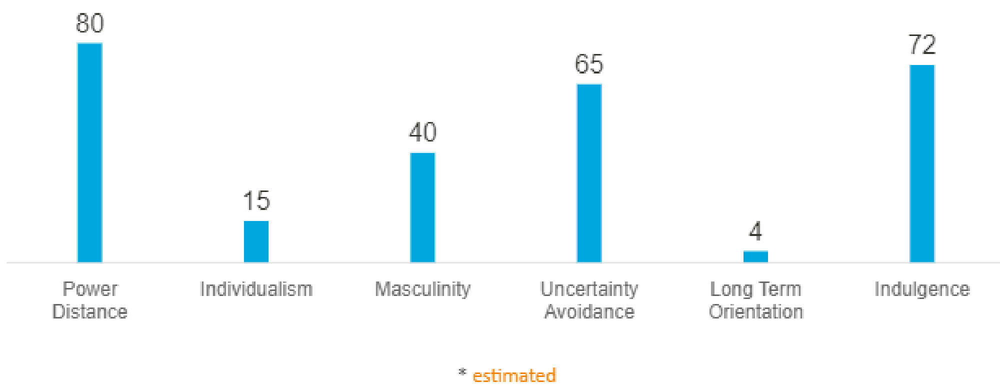
An underlying theme from the interviews focused on the expectation of the state leadership, education and support for green hydrogen as a prerequisite for acceptance and adoption.

"*We have no idea on the installation cost and knowledge we have on it is minimal. Maybe the government should look to educating us about it and bringing in experts*" (Assembly member, 5 years, public sector).

"*We don't have much education in it*". *There is no information about hydrogen in the public space. Maybe the state can lead the education of the public about this*"(Operations manager, 3 years, private sector).

"*The conversation on RETs hasn't started at all much less green hydrogen. It hasn't been considered and discussed. I believe it's primarily due to the lack of knowledge in that area. If you do not know about it, how do you implement it?*." (Operations Manager, 2 years, private sector).

Figure 3: Ghana on the Hofstede Cultural Dimensions



Source: Hofstede (2010)

As shown in Figure 3 , Ghana is a highly collectivist (80) , high uncertainty avoidance (65) country that is mildly masculine but highly indulgent society (72) with low long term orientation. This has significant implications for the potential adoption of RETs such as green hydrogen.

As a highly collectivist society with a high power distance index, Ghana may exhibit hesitance towards the adoption of renewable energy. Huang (2022) found that a high power distance index has a strong negative impact on renewable energy adoption. Furthermore, the high uncertainty avoidance in Ghanaian culture may explain why there is always an expectation and burden on the state to lead in the adoption of new technologies and innovations. This is evidenced by the fact that, despite Ghana running a capitalist economy, leaders in both public and private institutions expect the state to lead in education and knowledge capacity development for green hydrogen (Hofstede et al., 2010).The high uncertainty avoidance in Ghanaian culture may explain why managers seem hesitant due to their perceived ‘ lack of knowledge’ especially as they anticipate green hydrogen would require significant investments (Kaminsky, 2016). This may pose a challenge to the widespread adoption of green hydrogen, which is a relatively new technology that requires substantial investments in infrastructure, equipment, and training.

Again the low long-term orientation in Ghanaian culture may also hinder the adoption of RETs. In a society where immediate gratification is valued, there may be a limited appetite for long-term investments in sustainable energy solutions that may not yield immediate benefits. This may further impede the adoption of green hydrogen, which requires significant investments in the short term but offers substantial long-term benefits.

Discussion

The adoption of green hydrogen technology in Ghana requires the knowledge and understanding of renewable energy technologies by managers and senior-level staff. Our study revealed that while 86 per cent of the respondents had heard of renewable energy technologies, indicating a relatively high level of awareness of RET such as solar energy, they lacked enough information about green hydrogen in particular.

Interestingly, the level of ignorance of renewable energy technologies was higher among public sector respondents than private sector respondents. This finding is consistent with previous research that suggests that private institutions tend to be more innovative and knowledgeable about innovative concepts like renewable energy technologies compared to public institutions. Thus, public institutions need to invest more in knowledge acquisition and learning opportunities to catch up with their private counterparts.

Secondly, the perception of cost and lack of technical human resource personnel were seen to be major factors of consideration for both public and private institutions. According to Dapaah et al (2018), most individuals and organizations alike, who have interest in renewable energy sources and are willing to adopt are usually faced with the barrier of high initial installation cost. This finding was further substantiated by the qualitative interviews. The interviews also gave an indication that the lack of commitment on the part of the state and the unavailability of supporting policies serve as barriers to adoption. This result is consistent with a study by D'Souza & Yiridoe (2021) who found the barriers to RET implementation in Egypt to be categorized into economic and financial, awareness and information, technical, market, social and institutional and policy of the state.

Thirdly, our findings highlight the importance of culture in the acceptance of RETs such as green hydrogen. Follwing the institutional theory,social norms and expectations were found to be an underlying factor in our findings (Scott, 2014). The national culture of the Ghanaian society is such that state leadership is expected to legitimise innovation. Institutional theory suggests that organisations conform to social and cultural norms, values, and rules to achieve legitimacy and reduce uncertainty. We found that managers and decision-makers expected governmental policies and support for green hydrogen. Based on Hofsteds cultural dimensions, it was clear that being highly collectivist and a high uncertainty avoidance may pose challenges to the acceptance of green hydrogen. This implies that policy makers need to create a strong emphasis on collaboration, shared responsibility, and conformity to social norms, values, and rules. The adoption of renewable energy technologies (RETs) such as green hydrogen may require a collective effort that involves stakeholders in both the public and private sectors, as well as the general public (Gudykunst & Kim, 2017; Chowdhury & Baumann, 2019).

On the other hand, the high indulgence in Ghanaian culture may also provide an opportunity for advocacy to indicate the ways in which the adoption of RETs would be more profitable financially and reduce their cost and expenses and provide a means to having a higher quality of life. As reflected by studies such as those Karber (2018) awareness of financial benefits could provide a strong motivator for the adoption of RETs.

Finally, our study makes significant contributions to theory. Based on Hofestede cultural dimensions we highlight the significance of national culture of acceptance and adoption of green hydrogen. Next, based on institutional theory, we highlight the importance of government policies, advocacy, and state leadership in promoting the adoption of green hydrogen. There is a need for advocacy and state leadership in promoting the adoption of green hydrogen in Ghana. As per the institutional theory, governments can play a crucial role in setting policies and regulations that promote the adoption of sustainable technologies. Moreover, stakeholders in both public and private sectors must coordinate their efforts to address barriers and promote the adoption of green hydrogen. When the state takes leadership it can help the idea of green hydrogen achieve legitimacy and also reduce the uncertainty and apprehension currently been experienced by managers due to their perception of having no technical expertise

Recommendations and Conclusion

Our findings have revealed the perception of 'low knowledge ' and awareness levels as well as a 'lack of education' from managerial leadership in both public and private institutions. These indicate that there is a significant knowledge gap among these senior level stakeholders, regarding the technical and economic aspects of green hydrogen. This lack of knowledge can create a barrier to adoption, as decision-makers may be hesitant to invest in new technologies that they do not fully understand.

To address this knowledge gap, we paper recommend a manager-level approach that prioritizes education, training, and capacity-building of managers and senior-level staff of Ghanaian institutions on green hydrogen. This approach is based on the idea that effective decision-making requires a thorough understanding of the technology and its potential benefits and risks. By investing in education and training for key decision-makers, the paper argues that Ghana can create a more supportive policy and regulatory environment for green hydrogen adoption, which can in turn encourage private sector investment and innovation (Budinis and Aragão, 2020).By increasing the technical expertise of decision makers, the concerns and apprehension about cost elements can be minimised.

Based on our findings, it is recommened that the type capacity-building initiatives be collaborative in nature and aim to create private-public partnerships (PPP). PPPs have been found to be effective in technology diffusion in collectivist societies (Budinis and Aragão, 2020; Carrillo & Gutiérrez-Martín, 2019). By prioritising capacity building, Ghana can foster collaboration among industry players, policy makers and other stakeholders to facilitate the development of green hydrogen value chains.

While our study provides novel findings on the impact of culture and institutional leadership in a acceptance of green hydrogen there are some limitations worthy of attention. First, the sample size of respondents were limited to senior managerial-level employees in Ghanaian institutions. As a result, the findings may not be applicable to other stakeholders in the green hydrogen value chain, including investors, policymakers, and consumers. Future research could seek to include a more diverse range of participants in order to provide a more comprehensive comprehension of the levels of awareness and barriers to green hydrogen adoption in Ghana.

In conclusion, successful adoption of green hydrogen technology in Ghana depends on several factors. Firstly, it is crucial to acknowledge the cultural context of the country to ensure that the technology is accepted and integrated into existing societal structures. Secondly, a managerial approach that prioritizes education, training, capacity building, and technical knowledge of managers and senior-level staff is essential to ensure effective implementation and management of the technology. Moreover, the government should provide overt support and leadership to drive the adoption of green hydrogen technology in Ghana. This could be achieved through advocacy for the general public, training and learning programs for senior executives and decision-makers, and policy support at the state level. By implementing these measures, Ghana can achieve a more sustainable and resilient energy future, reducing its dependence on fossil fuels and promoting environmental protection.

References

Al-Samarraie, H., Fleury, A., & Carrillo, P. (2019). A survey of green ICT practices in the broadcast industry. *Sustainable Computing: Informatics and Systems, 22,* 109-118.

Ajanovic, A., & Haas, R. (2021). Prospects and impediments for hydrogen and fuel cell vehicles in the transport sector. *International journal of hydrogen energy, 46*(16), 10049-10058

Amir, M., & Khan, S. Z. (2022). Assessment of renewable energy: Status, challenges, COVID-19 impacts, opportunities, and sustainable energy solutions in Africa. *Energy and Built Environment, 3*(3), 348-362.

Ayodele, T. R., & Munda, J. L. (2019). Potential and economic viability of green hydrogen production by water electrolysis using wind energy resources in South Africa. International *Journal of Hydrogen Energy, 44*(33), 17669–17687. https://doi.org/10.1016/j.ijhydene.2019.05.077.

Azouzoute, A., El Ydrissi, M., Elmaazouzi, Z., Benhaddou, M., Salihi, M., Hajjaj, C., & Garoum, M. (2021). Thermal production and heat cost analysis of the potential of solar concentrators for industrial process applications: A case study in six sites in Morocco. *Scientific African, 12*, e00765.

Budinis, S., & Aragão, M. (2020). Capacity-building in the renewable energy sector: A review of practices and recommendations for green hydrogen. *Energy Policy,* 147, 111957.

Bouacida, I., Hege, E., Iacobuta, G., Keijzer, N., & Koch, S. (2022) *African Union-European Union cooperation on climate and energy Discussing perspectives on hydrogen and just transitions.* The European Think Tanks Group.

Chowdhury, M., & Baumann, C. (2019). The impact of cultural values on firm behavior and performance: A systematic review. *Journal of World Business, 54*(6), 1-17.

Davidson, A. (2017). Public versus private innovation: The case of green energy patents. *Energy Policy,* 105, 310-320.

Davidson, K. (2017). Renewable energy in the public sector: Investigating organisational motivations and barriers in Australia. *Energy Research & Social Science, 29,* 135-144. doi: 10.1016/j.erss.2017.05.024

DiMaggio, P. J., & Powell, W. W. (1983). The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. *American Sociological Review, 48*(2), 147-160. doi: 10.2307/2095101

Energy Commission. (2006). Strategic national energy plan 2006–2020. *Energy Commission: Accra, Ghana*.

Eicke, L., & De Blasio, N. (2022). Green hydrogen value chains in the industrial sector—Geopolitical and market implications. *Energy research & social science, 93*, 102847.

Eshun, M. E., & Amoako-Tuffour, J. (2016). A review of the trends in Ghana's power sector. Energy, Sustainability and Society, 6(1), 9. https://doi.org/10.1186/s13705-016-0075-y

Field, R. A., & Derwent, R. G. (2021). Global warming consequences of replacing natural gas with hydrogen in the domestic energy sectors of future low-carbon economies in the United Kingdom and the United States of America. *International Journal of Hydrogen Energy, 46*(58), 30190-30203.

Flynn, R., Bellaby, P., & Ricci, M. (2008). Environmental citizenship and public attitudes to hydrogen energy technologies. *Environmental Politics*, *17*(5), 766–783. https://doi.org/10.1080/09644010802421539

Franco, A., Shaker, M., Kalubi, D., & Hostettler, S. (2017). A review of sustainable energy access and technologies for healthcare facilities in the Global South. *Sustainable Energy Technologies and Assessments,* 22, 92-105.

Genovese, M., Schlüter, A., Scionti, E., Piraino, F., Corigliano, O., & Fragiacomo, P. (2023). Power-to-hydrogen and hydrogen-to-X energy systems for the industry of the future in Europe. *International Journal of Hydrogen Energy*.

Gudykunst, W. B., & Kim, Y. Y. (2017). *Communicating with strangers: An approach to intercultural communication.* Routledge.

Harrison, J. S., Freeman, R. E., & Abreu, M. C. S. D. (2015). Stakeholder theory as an ethical approach to effective management: Applying the theory to multiple contexts. *Revista brasileira de gestão de negócios,* 17, 858-869.

Hamukoshi, S. S., Mama, N., Shimanda, P. P., & Shafudah, N. H. (2022). An overview of the socio-economic impacts of the green hydrogen value chain in Southern Africa. Journal of Energy in Southern Africa, 33(3), Article 3. https://doi.org/10.17159/2413-3051/2022/v33i3a12543

Hofstede, G. (1980). *Culture's consequences: International differences in work-related values*. Sage.

Hofstede, G., Hofstede, G. J., & Minkov, M. (2010). *Cultures and organisations are the mind's software*. McGraw-Hill.

Huang, C.-J., Liu, H.-Y., Lin, T.-L., & Lai, J.-Y. (2022). Revisiting Hofstede's dimensions of national culture and environmental sustainability. *Energy & Environment,* 0(0). https://doi.org/10.1177/0958305X221140579

Ibrahim, I. D., Hamam, Y., Alayli, Y., Jamiru, T., Sadiku, E. R., Kupolati, W. K., ... & Eze, A. A. (2021). A review on Africa energy supply through renewable energy production: Nigeria, Cameroon, Ghana and South Africa as a case study. *Energy Strategy Reviews*, 38, 100740.

Imasiku, K., Farirai, F., Olwoch, J., & Agbo, S. N. (2021). A Policy Review of Green Hydrogen Economy in Southern Africa. *Sustainability, 13*(23), Article 23. https://doi.org/10.3390/su132313240

Ingaldi, M., & Klimecka-Tatar, D. (2020). People's Attitude to Energy from Hydrogen—From the Point of View of Modern Energy Technologies and Social Responsibility. Energies, 13(24), Article

24. https://doi.org/10.3390/en13246495
International Energy Agency, (2015). *World Energy Outlook 2015.* http://www.worldenergyoutlook.org/pressmedia/recentpresentations/151110_WEO2015_ presentation.pdf
International Energy Agency (IEA) (2022) *Africa Energy Outlook 2022.* https://www.iea.org/reports/africa-energy-outlook-2022
Jensterle, M., Narita, J., Piria, R., Samadi, S., Prantner, M., Crone, K., ... & Thesen, J. (2019). *The role of clean hydrogen in the future energy systems of Japan and Germany: an analysis of existing mid-century scenarios and an investigation of hydrogen supply chains.* Adelphi consult GmbH Berlin, Germany.
J.A. Plant Pool. (2022). About us. http://japlantpool.com/about-us/
Jiang, Y., Zhou, J., & Zhang, X. (2021). Energy management strategies for radio and television broadcasting: A review. *Renewable and Sustainable Energy Reviews*, 143, 110978.
Kvale, S., & Brinkmann, S. (2009). *Interviews: Learning the craft of qualitative research interviewing* (2nd ed.). Sage.
Kim, H., & Park, H. (2016). Public perceptions of science and technology in Korea: Implications for science communication policy. *Public Understanding of Science, 25*(1), 64-78. doi: 10.1177/0963662514546941
Kivimaa, P., & Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy, 45*(1), 205–217.
Kaminsky, J. A. (2016). Cultured construction: Global evidence of the impact of national values on renewable electricity infrastructure choice. *Environmental Science & Technology, 50*(4), 2108-2116.
Landfill Technologies Limited. (2021). About us. https://landfilltechnologiesltd.com/about-us/Meyer, J. W., & Rowan, B. (1977). Institutionalized Organizations: Formal Structure as Myth and Ceremony. American *Journal of Sociology, 83*(2), 340-363. doi: 10.1086/226550
Lebrouhi, B. E., Djoupo, J. J., Lamrani, B., Benabdelaziz, K., & Kousksou, T. (2022). Global hydrogen development-A technological and geopolitical overview. *International Journal of Hydrogen Energy*.
Li, M., Li, S., & Guo, Y. (2017). Culture and creativity: A literature review. *Creativity Research Journal, 29*(1), 1-9.
Li, Y., Wu, H., & Zhao, X. (2018). Evidence from China exploring the relationship between cultural dimensions and innovation. 55:15-23 Technology in Society.
Leonidou, L. C., Katsikeas, C. S., Fotiadis, T. A., & Christodoulides, P. (2013). Antecedents and consequences of an eco-friendly export marketing strategy: The moderating role of foreign public

concern and competitive intensity. *Journal of International Marketing, 21*(3), 22-46. http://dx.doi.org/10.1509/jim.12.0139

Lin, B., Omoju, O. E., & Okonkwo, J. U. (2016). Factors influencing renewable electricity consumption in China. *Renewable and Sustainable Energy Reviews,* 55, 687-696. http://dx.doi.org/10.1016/j.rser.2015.11.003

Maalouf, G. Y. (2019). Effects of collaborative leadership on organizational performance. *International Journal of Multidisciplinary Research and Development*, *6*(1), 138-144.

Mawhood, M. (2020). Renewable energy for broadcast: The future is bright. *Journal of the Institute of Telecommunications Professionals, 14*(1), 47-52.

Morris, M. H., Schindehutte, M., & Allen, J. (2013). The business model of the entrepreneur: Towards a unified perspective. *Journal of Business Research 66(*10), 1739-1746.

Mukelabai, M. D., Wijayantha, U. K., & Blanchard, R. E. (2022). Renewable hydrogen economy outlook in Africa. *Renewable and Sustainable Energy Reviews, 167*, 112705.

Noussan, M., Raimondi, P. P., Scita, R., & Hafner, M. (2020). The role of green and blue hydrogen in the energy transition—A technological and geopolitical perspective. *Sustainability, 13*(1), 298.

Osei-Kyei, A. P. Chan, and E. E. Ameyaw (2017). Factors influencing the adoption of innovation by small and medium-sized enterprises: Evidence from an emerging economy. *Journal of Business Research.* 78, 275-283

Osman Awaleh, M., Adan, A. B., Assowe Dabar, O., Jalludin, M., Mahdi Ahmed, M., & Abdillahi Guirreh, I. (2021). Economic feasibility of green hydrogen production by water electrolysis using wind and geothermal energy resources in Asal-Ghoubbet Rift (Republic of Djibouti): A comparative evaluation. *Energies, 15(*1), 138. https://doi.org/10.3390/en15010138

Oliveira, A. M., Beswick, R. R., & Yan, Y. (2021). A green hydrogen economy for a renewable energy society. *Current Opinion in Chemical Engineering*, *33*, 100701.

Oyekanmi, B. A., Fajobi, M. A., & Otunuga, B. A. (2021). Investigating the energy consumption pattern of digital television broadcasting in Nigeria*. Journal of Cleaner Production*, 312, 127701

Pan, S. Y., Du, M. A., Huang, I. T., Liu, I. H., Chang, E. E., & Chiang, P. C. (2015). Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review. *Journal of Cleaner Production*, 108, 409-421.

Pelau, C., & Pop, N. A. (2018). Implications for the energy policy derived from the relation between the cultural dimensions of Hofstede's model and the consumption of renewable energies. *Energy Policy*, 118, 160-168.

Puma Energy Ghana. (2020). About us.

https://www.pumaenergy.com/en/worldwide/puma-energy-in-africa/puma-energy-ghana/about-us/

Roos, T. H. (2021). The cost of production and storage of renewable hydrogen in South Africa and transport to Japan and EU up to 2050 under different scenarios. International *Journal of Hydrogen Energy, 46*(72), 35814-35830.

Sadik-Zada, E. R. (2021). Political Economy of Green Hydrogen Rollout: A Global Perspective. *Sustainability, 13*(23),. https://doi.org/10.3390/su132313464

Sandelowski, M. (2000). Focus on research methods: Whatever happened to qualitative description? *Research in Nursing & Health, 23(*4), 334-340.

Saygin, D., & Gielen, D. (2021). Zero-emission pathway for the global chemical and petrochemical sector. *Energies, 14*(13), 3772.

Scita, R., Raimondi, P. P., & Noussan, M. (2020). Green hydrogen: the holy grail of decarbonisation? An analysis of the technical and geopolitical implications of the future hydrogen economy. FEEM Working Paper No. 13.

Scott, W. R. (2014). *Institutions and organizations: Ideas, interests, and identities*. Sage

Tian, J., Yu, L., Xue, R., Zhuang, S., & Shan, Y. (2022). Global low-carbon energy transition in the post-COVID-19 era. *Applied energy*, *307*, 118205.

Tolbert, A. K., Perera, L. P., & Robinson, J. A. (2019). Power management strategies for broadcast television transmission systems. *IEEE Transactions on Broadcasting, 65*(1), 279-287.

Trollip, H., McCall, B., & Bataille, C. (2022). How green primary iron production in South Africa could help global decarbonization. *Climate Policy*, *22*(2), 236-247.

Twidell, J., & Weir, T. (2016). *Renewable energy resources*. Routledge.

United Nations Development Program (UNDP) (2023). Sustainable Development Goals. United Nations Development Programme. https://www.undp.org/sustainable-development-goals

Van de Mortel, T. F. (2008). Faking it: social desirability response bias in self-report research. *Australian Journal of Advanced Nursing, The*, *25*(4), 40-48.

Vallejos-Romero, A., Cordoves-Sánchez, M., Cisternas, C., Sáez-Ardura, F., Rodríguez, I., Aledo, A., Boso, Á., Prades, J., & Álvarez, B. (2023). Green Hydrogen and Social Sciences: Issues, Problems, and Future Challenges. *Sustainability, 15*(1), https://doi.org/10.3390/su15010303

EFFICIENT PRODUCTION OF GREEN HYDROGEN IN AFRICA

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Abstract

Ecological and environmental issues have become the recent area for discussion regarding energy production and consumption, which has triggered the interest of various stakeholders to seek cleaner and sustainable solutions to these issues. This is demonstrated by the energy industry's dedication to developing energy alternatives that are commercially viable and capable of competing with other established forms of energy generation while also meeting the necessary ecological criteria.[25] A switch to renewable energy sources is needed to achieve sustainable growth. Green hydrogen is an environmentally sustainable alternative among the commonly used renewable energy sources. Africa is naturally endowed with abundant renewable energy sources that can help satisfy the continent's demand for various forms of energy to boost economic growth and achieve global targets for CO2 reduction[26]. Green hydrogen is one of the most promising technologies for energy production, transmission, and storage. This study examines the potential for producing green hydrogen in several African nations and its application in the future. A summary of the advantages of switching to green hydrogen technology is provided. African infrastructure and policies were also evaluated considering the stated objectives[27].

Introduction

A proposed method to decarbonize the energy industry and cut greenhouse gas emissions is green hydrogen. Green hydrogen, produced through electrolysis powered by renewable energy, has gained attention as a key component in the transition to a low-carbon economy. African countries, endowed with abundant renewable energy resources, are poised to leverage the potential of green hydrogen to unlock economic growth, increase energy security, and reduce carbon emissions. Green hydrogen production has been gaining significant attention worldwide as a promising alternative to traditional fossil fuels. The process involves the use of renewable energy sources, such as solar and wind power, to power electrolysers that split water into hydrogen and oxygen. This process produces no carbon emissions, making it a viable solution to reduce greenhouse gas emissions and fight climate change[28].

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[25] (Seada and Hatem)
[26] (Ayodele and Munda)
[27] (Bhandari)
[28] (IREANA 2020)

In Africa, green hydrogen production presents a unique opportunity to promote sustainable development while also driving economic growth. The continent is endowed with abundant renewable energy resources, including solar, wind, and hydropower, which can be harnessed to produce green hydrogen. Additionally, the development of green hydrogen infrastructure and the adoption of hydrogen-powered vehicles could create new jobs and stimulate innovation in African economies. Studies have shown that green hydrogen production could have a significant impact on the African economy. For instance, a report by the African Development Bank (AfDB) estimates that green hydrogen production could generate up to $200 billion annually by 2050, while creating up to 10 million new jobs across the continent. The report further suggests that green hydrogen could be used to power a range of sectors, including transportation, power generation, and industrial processes[29].

Moreover, green hydrogen production could also help to reduce energy poverty in Africa. Currently, over 600 million people in sub-Saharan Africa lack access to electricity, and the region has the lowest electrification rates in the world. The development of green hydrogen infrastructure could provide a reliable and sustainable source of energy to remote and under-served communities[30]. It can change the energy landscape and open new options for economic growth as a sustainable and environmentally friendly energy source[31]. But nonetheless, nothing is known about how producing green hydrogen would affect the continent of Africa's economy. By examining the potential advantages and difficulties of manufacturing green hydrogen in Africa and its effects on the economy, this essay tries to close this gap. The study is founded on a survey of related material from earlier investigations. Peer-reviewed literature, official reports, and trade publications are some examples of sources.

The African Development Bank's Energy Outlook Report, the International Renewable Energy Agency's Global Energy Transformation Report, and the United Nations Development Program's report on the use of renewable energy in sustainable development in Africa are a few of the major sources used in this study. This study will shed light on the financial advantages of green hydrogen production in Africa, including enhanced economic growth, energy security, and employment. It also looks at potential difficulties and hindrances to the use of green hydrogen in Africa, such as expensive production costs, inadequate infrastructure, and political and regulatory constraints.

Literature Review

Due to its potential to reduce carbon emissions across a range of industries, including transportation, manufacturing, and power generation, green hydrogen is developing as a promising energy source. Economic, social, and environmental gains may arise from its manufacturing and introduction. On the African continent, where access to energy is still a problem, green hydrogen may change the game.

29 (African Development Bank 2021)
30 (IRENA 2021)
31 (Ayodele and Munda)

This study of the literature attempts to examine the body of knowledge about the viability of producing green hydrogen for the African economy. The transition to a low-carbon economy has the potential to be significantly aided by hydrogen.

It has a wide range of possible uses, including transportation, industry, and power generation, and it may be produced from several sources, including natural gas, coal, and renewable energy[32]. Africa might gain from the production and use of hydrogen given its wealth of renewable energy resources and rising energy demand. In this assessment of the literature, we investigate the status of research on the impact of hydrogen generation on the African economy[33].

Current Energy Situation in Africa

With 600 million people lacking access to power, Africa confronts severe energy difficulties. Furthermore, the energy sector of the continent is mostly dependent on expensive and harmful fossil fuels. Despite the vast amount of renewable energy potential in Africa, renewable energy sources are yet undeveloped[34]. Green hydrogen might therefore hasten Africa's transition to a low-carbon and sustainable energy sector. Significant renewable energy potential exists in Africa for the generation of green hydrogen, notably in the form of solar and wind energy, which are essential inputs. Green hydrogen projects are being developed in a number of African nations, including South Africa, Morocco, and Egypt. These initiatives might strengthen the local economy by fostering employment growth, technological transfer, and prospective exports.

Lack of access to power and modern fuels, particularly in rural regions, distinguishes the African energy industry[35]. Almost 580 million people in sub-Saharan Africa did not have access to electricity in 2019, while nearly 900 million relied on traditional biomass for cooking and heating, according to the International Energy Agency. Despite this, Africa has a wealth of renewable energy resources, such as solar, wind, and hydropower, and the continent has a great potential for the growth of renewable energy[36].

In West Africa, the energy mix is dominated by fossil fuels, particularly oil and gas, with limited renewable energy sources. The region faces challenges in energy access, with low electrification rates in rural areas. However, there are ongoing efforts to increase renewable energy deployment, particularly solar and hydropower, to enhance energy security and reduce carbon emissions[37]. In East Africa, there is a high potential for renewable energy due to abundant solar, wind, and geothermal resources. The region has made significant strides in renewable energy deployment, with Ethiopia and Kenya leading in geothermal and wind power respectively. However, the energy access rate in the region remains low, with

32 (African Development Bank 2020)
33 (African Development Bank 2021)
34 (International Renewable Energy Agency 2020)
35 (International Renewable Energy Agency 2019)
36 (International Renewable Energy Agency 2019)
37 (African Development Bank Group 2019)

rural areas bearing the brunt of energy poverty[38].

North Africa has significant fossil fuel reserves, particularly oil and gas, which are the primary source of energy. However, the region has recognized the need to diversify its energy mix and increase renewable energy deployment, particularly solar and wind power. Morocco and Egypt are leading in the deployment of renewable energy, with ambitious plans to increase their renewable energy share in the energy mix[39]. In South Africa, coal dominates the energy mix, contributing to high carbon emissions. However, there are ongoing efforts to increase renewable energy deployment, particularly solar and wind power, to reduce carbon emissions and enhance energy security. The country has implemented a successful renewable energy program, with significant investment in renewable energy projects[40].

In Central Africa, the energy situation is characterized by low access rates, limited infrastructure, and low renewable energy deployment. However, the region has significant untapped hydropower potential, which can be harnessed to enhance energy access and promote economic development. The energy situation in the five African blocs varies, with some regions having significant fossil fuel reserves while others have abundant renewable energy resources. The region faces significant challenges in energy access, infrastructure development, and investment in renewable energy. However, there are ongoing efforts to increase renewable energy deployment and diversify the energy mix to promote sustainable development.

Hydrogen Production Potential in Africa

Africa has a lot of potential for producing hydrogen from renewable energy, especially the sun and wind. Africa's solar potential alone could provide 10,000 terawatt hours of power annually, which is more than 10 times the continent's current electricity demands, according to research by the International Renewable Energy Agency (IRENA)[41]. The projected annual wind potential for Africa is also approximately 180,000 terawatt-hours. In Africa, hydrogen is used for a variety of purposes, particularly in the transportation industry. Traditional petrol and diesel automobiles could be replaced by hydrogen fuel cell electric vehicles (FCEVs), which might offer a clean and effective alternative. In addition, hydrogen may be utilised as a raw material for industrial operations like the manufacturing of ammonia and as a standby power source for remote locations[42].

West African, countries such as Senegal and Mali have significant potential for solar and wind energy, which can be harnessed for green hydrogen production. The West African Power Pool (WAPP)

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38 (IRENA 201)
39 (Mashat and El-Said 2020)
40 (United Nations Economic Commission for Africa 2021)
41 (International Renewable Energy Agency 2020)
42 (United Nations Development Program 2019)

has been established to promote regional cooperation and the development of renewable energy infrastructure. In East Africa, countries such as Ethiopia and Kenya have abundant geothermal resources, which can be used to produce green hydrogen. The East African Community (EAC) has set targets to increase the share of renewable energy in the region's energy mix, which can contribute to the development of green hydrogen production[43].

In North Africa, countries such as Morocco and Egypt have significant solar resources, which can be leveraged for green hydrogen production. The Desertech project, a large-scale renewable energy initiative, aims to connect North African countries with Europe through a network of transmission lines. South Africa, the Renewable Energy Independent Power Producer Procurement (REIPPP) program has facilitated the deployment of renewable energy projects, including solar and wind farms, which can be used for green hydrogen production. South Africa also has significant reserves of platinum, which is a key component in the electrolysis process used to produce green hydrogen[44].

In Central Africa, countries such as Cameroon and the Democratic Republic of Congo have abundant hydropower resources, which can be used for green hydrogen production. However, the lack of adequate infrastructure and political instability can pose challenges to the development of green hydrogen in the region. The African continent has significant potential for green hydrogen production, with each bloc offering unique opportunities and challenges. The development of green hydrogen production in Africa can contribute to the continent's economic growth, energy security, and climate change mitigation efforts.

Benefits of Green Hydrogen Production in Africa

Africa's adoption of green hydrogen generation might have a positive impact on the economy, society, and environment. Employment growth, industrial development, and export revenue are all considered economic advantages. Improvements in health, education, and energy availability are all social advantages. Environmental advantages include less greenhouse gas emissions, better air quality, and averting climate change[45]. Africa's economy might profit significantly from the manufacturing of hydrogen. By 2050, the global hydrogen industry may provide $2.5 trillion in yearly income and add 30 million jobs, according to a forecast by the Hydrogen Council. Production of hydrogen in Africa might result in employment in the renewable energy sector and new commercial prospects for regional firms[46].

West African, countries such as Nigeria and Senegal have abundant natural gas reserves, which can be used to produce blue hydrogen through steam methane reforming. Furthermore, the region has

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43 (IRENA 2021)
44 (IRENA 2021)
45 (Graaf et al., 2020)
46 (Hydrogen Council 2020)

ample renewable energy resources, such as solar and wind, that can be used to produce green hydrogen. The adoption of hydrogen production can contribute to energy security and economic growth in the region. In East Africa, countries such as Ethiopia and Kenya have vast geothermal resources, which can be used to produce green hydrogen. The adoption of hydrogen production can help these countries meet their energy needs, reduce reliance on fossil fuels, and contribute to the development of a low-carbon economy[47].

North African, countries such as Morocco and Egypt have abundant solar resources, which can be used to produce green hydrogen. Furthermore, the proximity to Europe provides opportunities for the export of green hydrogen to meet the region's increasing demand for clean energy. The adoption of hydrogen production can contribute to the development of a sustainable and competitive energy sector in the region. In South Africa, the adoption of hydrogen production can contribute to the country's transition to a low-carbon economy. The country has abundant wind and solar resources that can be used to produce green hydrogen. Furthermore, the adoption of hydrogen production can create job opportunities and contribute to the development of a skilled workforce[48].

In Central Africa, countries such as Cameroon and the Democratic Republic of Congo have significant hydroelectric potential, which can be used to produce green hydrogen. The adoption of hydrogen production can help these countries meet their energy needs and contribute to the development of a sustainable energy sector[49]. The adoption of hydrogen production presents significant potential benefits for the five African blocs. Each bloc has unique characteristics and opportunities that can be leveraged to develop a hydrogen economy. The successful implementation of hydrogen production requires a supportive policy environment, adequate infrastructure, and investment in renewable energy systems.

Challenges and Opportunities for Green Hydrogen in Africa

Africa's economy might profit significantly from the manufacturing of hydrogen. By 2050, the global hydrogen industry may provide $2.5 trillion in yearly income and add 30 million jobs, according to a forecast by the Hydrogen Council. Production of hydrogen in Africa might result in employment in the renewable energy sector and new commercial prospects for regional firms[50]. Green hydrogen generation has the potential to revolutionise the continent's energy industry and advance its social, economic, and environmental progress.

Hydrogen production has the potential to transform the energy sector in Africa, with opportunities

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47 (Energy Research Centre 2021)
48 (African Development Bank 2021)
49 (Energy Research Centre 2021)
50 (Dincer and Acar 2020)

and challenges varying across the five African blocs. In West Africa, the abundant solar and wind resources can support the development of green hydrogen production, while the region's limited infrastructure remains a challenge. In East Africa, the presence of geothermal resources can enable the production of low-cost hydrogen, but the lack of policy and regulatory frameworks may hinder investment. In North Africa, the mature oil and gas industry can facilitate the integration of hydrogen into the energy mix, while the limited access to finance may impede the scaling up of projects. In Southern Africa, the potential for green hydrogen production is high, but the lack of adequate infrastructure and a skilled workforce may limit the growth of the industry. In Central Africa, the focus on oil and gas may impede the transition to renewable energy and hydrogen production, while the lack of political stability and weak institutions may hinder investment[51].

Despite the challenges, the opportunities for hydrogen production in Africa are significant. The adoption of green hydrogen production can enhance energy security, reduce carbon emissions, and drive economic growth. Moreover, the growing demand for hydrogen in Europe, Asia, and other regions can provide a market for African producers. According to a report by the African Development Bank, the potential for hydrogen production in Africa is estimated at 7,000 TWh per year, which is more than twice the current electricity demand in the continent. To realize the potential of hydrogen production in Africa, governments and stakeholders need to address the challenges and leverage the opportunities. This can be achieved through the development of supportive policy and regulatory frameworks, investment in infrastructure and human capital, and collaboration with international partners[52]. The African Union's Agenda 2063 and the United Nations' Sustainable Development Goals provide a framework for the transition to a low-carbon and sustainable energy system in Africa, with hydrogen production as a key component. Yet, overcoming the obstacles and grabbing the chances calls for a thorough and coordinated strategy including decision-makers, investors, and other stakeholders[53].

Conclusion

Due to its potential to replace fossil fuels and contribute to the reduction of greenhouse gas emissions, hydrogen is becoming more and more acknowledged as a practical energy source across the globe. This has increased interest in hydrogen production in Africa, a continent with a wealth of natural resources and the potential to become a significant hydrogen exporter in the future. In this regard, it's critical to evaluate hydrogen production's usefulness for the African economy while taking into account both its possible advantages and disadvantages. The manufacturing of hydrogen has tremendous economic possibilities for Africa.

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51 (African Development Bank 2021)
52 (Mengesha and Focke 2021)
53 (Zwaan et al., 2021)

Firstly, it may aid in lowering the continent's reliance on fossil fuels and boosting its energy security. Hydrogen production might be facilitated by the abundance of renewable energy sources found in Africa, including sun, wind, and hydropower. As hydrogen may be utilised to supply clean, inexpensive energy to rural places that are not linked to the power grid, this might also aid in reducing fuel poverty in many African nations[54].

Second, the generation of hydrogen can open up new business prospects and employment in Africa. Infrastructure for hydrogen generation, storage, and transportation, as well as fuel cells, might spur considerable economic activity and employment across a range of industries, including engineering, building, and maintenance. Moreover, this may draw in foreign capital and spur the transfer of technologies, which would accelerate innovation and economic progress.

Finally, by lowering greenhouse gas emissions, the generation of hydrogen may support international efforts to slow down global warming. Electrolysis is a method for producing hydrogen from renewable energy sources like the sun and wind without creating any greenhouse emissions. Hydrogen may also be utilised as a clean fuel for industry, electricity production, and transportation, substituting fossil fuels and cutting emissions. Yet, there are other difficulties and dangers connected to the manufacturing of hydrogen in Africa. One of the biggest issues is a lack of infrastructure and investment. However, the majority of African countries lack the resources and infrastructure necessary to build a hydrogen economy, such as production facilities, fuel cells, storage facilities, and transportation networks[55].

This may impede the growth of hydrogen generation and reduce its potential economic advantages for Africa. The high expense of producing and storing hydrogen is another difficulty. Although the price of producing hydrogen has decreased recently, it is often still more expensive than fossil fuels. This may reduce hydrogen's short-term competitiveness and restrict consumer adoption. In addition, the cost of hydrogen storage continues to be a significant issue because it necessitates considerable infrastructural and technological expenditures. The generation of hydrogen is also related to ecological and societal problems, such as possible water shortages, air pollution, and land conflicts[56]. To make sure that the expansion of hydrogen production in Africa is sustainable and advantageous to all stakeholders, these risks need to be properly evaluated and handled.

In conclusion, the generation of hydrogen has the potential to significantly boost the African economy by lowering fuel poverty, bringing about new business possibilities and jobs, and minimising climate change. Nevertheless, there are several obstacles and dangers to building a hydrogen economy in Africa, including a lack of infrastructure and financial support, high costs for production and storage, and

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[54] (Zwaan et al., 2021)
[55] (Nkemdirim 2021)
[56] (Kakoulaki et al., 2021)

negative social and environmental effects. The entire potential advantages of hydrogen production in Africa must be realised through a thorough and coordinated strategy that encompasses the public, business, and civil society sectors as well as takes into account the unique context and requirements of each African nation.

REFERENCES

Abouseada, N., & Hatem, T. M. (2022). Climate action: Prospects of green hydrogen in Africa. *Energy Reports*, *8*, 3873–3890. https://doi.org/10.1016/j.egyr.2022.02.225

Ayodele, Temitope Raphael and Josiah Lange Munda. “The potential role of green hydrogen production in the South Africa energy mix.” *Journal of Renewable and Sustainable Energy* (2019): 11.4.

African Development Bank. (2020). Energy Outlook in Africa 2020-2024. Retrieved from https://www.afdb.org/en/documents/africa-energy-outlook-report-2020-2024.

African Development Bank. (2021). Hydrogen for Africa: A roadmap for a green hydrogen economy.https://www.afdb.org/en/documents/hydrogen-africa-roadmap-green-hydrogen-economy.

African Development Bank. (2021). Africa's energy outlook 2021: Accelerating the energy transition in a COVID-19 world. Retrieved from https://www.afdb.org/sites/default/files/documents/publications/Africa%27s%20Energy%20Outlook%202021%20Accelerating%20the%20energy%20transition%20in%20a%COVID19%20world.pdf

African Development Bank. (2021). Africa’s hydrogen potential: Opportunities and challenges. Retrieved fromhttps://www.afdb.org/en/blogs/afdb-championing-inclusive-growth_/africas-hydrogen potential-opportunities-and-challenges

Bhandari, Ramchandra. “Green hydrogen production potential in West Africa – Case of Niger.” Elsevier (2022): 800-811.

Dincer, I., & Acar, C. (2020). Hydrogen economy and challenges.

Energy Research Centre. (2021). Hydrogen for Africa: Opportunities and challenges. Retrieved from https://www.ercblogs.co.za/hydrogen-for-africa-opportunities-and-challenges/

Graaf, T. Van De, Overland, I., Scholten, D., & Westphal, K. (2020). Energy Research & Social Science The new oil? The geopolitics and international governance of hydrogen. *Energy Research & Social Science*, *70*(April), 101667. https://doi.org/10.1016/j.erss.2020.101667

Hydrogen Council. (2020). Path to Hydrogen Competitiveness: A Cost Perspective. Paris:Hydrogen Council. Retrieved from https://hydrogencouncil.com/wp content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study.pdf.

International Energy Agency. (2020). Energy Access Outlook 2020. Paris: IEA. Retrieved from https://www.iea.org/reports/energy-access-outlook-2020.

International Renewable Energy Agency. (2020). Global Energy Transition: A Roadmap to 2050.

Retrieved from https://www.irena.org/publications/2020/Apr/Global-Energy Transformation-A-Roadmap-to-2050-2020-Edition

International Renewable Energy Agency. (2020). Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5°C climate goal. https://www.irena.org/ /media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_Hydrogen_Cost_Red

International Renewable Energy Agency (IRENA). (2020). Green hydrogen: A guide to policy making. Retrieved from https://www.irena.org/ /media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Green_Hydrogen_2020.pdf

International Renewable Energy Agency. (2019). Renewable Power Generation Costs in 2019. Abu Dhabi: IRENA. Retrieved from https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in 2019.

International Renewable Energy Agency. (2020). Renewable Energy Statistics 2020. Abu Dhabi: IRENA. Retrieved from https://www.irena.org/publications/2020/Jun/Renewable Energy-Statistics-2020.

International Renewable Energy Agency (IRENA). (2021). Renewable energy statistics 2021. Retrieved from https://www.irena.org/publications/2021/Apr/Renewable-energy statistics-2021

IRENA. (2021). Green hydrogen from renewable power: Technology outlook for the energy transition.Retrieved from https://www.irena.org//media/Files/IRENA/Agency/Publication/2021/Jan/IRENAGreen Hydrogen_from_Renewable_Power_2021.pdf

Kakoulaki, G., Kougias, I., Taylor, N., Dolci, F., & Moya, J. (2021). *Green hydrogen in Europe– A regional assessment: Substituting existing production with electrolysis powered by renewables*. *228*(October 2020). https://doi.org/10.1016/j.enconman.2020.113649

Mengesha, A. T., & Focke, W. W. (2021). Green hydrogen potential for Africa: Opportunities, challenges, and the role of the African Union. Renewable Energy, 174, 500-512. doi: 10.1016/j.renene.2021.03.017

Nkemdirim, L. (2021). Effectiveness of Green Hydrogen Production on the African Economy. African Journal of Energy, 1(2), 45-56. https://doi.org/10.1016/j.afje.2021.05.001

Seada, Nour Abou and Tarek M. Hatem. "Power to hydrogen: The prospects of green hydrogen production potential in Africa." *Springer International Publishing* (2022): pp. 153-159.

United Nations Development Program. (2019). Renewable Energies in Africa: From Resource Abundance to Sustainable Development. Retrieved from https://www.africa.undp.org/content/rba/en/home/library/renewable-energy-in-africa.html

Zwaan, B. Van Der, Lamboo, S., & Dalla, F. (2021). Timmermans' dream: An electricity and hydrogen partnership between Europe and North Africa. *Energy Policy*, *159*(October), 112613. https://doi.org/10.1016/j.enpol.2021.112613.

UNLOCKING THE CRITICAL BARRIERS TO GREEN HYDROGEN ADOPTION IN AFRICA THROUGH TRAINING AND EDUCATION

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Abstract

The need for green hydrogen is expanding as a result of the importance of maintaining global warming below 1.5°C per the pre-industrial thresholds in accordance with the Paris Agreement. This study aims to unlock the barriers to Africa's adoption of green hydrogen through training and education which could help identify the continent's potential source of clean energy. A total of 447 industry participants in Ghana completed the survey instrument. The findings revealed common perspectives that training, education and skill development are crucial to the industry, but inadequately offered in the informal sector. By looking into the relationship between green hydrogen and training and education, the study attempts to examine the obstacles facing the government, corporate bodies, investors, and entrepreneurs in the sector. This study intends to advocate for extensive collaborations between governments, formal and informal sectors, in order to secure adequate funding for the provision of adequate skill training and the construction of essential facilities to drive green hydrogen adoption and production. It is recommended that training, education and skill development systems in Africa should be intensified, if the prospect of green hydrogen as a clean energy source is to be realised. Also, key sources of green hydrogen production in Africa should be matched with relevant training and education requirements. The study seeks to contribute to helping key stakeholders in Africa, including businesses, educational institutions, and policymakers to better understand the potential for green hydrogen on the continent, as well as the implications for what needs to be done to accomplish this ambition, considering all the abundant natural resources in the form of sunlight, water bodies, rainfall, and landscapes.

Keywords: *Green Hydrogen, Training, Education, Stakeholders, Africa*

INTRODUCTION

As the years go by, the emergency facing the climate change seems to be alarming. However, the emergence of expertise and technology have brought about various means of addressing this emergency issue of climate change. Green future economy has emerged as one major means of addressing this issue of climate change through the harnesses of human ingenuity to protect the future of the planet (Okada & Gray, 2023). The need for green hydrogen is expanding as a result of the importance of maintaining global warming below 1.5°C per the pre-industrial thresholds in accordance with the Paris Agreement.

This study aims to unlock the barriers to Africa's green hydrogen adoption and identify its potential clean energy source. The study aims to examine all the obstacles facing government, corporate bodies, individual investors, and entrepreneurs in the sector. According to Roche (2023), increasing number of countries are getting committed to reduce the carbon and greenhouse emissions. As such, much more effort is needed to ensure energy generated would be from renewable sources including solar, wind and hydro. There could be number of factors that could have reason why this effort had not come into reality. These include: variability of supply of energy generated from renewable energy source; cost of producing energy compared with energy produced fossil fuel-base. Apart from these challenges stated, there is also the problem of regulatory policies. This could be challenging because of the role of different actors in the hydrogen value chain. Having identified challenges, efforts are being put in place to forestall this technological transformation. Should Africa as continent embraces the opportunity introduced by the green hydrogen, there is that possibility that African countries could reduce their reliant fossil fuel, while meeting the Paris Agreement. Some African countries have announced their intention to intensify collaboration towards the development of green hydrogen projects. Six leading African countries, Egypt, Kenya, Mauritania, Morocco, Namibia and South Africa, have formed the Africa Green Hydrogen Alliance (AGHA) to intensify collaboration and supercharge development of green hydrogen projects on the African continent Africa (Agyekum et al., 2023). This is a good start as the successes and challenges of these countries in their collaborations will serve as learning curve for the remaining countries to follow suit. However, the desire of Africa meeting the growing demand for energy at home and export would soon be achieved to boost their economic development. The Africa Green Hydrogen Alliance (AGHA, 2022) proposed five key steps to unlock African green hydrogen potential as described in the diagram below.

Source: AGHA - Green Hydrogen Potential Report (2022)

Potential solutions that could make the green hydrogen production be a reality include: regulatory framework, financial incentives, market mechanism, public awareness and engagement, international collaborations, sector specific strategies (Ayodele & Munda, 2019; Li et al, 2022; Müller et al., 2023).

LITERATURE REVIEW

Producing green hydrogen by electrolysis with renewable energy sources is seen as a promising answer to the world's climate problems and the need to cut carbon emissions (IRENA, 2021). Green hydrogen generation has great promise in Africa because of the continent's abundant renewable energy sources (Schmidt et al., 2017). However, there are a number of obstacles that must be overcome before this potential can be tapped into, including a dearth of technical expertise, insufficient education and training, and a scarcity of public-private partnerships. With an eye toward the African setting, this literature review seeks to investigate these difficulties and propose solutions.

Technical Expertise and Workforce Challenges

Lack of technical knowledge and trained personnel in the green hydrogen industry is holding back progress in Africa (Van den Broek et al., 2018). A dearth of green hydrogen generation and use experts, inadequate research facilities, and minimal industry involvement in academic institutions all contribute to Africa's existing technological skill deficit. This circumstance hinders our ability to solve environmental and climate change concerns, including the development and implementation of green hydrogen technology. Technical schools and engineering programmes can help address the green hydrogen industry's worker shortage by including industry-specific knowledge into their curricula (Ram et al., 2019). Educational institutions can better prepare students to contribute to the expansion of the green hydrogen industry if they include instruction in green hydrogen technology in their curricula. In addition, multidisciplinary techniques that bring together engineering, environmental sciences, and economics can help students better grasp the intricate web of relationships between green hydrogen's technology, policy, and market dynamics. Successful workforce development projects have been undertaken in other locations to address the skill gaps in the renewable energy sector. One such region is the European Union. Skilling up the labour force to meet the needs of the renewable energy transition is the goal of the European Commission's "Skills Agenda for Europe" (European Commission, 2020). The goals of this plan are to improve vocational education and training, encourage lifelong learning, and increase collaboration between businesses and educational institutions. African nations can accelerate the development and deployment of environmentally friendly hydrogen technology if they adopt policies along these lines. In sum, if Africa is going to realise its potential in the green hydrogen sector, it is imperative that the continent's manpower difficulties and lack of technical skills be resolved. African nations can help the global effort to combat climate change by producing a competent workforce to drive the expansion of the green hydrogen sector through the implementation of applicable curricula and the promotion of workforce development initiatives.

Education and Training in Green Hydrogen

Adopting renewable energy technologies, such as green hydrogen, necessitates extensive education and training. The attainment of climate targets and a sustainable energy future depends on the development, deployment, and maintenance of green hydrogen technologies, which in turn depends on a competent workforce. The shift to a low-carbon economy can be made more easily thanks to the role that education and training play in fostering innovation and easing the incorporation of green hydrogen technologies into current energy infrastructure. However, there are many obstacles in Africa that make it difficult to implement green hydrogen-related education, such as a lack of resources, a lack of funding, and a lack of industry engagement with educational institutions. As a result, the industry's ability to foster professional growth and propel technological advancement is hampered. Attracting students and teachers to the field is made more difficult by the general public's lack of knowledge about green hydrogen as a practical energy source. The following proposals and solutions are offered to address these issues and improve green hydrogen training and education:

1. Implementing green hydrogen technologies into academic curricula at technical institutions and engineering schools (Ram et al., 2019). This involves multidisciplinary research that investigates the green hydrogen industry from multiple angles by combining engineering, environmental science, and policy studies.
2. For educational and training programmes to be both effective and relevant, collaboration between businesses, universities, and government must be established. Knowledge sharing, the sharing of technologies, and the sharing of training, internship, and research opportunities are all aided by these types of partnerships.
3. Obtaining money and other resources to improve schools' facilities and resources. Scholarships and grants are only two examples of the kinds of investments that may be made to inspire the next generation to enter the field of green hydrogen technology (Bazilian et al., 2012).

To sum up, training and education play a crucial role in fostering the spread of environmentally friendly hydrogen technology across Africa. African countries may help pave the way toward a low-carbon energy future by addressing the problems and implementing the offered solutions, which will allow for the development and implementation of green hydrogen technology.

Public-Private Partnerships (PPPs) and Collaboration

In order to accelerate the research, development, and implementation of green hydrogen technologies, public-private partnerships (PPPs) play a critical role in promoting their widespread acceptance (Banerjee, 2016). Public-private partnerships (PPPs) provide efficient and sustainable project implementation by facilitating the sharing of risks and obligations. In addition, public-private partnerships (PPPs) can spur innovation, mobilise investments, and improve access to green hydrogen technologies, all of which aid in the realisation of climate goals and sustainable development goals. The renewable energy industry is home to a number of successful public-private partnerships (PPPs). The Lake Turkana Wind Power project in Kenya, for instance, expanded the country's renewable energy capacity and drew large investments in the industry thanks to collaboration between the government, private investors, and international development partners (Banerjee, 2016). This undertaking exemplifies the value of PPPs in removing the economic, technological, and governmental obstacles to widespread use of renewable energy. The following suggestions are made to improve cooperation between public agencies, academic institutions, and businesses:

1. Creating transparent policy frameworks and enabling rules that encourage the development of green hydrogen technologies and PPP creation (IRENA, 2021). This includes financial incentives like tax credits and grants that attract private capital to the clean hydrogen industry.
2. Green hydrogen adoption can be sped up by increased inter-sectoral communication and the sharing of information and best practises (Nurdiawati & Urban, 2022). To achieve this goal, multiple fields may work together to provide seminars, conferences, and research projects.
3. Creating educational and vocational training programmes that facilitate the sharing of knowledge and experience between the public and commercial sectors (Bhagwat & Olczak, 2020). With the help of these initiatives, Africa may be better able to utilise green hydrogen technologies.

In sum, fostering green hydrogen adoption in Africa requires close cooperation between governmental and commercial sectors. To hasten the development and deployment of green hydrogen technologies and contribute to a sustainable and low-carbon energy future, African countries can benefit from implementing the proposed recommendations by leveraging the strengths of the public and private sectors as well as educational institutions.

Matching Green Hydrogen Production with Education and Training Requirements

Promoting the use of green hydrogen in Africa requires coordinating its production with the continent's workforce's educational and training needs (Beasy et al., 2023). Key green hydrogen production sources must be identified, together with the existing and future educational and training needs, and strategies for workforce development must be developed and implemented to meet the unique demands of the green hydrogen industry. Understanding the knowledge and experience needed to tap into Africa's green hydrogen resources begins with pinpointing the continent's most important generators of the fuel. Africa has an abundance of sunlight, water bodies, and landscapes that can be used to produce green hydrogen (Ram et al., 2019). Electrolysers for the generation of green hydrogen, for instance, can be powered by renewable sources like solar and wind energy, and water resources can be used as feedstock for the electrolysis process (Beasy et al., 2023). To better prepare students for the technical and environmental problems of green hydrogen generation in Africa, educational institutions and training programmes can look to these major sources to inform their curricula and training modules. To establish a workforce equipped to meet the evolving needs of the green hydrogen sector, it's vital to assess present and future educational and training demands. With the anticipated growth of this industry, evaluating existing educational programs, identifying knowledge shortfalls, and anticipating labor force requirements is crucial (Ram et al., 2019). Continually analyzing students' and professionals' knowledge and adjusting curricula accordingly will enable educational institutions to better prepare individuals for contributing to the advancement and deployment of green hydrogen technologies. Forging collaborations among industry, academia, and government, fostering cross-disciplinary methodologies in education and training, and offering incentives for students and professionals to seek opportunities in the green hydrogen sector, are all key tactics for harmonizing workforce development with green hydrogen production (Beasy et al., 2023). Such actions can nurture a workforce capable of driving Africa's green hydrogen industry forward, ultimately contributing to a more sustainable, low-carbon energy landscape across the continent.

METHODOLOGY

The investigation seeks to address the knowledge gap regarding the barriers to Africa's adoption of green hydrogen through training and education, by working with various industries across a number of diverse sectors, including automobile, electricity, mining, agriculture, infrastructure and health to achieve the research goal. From these sectors, a sample size of 500 was generated through random sampling. Out of this total number, 447 responses (representing 89.4%) were complete, acceptable and usable. The methodology included an online survey, followed by industry talks with group respondents to collect additional data for the study. Contacts were made through consultations, meetings and discussions with energy officials, industry experts, transport operators, fitters, gas welders, medical practitioners, mineworkers, agriculturalists, real estate affiliates, processing and manufacturing companies. Each meeting between the research team members and the stakeholders spanned between 30 and 60 minutes. During the meeting, a member of the research team transcribed field notes, which were then analyzed for novel themes and additional information to supplement the survey findings. The key industry participants were primarily selected and engaged for data collection, since they have a stake in the emerging hydrogen energy economy. The quantitative items relied on a five-point Likert scale (1 - Strongly disagree; 2 – Disagree; 3 – Neutral; 4 – Agree; 5 - Strongly Agree). In addition, some open-ended questions were included in the survey to allow respondents to express their opinions on the adoption of green hydrogen through training and education. To avoid burdening respondents with an excessive number of questions, the survey was concise and required less than 10 minutes to complete. At the conclusion of the survey, respondents indicated whether they would be willing to partake in future research studies. From the 447 usable responses, 409 (representing 91.50%) consented or agreed to participate in subsequent investigations, and were noted to be contacted for future projects. Descriptive statistics and multivariate regression were applied for the quantitative data to evaluate survey participant responses to the statements.

RESULTS AND ANALYSIS

Table 1: Research Variables

Labels	**Variables**
Dependent variable:	
GRHYD	Green Hydrogen Adoption
Independent variables:	
ENGMT	Engagement with Stakeholders
WORKF	Workforce Safety Training
DIPOL	Diffusion of Policy Framework

KNOSH	Knowledge Sharing and Capacity Building
SOCIO	Training on Socio-economic Impact

The study variables implemented in this research are categorized into dependent and independent variables as illustrated in (Table 1). Green hydrogen adoption is measured in a 5-point Likert-scale in which responses were rated by participants from both formal and informal sectors in Ghana. Stakeholders, companies, individuals in diverse sectors including automobile, electricity, mining, agriculture, infrastructure and health took part in the survey. For the purposes of policy decisions and implementation regarding alternative power generation using green hydrogen in Africa, the study resorted to examine which factors among the independent variables can be strong determinants of Green hydrogen adoption in the context of Ghana. It is believed that, the outcome of the inferential statistical results could be used and applied in other African countries. The outcome of the survey responses allowed the researchers to measure the causal relationships between the selected variables using a multiple regression technique. Multiple regression was deemed suitable for this study due to its wide popularity, accuracy and robustness of estimating results with minimum errors in the model. The study relied on past empirical findings that have utilized variables like; stakeholder engagement, workforce training and diffusion of policy frameworks (Nurdiawati & Urban, 2022; Kar et al., 2023; Lindner, 2023). Knowledge sharing and capacity building are seen as critical bottlenecks affecting public policy initiatives in developing countries (Lartey et al., 2021). Previous studies emphasized using knowledge sharing tools to produce worthwhile innovations. In the context of green hydrogen, the study finds it critical to generate or resolve the argument about the role of knowledge sharing and capacity building towards innovation policies such as green hydrogen adoption. The variable explains conditions such as the inadequate training, technology, infrastructure, lack of funding, lack adequate expertise and education and job mismatch in the case of new graduates lacking the knowledge in the sector. Training on Socio-economic impact is a characteristic associated with developing countries in Africa. It is a condition where post-secondary educational institutions, colleges and universities fail to design relevant curriculum to train graduates to fill existing gaps on the job market.

Table 2: Correlation Estimates

VARIABLE	(1)	(2)	(3)	(4)	(5)	(6)
(1) GRHYD	1					
(2) ENGMT	0.841**	1				
(3) WORKF	0.515*	0.304	1			
(4) DIPOL	0.252	0.351	0.167	1		
(5) KNOSH	0.916**	0.723**	0.118	0.380	1	
(6) SOCIO	0.675**	0.318	0.244	0.709**	0.451	1

** Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

The correlation between green hydrogen and the five critical factors is reported in Table 2. According to (Zhou et al., 2022), the strength of relationship can be anywhere between -1 and +1. A variable scoring a coefficient closer to 1 has a stronger association with the target variable. If the coefficient is a positive number, it indicates the variables are directly related (i.e., as the value of one variable goes up, the value of the other also tends to do so). The first observation is the positively strong relationship between the dependent variable, Green Hydrogen Adoption (GRHYD) and the independent variable, Engagement with Stakeholders (ENGMT) which is 0.841. Similarly, there is a strong positive degree of association between Green Hydrogen Adoption (GRHYD) and Knowledge Sharing and Capacity Building (KNOSH); $r = 0.916$, $P < 0.001$. With the correlation coefficients of 0.252, Diffusion of Policy Framework (DIPOL) has a positive but weak relationship with Green Hydrogen Adoption (GRHYD). Farrell (2023) advocates that policy design is needed to dispel uncertainty surrounding the cost-effective deployment of green hydrogen technologies. What is more obvious is that without collective stakeholder engagement, the implementation and adoption of green hydrogen may face serious challenge. It is evident to this point that lack of broader policy consultation is having a little influence on green hydrogen adoption. Nevertheless, Training on Socio-economic Impact (SOCIO) and Workforce Safety Training (WORKF) are reasonably correlated with Green Hydrogen Adoption (GRHYD) at 0.675 and 0.515 respectively. The findings illustrate that SOCIO and WORKF are more likely to influence the adoption of green hydrogen if policy makers can prioritize these two factors. This initial observation suggests that stakeholders should endeavor to prioritize relevant workforce training and training on socio-economic impact as part of the applicable solutions to hydrogen adoption. Table 2 also reveals that the majority of cross-correlation values for the independent variables are relatively small. This provides justification for less concern regarding the issue of multicollinearity among the independent variables (Afriyie et al., 2020).

Regression Results

In Table 3, the study examines the explanatory power of the regression model while assessing the variance of individual variables on green hydrogen adoption. Having fixed the confidence interval at 95%, the model predicted the dependent variable at R-squared value of 0.907, with a highly significant p-value of 0.001. The R-squared value of 0.907 indicates that the variance of the independent variable explains 90.7% of the variance of the studied dependent variable. The greater the percentage of accurate predictions (R-squared), the better the fitting of the research model. It gives a collective indication that the independent variables are strong determinants of green hydrogen adoption in Ghana. The coefficient of regression depicts the amount of change in the dependent variable as per unit change in the independent variable. For instance, if Engagement with stakeholders (ENGMT) is to be improved, then there is a probability that Green Hydrogen Adoption (GRHYD) will be heightened, and vice versa. As seen in Table 3, the coefficient of ENGMT is found to be positive (0.732) for GRHYD. This demonstrates that every unit increase in ENGMT, there is an expectant of unit increase of 0.732 in GRHYD, holding all other variables constant. Also, the result produced a highly significant value of 0.000, indicating that ENGMT has a higher tendency of activating the adoption of green hydrogen. Congruently, the investigation revealed that Workforce Safety Training (WORKF) had a coefficient of 0.621 and a high significance value of 0.002, suggesting that WORKF has a high propensity towards the adoption of green hydrogen by the populace. The result further suggests that Knowledge Sharing and Capacity Building (KNOSH) with coefficient of 0.503 is likely to influence green hydrogen based on its 0.003 p-value. The model efficiency and accuracy are emphasized by the magnitude of t-statistics corresponding to each beta coefficient and p-value for all variables. There is a strong justification to reject the null hypotheses when there is statistical evidence the model produces a positive variance to the dependent variable. The larger the t-statistic values, the stronger the evidence against the null hypotheses (Winship & Zhuo, 2020). Comparatively, Training on Socio-economic Impact (SOCIO) has a higher coefficient $\beta = 0.816$. This condition implies that respondents are overwhelmingly endorsing training programs that educate the society about the economic benefits of green hydrogen. It also supports the concerns raised in previous study by Nitte & Salahudeen (2023), where it emphasizes the important collaborations between technical institutions and stakeholders to ensure adequate training and infrastructure to attract new graduates to relevant sectors.

Table 3: Green Hydrogen Adoption through Training and Education

Independent Variables	Dependent Variable	
	Green Hydrogen Adoption (GRHYD)	
	B	**t-Statistic**
Engagement with stakeholders (ENGMT)	0.732	8.305 (0.000)
Workforce Safety Training (WORKF)	0.621	7.104 (0.002)
Diffusion of Policy Framework (DIPOL)	0.347	4.452 (0.005)
Knowledge Sharing and Capacity Building (KNOSH)	0.503	0.631 (0.003)
Training on Socio-economic Impact (SOCIO)	0.816	7.027 (0.000)
R-squared	0.907	
p-value	0.001	

Robustness Check

Further robustness check (as found in Table 4) is conducted to improve the reliability of the results by adjusting for standardized errors. Any change in the variance would constitute positive improvement by the model accuracy at 95% confidence internal. Total variance is improved by R-squared of 95.1% with a minimum error of approximately 5% in the model. The error represents the unexplained conditions outside the scope of this study and limitations in the model design. The values of the standard errors are relatively lower and that is a good representation of the population mean. Other important parameters that should be reported are the enhanced regression coefficients. Undoubtedly, there is consistency in the findings. For example, the t-statistics for Engagement with stakeholders (ENGMT) increased to 9.15 corresponding to 0.000 p-value and β=7.753. Workforce Safety Training (WORKF) and Training on Socio-economic Impact (SOCIO) have respectively increased in t-values and coefficients, with high statistically significant values. Taking into account the contributions of each independent variable to total variance, it is justified to conclude that the model is reliable, accurate and consistent if relied on to develop green hydrogen projects. However, emphasis must be on boarder stakeholder engagement, meeting all the training needs, collaborating with knowledge institutions and finally educating the public about the significance of alternative sources of energy and the financial implications.

Table 4: Robustness Test of Training and Education on Green Hydrogen Adoption

GRHYD	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
ENGMT	7.753	2.201	9.15	0.000	8.852	19.389
WORKF	8.071	3.413	9.03	0.001	6.044	15.162
DIPOL	5.640	2.087	5.11	0.003	5.959	8.210
KNOSH	4.897	0.445	5.97	0.002	4.840	6.778
SOCIO	7.512	2.843	8.26	0.000	9.127	10.025
R-squared		0.951				
p-value		0.000				

Discussion of Emerging Issues

Developing countries in Africa including Ghana are capable of meeting the current green energy demands if efforts are channelled into improving financial allocations towards realising the UN CO_2 reduction goal. The present natural resources can produce abundant raw materials to support renewable energy such as green hydrogen production (Bhandari, 2022), if the planning involves a larger opinion made up of government, educational institutions, civil society, the parliament, and various investment partners. From the findings of Eljack & Kazi (2021), it became obvious that major capable projects fail due to lack of adequate funding, lack of local technical expertise to advice government on viability of the project. The condition lead to hiring foreign architects who end up charging colossal amounts for their services, which could trigger local community protests (Pietrzak, 2021). In order to address these challenges, relevant training for new graduates is recommended, including apprenticeship training to meet the labor requirements. Proper policy dialogue between stakeholders is often lacking in addition to miscommunication of the relevance of the project to the society. This condition creates dissatisfaction among members of the society and eventually leads to low participation and rejection. However, the challenges facing these initiatives are peculiar to each country due to the unequal development of technology infrastructure. Some African governments have started tracking more environmental policies as green hydrogen which will help achieve the national energy and decarburization goals (AbouSeada & Hatem, 2022). As highlighted by Afrane et al. (2022), recent continental reports pointed to the lack of relevant green energy policies by various governments. In some cases, private sector developers taking initiatives bemoan the lack of an existing hydrogen value chain represents one of the major obstacles in Africa (Ballo, 2022). This calls the need for consultation among public and private sector stakeholders. In some cases, the international community may be involved to provide expert advice. For example, the Norwegian-Egyptian collaboration funded the green hydrogen plant having a capacity to produce 100MW of power along the Red Sea (Bizclik, 2022). Such a large project was realised through government support with relevant legislation, public education and acceptance, and the country's commitment to innovation. In the case of Ghana, the benefits of green hydrogen are not widely communicated to the larger society. Civil education is required nationwide to encourage funders to support emerging initiatives and ongoing projects. Collaboration between Universities, Ghana Tertiary Education Commission and Ministry of Education for training and designing relevant teaching materials to produce the talent needed for the energy sector. One of the challenges facing the energy sector in Ghana is revenue mobilisation. Storage time, safety, and security concerns have to be determined, in addition to distribution infrastructure and the mode of transport. Consistent long-term energy strategic plans for hydrogen projects are to be prioritized, if regional security issues, population crises, economic challenges, and related pockets of unrest are holistically dealt with.

CONCLUSION

The obstacles associated with sustainable hydrogen production include inadequate financing, a lack of advanced technology, a lack of road infrastructure, and inadequately serviced industrial lands to accommodate mega projects. A few previous studies identified a lack of storage facilities and security concerns. These conditions make hydrogen adoption challenging. Moving forward, governments in the sub-region and similar developing countries where the potential of green hydrogen production is promising must take frantic steps to eliminate the major barriers to these projects in the future. This paper emphasizes on peculiar challenges that may affect the implementation and adoption of hydrogen power production in Ghana. With the current empirical evidence, policy makers are advised to develop consultative approach to adopting clean energy, climate actions and similar Sustainable Development Goals (SDGs) in Africa. As re-counted by Ackah (2016), Goal 7 of the SDGs seeks to ensure universal access to affordable, reliable and modern energy services and increase substantially the share of renewable energy in the global energy mix by 2030. This target provides an opportunity as well as a challenge to African countries including Ghana. Furthermore, the economic importance of the hydrogen project such as employment generation, industrialization, environmental protection and climate protection must be communicated appropriately. However, concerns or grievances of the society must be swiftly addressed, else they could escalate to unpleasant levels or breed resentment. In order to improve the domestic production of energy from renewable energy, the Government of Ghana has set clearly the definition of key targets for its energy sector. One of the targets is achieving 10% contribution of renewable energy (large hydro) in the electricity generation mix by 2025. The government is, therefore, increasing investment support to attain renewable energy targets (Kipkoech, et al., 2022). The UN estimating that by 2030 renewable energy will account for 1403 megawatts of Ghana’s clean energy supply, leading to fundamental issues like direct job creation, job creation, appreciable exchange rate, education and foreign direct investment (Ankrah & Lin, 2020). Clean energy investment is also estimated to reduce CO_2 emission by 12 million tonnes by 2050. Ghana’s energy supply is overly reliant on fossil fuel production such as kerosene, petrol, diesel, and liquefied petroleum gas, which may no longer meet current demands (Mensah, et al., 2016). While efforts are ongoing to meet the continents energy supply, the environment has to be taken into consideration and emphasize on green hydrogen which can achieve zero emission. Moving forward, Africa's sustainable hydrogen programmes must begin with policy frameworks, followed by the construction of energy infrastructure, education, and relevant training. The allocation of industrial lands and the assessment of the country's cultural and innovation readiness must also be taken into account. Subsequently, a strategic green hydrogen plan is required with full constitutional support to ensure transparency and accountability of the process. Inter-governmental committee can be created to engage the services of industry researchers on the feasibility of every capital project in the energy sector before acting on recommendations.

REFERENCES

AbouSeada, N., & Hatem, T. M. (2022). Climate action: Prospects of green hydrogen in Africa. *Energy Reports*, *8*, 3873-3890.

Ackah, I. (2016). Policy interventions in renewable energy for sustainable development: is Ghana on the right path to achieve SDG 7?. *Available at SSRN 2799150*.

Afrane, S., Ampah, J. D., & Aboagye, E. M. (2022). Investigating evolutionary trends and characteristics of renewable energy research in Africa: a bibliometric analysis from 1999 to 2021. *Environmental Science and Pollution Research*, *29*(39), 59328-59362.

Afriyie, S. O., Kong, Y., Lartey, P. Y., Kaodui, L., Bediako, I. A., Wu, W., & Kyeremateng, P. H. (2020). Financial performance of hospitals: A critical obligation of corporate governance dimensions. *The International Journal of Health Planning and Management*, *35*(6), 1468-1485.

AGHA (2022). The Africa Green Hydrogen Alliance; Realising Africa's green hydrogen potential through government leadership. Retrieved from https://gh2.org/africa-green-hydrogen-alliance-agha. Date accessed 23/12/2022.

Agyekum, E. B., Ampah, J. D., Uhunamure, S. E., Shale, K., Onyenegecha, I. P., & Velkin, V. I. (2023). Can Africa Serve Europe with Hydrogen Energy from Its Renewables? - Assessing the Economics of Shipping Hydrogen and Hydrogen Carriers to Europe from Different Parts of the Continent. *Sustainability*, *15*(8), 6509.

Ankrah, I., & Lin, B. (2020). Renewable energy development in Ghana: Beyond potentials and commitment. *Energy*, *198*, 117356.

Ayodele, T. R., & Munda, J. L. (2019). Potential and economic viability of green hydrogen production by water electrolysis using wind energy resources in South Africa. *International Journal of Hydrogen Energy*, *44*(33), 17669-17687.

Ballo, A., Valentin, K. K., Korgo, B., Ogunjobi, K. O., Agbo, S. N., Kone, D., & Savadogo, M. (2022). Law and Policy Review on Green Hydrogen Potential in ECOWAS Countries. *Energies*, *15*(7), 2304.

Banerjee, B. (2016). Model of transformation to green hydrogen economy in emerging countries. *Global Journal of Business and Integral Security*. https://gbis.ch/index.php/gbis/article/view/139.

Bazilian, M., Nussbaumer, P., Cabraal, A., Centurelli, R., Detchon, R., Gielen, D., Rogner, H. H., Howells, M., McMahon, H., Modi, V., & Nakicenovic, N. (2012). Informing the financing of universal energy access: An assessment of current flows. Energy Policy, 47, 656-666.

Beasy, K., Emery, S., Pryor, K., & Vo, T. A. (2023). Skilling the green hydrogen economy: A case study from Australia. *International Journal of Hydrogen Energy*. https://doi.org/10.1016/j.ijhydene.2023.02.061.

Bhagwat, S., & Olczak, M. (2020). *Green hydrogen: Bridging the energy transition in Africa and Europe* [Technical Report]. European University Institute. https://doi.org/10.2870/126402.

Bhandari, R. (2022). Green hydrogen production potential in West Africa-Case of Niger. *Renewable Energy*, *196*, 800-811.

Bizclik, A. (2022). https://energydigital.com/articles/cop27-egypt-and-norway-to-build-100mw-green-hydrogen-plant. (accessed Feb. 20, 2023).

Eljack, F., & Kazi, M. K. (2021). Prospects and challenges of green hydrogen economy via multi-sector global symbiosis in Qatar. *Frontiers in Sustainability*, *1*, 612762.

European Commission (2020). A European Skills Agenda: Strengthening the link between education, training, and the world of work. Retrieved from https://ec.europa.eu/migrant-integration/sites/default/files/2020-07/SkillsAgenda.pdf. Date accessed 28/4/2023.

Farrell, N. (2023). Policy design for green hydrogen. *Renewable and Sustainable Energy Reviews*, *178*, 113216.

Ghosh, A., Harihar, N., & Jain, P. (2022). *Co-development of technologies of the future*. Council on Energy, Environment and Water. https://euagenda.eu/upload/publications/2204x-8-ceew-s50-co-development-of-technologies-of-the-future-final.pdf.

IRENA (2021). Green hydrogen: A guide to policymaking. International Renewable Energy Agency. Retrieved from https://www.irena.org/publications/2021/May/Green-Hydrogen-Supply-A-Guide-To-Policy-Making. Date accessed 28/4/2023.

Kar, S. K., Sinha, A. S. K., Bansal, R., Shabani, B., & Harichandan, S. (2023). Overview of hydrogen economy in Australia. *Wiley Interdisciplinary Reviews: Energy and Environment*, *12*(1), e457.

Kipkoech, R., Takase, M., & Amankwa Afrifa, E. K. (2022). Renewable energies in Ghana in relation to market condition, the environment, and food security. *Journal of Renewable Energy*, *2022*, 1-8.

Lartey, P. Y., Kong, Y., Afriyie, S. O., Santosh, R. J., & Bah, F. B. M. (2021). Knowledge management issues in India: A public sector perspective. *International Journal of Public Administration*, *44*(3), 215-230.

Li, Y., Shi, X., & Phoumin, H. (2022). A strategic roadmap for large-scale green hydrogen demonstration and commercialisation in China: A review and survey analysis. *International Journal of Hydrogen Energy*, *47*(58), 24592-24609.

Lindner, R. (2023). Green hydrogen partnerships with the Global South. Advancing an energy justice perspective on “tomorrow's oil”. *Sustainable Development*, *31*(2), 1038-1053.

Mensah, J. T., Marbuah, G., & Amoah, A. (2016). Energy demand in Ghana: A disaggregated analysis. *Renewable and Sustainable Energy Reviews*, *53*, 924-935.

Müller, L. A., Leonard, A., Trotter, P. A., & Hirmer, S. (2023). Green hydrogen production and use in low-and middle-income countries: A least-cost geospatial modelling approach applied to Kenya. *Applied Energy*, *343*, 121219.

Nitte, I. S., & Salahudeen, T. M. (2023). Energy transitions in Nigeria: the role of policies for the adoption of low-carbon technologies and system integration. *EPRA International Journal of Research and Development (IJRD)*, *8*(3), 128-139.

Nurdiawati, A., & Urban, F. (2022). Decarbonising the refinery sector: A socio-technical analysis of advanced biofuels, green hydrogen and carbon capture and storage developments in Sweden. *Energy Research & Social Science*, *84*, 102358. https://doi.org/10.1016/j.erss.2021.102358

Okada, A., & Gray, P. (2023). A Climate Change and Sustainability Education Movement: Networks, Open Schooling, and the ‘CARE-KNOW-DO’Framework. *Sustainability*, 15(3), 2356.

Pietrzak, M. B., Igliński, B., Kujawski, W., & Iwański, P. (2021). Energy transition in Poland-Assessment of the renewable energy sector. *Energies*, *14*(8), 2046.

Ram, M., Bogdanov, D., Aghahosseini, A., Oyewo, A. S., Gulagi, A., Child, M., & Breyer, C. (2019). Global energy system based on 100% renewable energy – Power, heat, transport and desalination sectors*. Energy Conversion and Management*, 198, 111953.

Roche, M. Y. (2023). Built for net-zero: Analysis of long-term greenhouse gas emission pathways for the Nigerian cement sector. *Journal of Cleaner Production*, *383*, 135446.

Schmidt, O., Gambhir, A., Staffell, I., Hawkes, A., Nelson, J., & Few, S. (2017). Future cost and performance of water electrolysis: An expert elicitation study. *International Journal of Hydrogen Energy*, *42*(52), 30470–30492. https://doi.org/10.1016/j.ijhydene.2017.10.045.

Van den Broek, M., Berghout, N., & Rubin, E. S. (2018). The potential of renewables versus natural gas with carbon capture and storage for power generation under CO2 constraints. *Renewable and Sustainable Energy Reviews*, 82, 2690-2704.

Winship, C., & Zhuo, X. (2020). Interpreting t-statistics under publication bias: rough rules of thumb. *Journal of Quantitative Criminology*, *36*, 329-346.

Zhou, H., Wang, X., & Zhu, R. (2022). Feature selection based on mutual information with correlation coefficient. *Applied Intelligence*, 1-18.

Green Hydrogen Production in Africa: A systematic review of the Potentials and Pitfalls

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Abstract

In addition to country-specific initiatives, the African Renewable Energy Initiative (AREI) by the African Union and the Africa Green Hydrogen Alliance (AGHA) depict the growing interest and commitment to green hydrogen production in Africa. While these are intended to aid Africa's transition to a sustainable and low-carbon economy, there is the need to highlight the potentials and the pitfalls specific to the continent and its subregions to ensure the successful production, development, and adoption of green hydrogen in Africa. The paper uses a systematic review to highlight regional significance and challenges. It concludes with policy-driven recommendations such as development of a sophisticated strategic framework, human capital development, prioritizing investment in research and development, and sustainable sourcing, to help mitigate the challenges associated with green hydrogen production in Africa.

Keywords: *Systematic Review, Green hydrogen Production, Africa*

1.0 Introduction

Climate change in recent years has threatened the habitability of the earth by humans and raised concerns about the need to address the issue with urgency. Energy-related carbon dioxide (CO2) emissions, responsible for approximately 76% of global greenhouse gas emissions, have been identified as the main contributor to climate change (Ravikumar Bhagwat & Olczak, 2021). In order to keep global warming below 2 degrees Celsius and achieve net zero emissions by 2070, the Paris Agreement prescribes a 25% reduction in worldwide CO2 emissions in 2030 (UNFCCC, 2018). The Paris Climate Agreement accelerated global efforts towards achieving the Sustainable Development Goal (SDG) 7 which aims to ensure access to affordable, reliable, sustainable, and modern energy for all.

Currently, nuclear power plants or fossil fuels like coal or gas are the main sources of electricity. The production of hydrogen from these sources are very common now, which is quite a carbon-intensive process. Nonetheless, Green hydrogen which is produced by renewable energy has the capacity to supplement or even substitute electricity and other energy carriers, aiding in the extensive decarbonization of the energy sector and facilitating the utilization of energy in end-use sectors (Ravikumar Bhagwat & Olczak, 2021). However, in some countries, the capacity for producing renewable energy is limited, and industrial processes, such as the manufacture of iron and steel, obstruct or make the use of conventional renewable energy more challenging (IRENA, 2022).

Recent years have seen a growing interest in the production of green hydrogen in Africa. It has been mainly due to the fact that many African countries have been considered as having a great prospect for producing renewable energy. There have been international partnerships between industrialized countries and countries rich in renewable energy(Lindner, 2023). Several green hydrogen initiatives are underway in Africa demonstrating this rising interest. Country-specific initiatives include Morocco's Green Hydrogen Strategy, Hyphen Project in Namibia, Hydrogen South Africa (HySA), the National Strategy in South Africa, Nigeria's Green Hydrogen Pilot, and Egypt's Green Hydrogen Production (Beaucamp & Nforngwa, 2022; Hyphen, 2022; Panchenko et al., 2023; Zgheib, 2022). The initiatives reflect the ambition of capitalizing on Africa's renewable energy resources and contributing to the global green hydrogen agenda. The Hyphen project in Namibia for example was launched as the initial step in the implementation of the government's policy for the emergence of a large-scale green hydrogen sector in various Namibian regions to help both Namibia's economic development and the global community's efforts to achieving its decarbonization goals (Hyphen, 2022). Similarly, Morocco's Green Hydrogen Strategy is intended to make Morocco a major exporter of green hydrogen by leveraging its vast renewable resources to produce green hydrogen for use domestically and for export. The strategy is categorised in three phases: phase 1, intended to roll out between 2020 and 2030; Phase 2, 2030 and 2040 and phase 3 2040 to 2050. The strategy involves research and the use of hydrogen at the local level, making hydrogen a storage medium and exporting derivatives, and improving capacities to produce ammonia, hydrogen, and derivatives to be use as the local energy source (Beaucamp & Nforngwa, 2022).

In Ghana, although specific projects are still in the planning or early stages, the country has actively demonstrated interest in green hydrogen production. The Ministry of Energy's Renewable Energy Master Plan (REMP), 2019 highlights the government's interest in green hydrogen production. The Renewable Energy Master Plan was designed to provide an investment-focused framework for the promotion and development of the country's rich renewable energy resources to promote sustainable economic growth, contribute to improved social life, and reduce the harmful effects of climate change (MoE, 2019).

In addition to country-specific initiatives, the African Renewable Energy Initiative (AREI) by the African Union was to achieve at least 10 GW of new and additional renewable energy generation capacity by 2020, and to mobilize the African potential to generate at least 300 GW by 2030 (AREI, 2018). Similarly, the Africa Green Hydrogen Alliance (AGHA) was established to accelerate the production of green hydrogen in Africa.

While all these initiatives are intended to aid Africa and its subregions in transitioning to a sustainable and low-carbon economy, there is a need to highlight the potentials and pitfalls specific to the continent to ensure the successful production, development, and adoption of green hydrogen in Africa.

2.0 Methods

The paper adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Liberati et al., 2009) in carrying out the systematic review. This was to help obtain a structured and comprehensive review. The paper followed Liberati et al. (2009) and Shamseer et al. (2015) to develop a protocol to plan proceedings and specify eligibility criteria for the data. This was to answer the following research questions:

- Question 1: What are the main potentials of green hydrogen production in Africa?
- Question 2: What are the pitfalls of green hydrogen production in Africa identified?

The search was preceded by the development of a protocol to describe the analysis procedure and inclusion criteria. The search engines used are Scopus (http://www.scopus.com) and Web of Science (http://www.webofscience.com).

The keywords applied in the search engines were (((“Green hydrogen”) AND (“Production” OR “Generation” OR “Development” OR “creation” OR Manufacturing)) AND (“Africa” OR Sub-Saharan Africa”))

The search was conducted with no imposition of date restriction but restricted the language of documents to English. The type of documents included articles, conference papers, and reviews. The records on documents identified were exported to a Microsoft Excel spreadsheet and included Authors’ names, titles, abstracts, keywords, journal/conference names, year of publication, and affiliation of authors.

The first step eliminated duplicates after which titles and abstracts were assessed to determine documents to be included in full-text assessment based on the eligibility criteria. All the researchers worked independently on the review for inclusion and exclusion of the documents and then compared the results. There was always a consensus to include a document when divergence occurred. Finally, all papers included were carefully reviewed for the purpose of this study.

3.0 Results

A total of 70 papers were extracted from the electronic databases, Scopus and Web of Science. 24 duplicated records were excluded in the screening of titles and abstracts. Screening of titles and abstracts resulted in the exclusion of 13 more papers that did not meet the eligibility criteria. A more detailed full-text review was conducted on the remaining 33 papers which were all included in the systematic review. Figure 2 presents the selection process. Names of sources of documents; journals, conferences, and books are presented in . International Journal of Hydrogen Energy published the most articles reviewed followed by Sustainability. These are international peer-reviewed journals that are focused on areas of technology developments in hydrogen energy, and on sustainability and sustainable development respectively. The review included 33 documents from 18 journals, 2 conferences, and 2 books. These were made up of 29 journal articles, 2 conference papers, and 2 book chapters.

Although the search did not impose any date restriction, the documents retrieved and reviewed spanned from 2019 to 2013. Figure 3 presents the number of documents reviewed over time. The figure shows that there has been significant growth in the number of studies, with the highest number in 2022. This indicates that there is a rising interest in the production of green hydrogen in literature.

Based on the scope and objectives of this paper, the documents reviewed were carefully analysed with key consideration on possibilities and opportunities of producing green hydrogen in Africa, as well as the drawbacks or challenges.

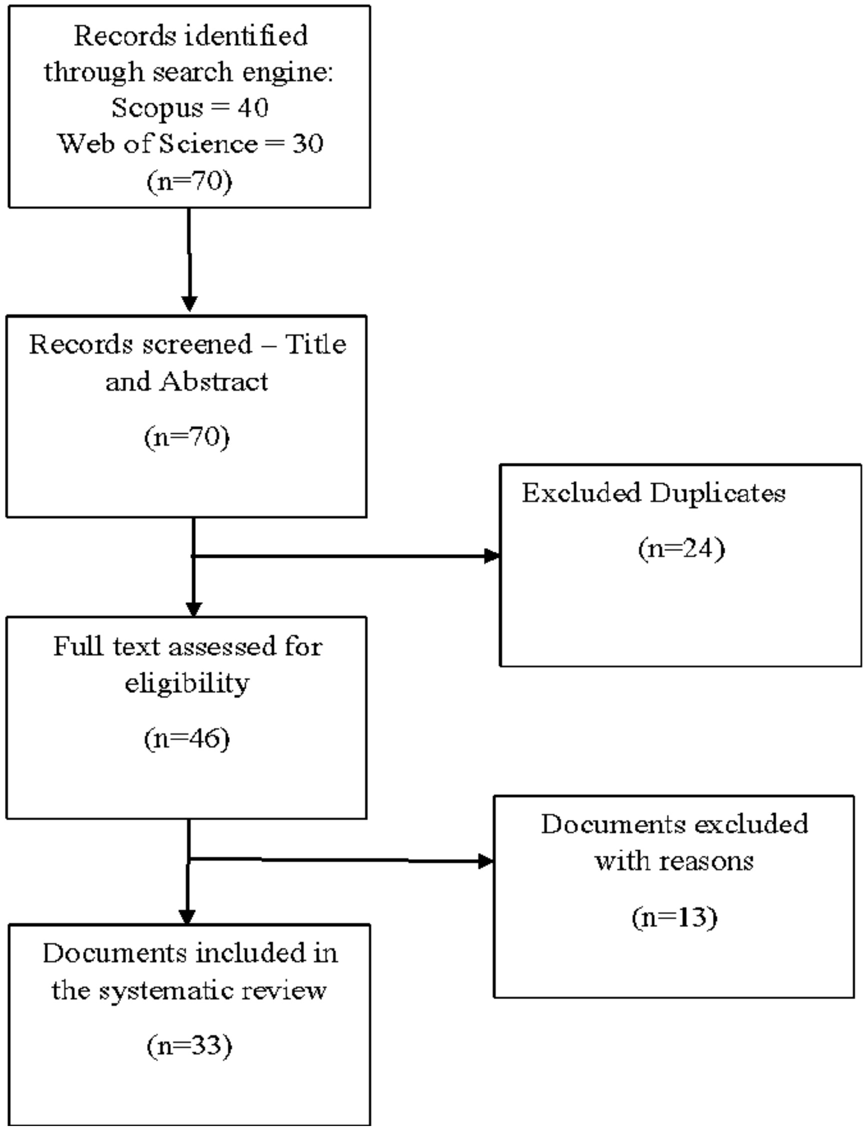

Figure 2:Flow Chart of the Selection Process

Table 1: Sources of Documents and Number of Documents Reviewed

Publication Name (Sources)	**Number of Documents**	**Type**
International Journal of Hydrogen Energy	5	Journal
Sustainability	3	Journal
Applied Energy	2	Journal
Energies	2	Journal
Energy Reports	2	Journal
Journal of Energy in Southern Africa	2	Journal
Petroleum Economist	2	Journal
Agricultural Engineering	1	Journal
Energy Conversion and Management	1	Journal
Energy For Sustainable Development	1	Journal
Environmental Science and Pollution Research	1	Journal
Frontiers in Energy Research	1	Journal
International Conference on the European Energy Market (EEM)	1	Conference
iScience	1	Journal
Journal of Cleaner Production	1	Journal
Journal of Renewable and Sustainable Energy	1	Journal
Minerals, Metals and Materials Series	1	Book
Proceedings - ISES Solar World Congress 2021	1	Conference
Renewable and Sustainable Energy Reviews	1	Journal
Renewable Energy	1	Journal
Shaping an Inclusive Energy Transition	1	Book
Sustainable Development	1	Journal
Total	**33**	

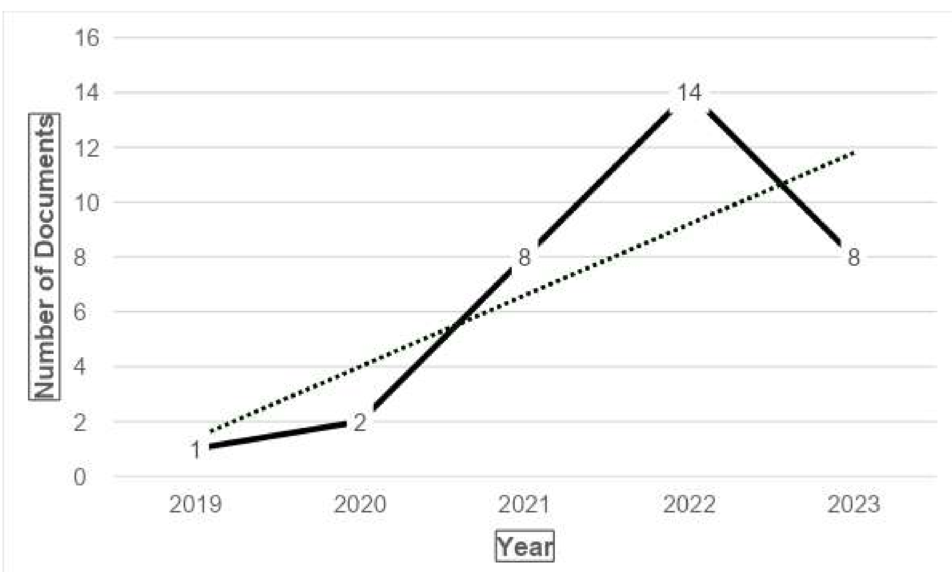

Figure 3: Number of Documents reviewed over time

4.0 Discussion

This section discusses the potentials and pitfalls of green hydrogen in Africa based on the documents extracted and reviewed.

4.1.0 Potentials

The factors considered as the potentials included the vast renewable resources in Africa, the potentials for economic development, export, provision of food security, and a tool for achieving the Sustainable Development Goals (SDGs).

4.1.1 Vast Resource and Favourable Climate Conditions

About 18 of the papers reviewed mentioned Africa as a suitable place for the production of green hydrogen due to its vast energy sources. Africa is rich in numerous renewable energy resources such as wind, solar, and various wealth of natural resources (AbouSeada & Hatem, 2022; Ayodele & Munda, 2019a, 2019b; Bhandari, 2022; Dunkley, 2021; Razi & Dincer, 2022; Seada & Hatem, 2022; Sens et al., 2022; Touili et al., 2020; van Wijk & Wouters, 2021). In assessing the performance of green hydrogen in various countries AbouSeada and Hatem (2022) found that although solar irradiation varies among countries, wind energy which is equally abundant in some parts of Africa may provide stability to hybrid power systems with constrained hydropower resources. Thus, making wind power an excellent substitute for solar photovoltaic. The researchers show that although there is a substantial variation in wind speed in a year for many African countries, Ethiopia, Eritrea, and Djibouti are suitable for wind energy development since these locations experience long-term annual average wind speed (Dabar et al., 2022).

According to the wind resource data released in October 2020 by the World Bank's International Finance Corporation, the technical wind resource potential on the African continent alone is over 59,000 GW, sufficient to provide the region's electricity demand for 250 times over. However, the continent is only tapping into about 0.01 per cent of its wind power potential (Pek, 2021).

Dyanti and Ncanywa (2022) suggest that aside wind and solar, a substantial quantity of hydrogen can be generated from sheep and cattle kraal manure that is in abundance in most parts of Africa, especially the Eastern Cape.

4.1.2 Economic Potential – Low Cost:

The papers reviewed suggest that Africa has the potential of producing green energy at a lower cost while providing significant emission reduction benefits. The Asal–Ghoubbet Rift area in East Africa for example can produce green hydrogen at a lower cost using wind energy (Osman Awaleh et al., 2022). Collis and Schomäcker (2022) examined the delivered cost for green hydrogen for usage locations globally and found among others that the minimum cost of delivering hydrogen for small-scale demand in Cologne, Germany is by liquid organic hydrogen carrier (LOHC) from northern Egypt. The study further identified North Africa and South West Africa as part of the regions with the lowest green hydrogen cost potential, ie. the cheapest locations to source green hydrogen from.

4.1.3 Economic Potential – Job creation

Africa's green hydrogen industry has the potential to generate employment opportunities along the value chain, from upstream industries to manufacturing and construction, thus, contributing to economic growth, technological advancement, and the transition to sustainable energy in the future (Mneimneh et al., 2023; Oyewo et al., 2022).

4.1.4 Export

Africa can serve as a green hydrogen market and supply green hydrogen to Europe and other parts of the world at cheaper prices (Leiblein et al., 2021; Oyewo et al., 2022). This is possible with an increase in Foreign and local participation in the development of the hydrogen market in Africa (Agyekum et al., 2023). It can offer the opportunity for European countries to decarbonize their energy supply through the importation of green hydrogen (Bhandari, 2022). Modernizing and possibly even constructing additional pipelines from Morocco, Algeria, and Tunisia could supply over half of the anticipated 60 million tonnes per year of demand for the European market by 2050 (Jalbout et al., 2022).

4.1.5 Food Security

Despite the vital role Agriculture plays in economic development in Africa, food security, and job creation, the sector depends on fossil fuels and therefore contributes to carbon emissions. The adoption of green hydrogen as an alternative to fossil fuels for powering farming equipment could benefit farmers greatly to lower carbon emissions, support sustainable practices, boost productivity and efficiency, and reduce the implications associated with food production using fossil fuel (Hamukoshi et al., 2022).

4.1.6 Achieving the UN SDGs

Green hydrogen production in Africa can make significant contribution towards the attainment to the Sustainable Development Goals; Goal 3 (Good Health and Well-Being), Goal 7 (Affordable and Clean Energy), and Goal 13 (Climate Action) (Mneimneh et al., 2023). Green hydrogen production will reduce the emission of harmful pollutants in the atmosphere that may have been caused by fossil fuel, thereby improving the quality of air and mitigating harmful impact on respiratory health. In addition to serving as an affordable and clean energy, green hydrogen as a tool for climate change enables decarbonization of several sectors; industrial, transportation, domestic and energy sectors.

4.2.0 Pitfalls

Although green hydrogen shows great potential as a source of renewable energy, several challenges need to be considered.

4.2.1 Technical Capacity

Without major investments in expanding electrolyser and technical capacity, the African countries cannot start the hydrogen rollout or make significant progress in green hydrogen production (Sadik-Zada, 2021). This is mainly because African countries lack the necessary human capital and infrastructure to grow the hydrogen economy. Unlike the developed economies, the continent also lacks seasoned and advanced hydrogen strategies, putting it at a comparative disadvantage.

4.2.2 Inadequate funding of Research and Development (R&D)

Afrane et al. (2022) highlights low commitment of African governments to fund basic and strategic research in the clean energy field as a major pitfall in the production of green energy in Africa. According to the authors, most African countries do not invest at all, and those that do invest do so at a rate of less than 1% of their GDP. Considering the importance of R&D in exploring concepts for advancing the production of green hydrogen, improving efficiency, reducing costs, ensuring safety, and maximizing its potential, African countries have the risk of not fully unlocking the potential of green hydrogen if investment in R&D is not prioritize (Imasiku et al., 2021).

4.2.3 Risk to social life

When major equipment for the production of green hydrogen is produced domestically as opposed to being imported from foreign countries, the risk to most negative social indicators such as child labour, wage inequalities, unemployment, association and bargaining rights, and gender wage gap would be significantly reduced. However, Africa imports most of the key components for the production of green hydrogen from various parts of the world owing to the increased complexity of the green hydrogen supply chain (Akhtar et al., 2023). Akhtar et al. (2023) study of the performance of green hydrogen production on social life cycle assessment (S-LCA) indicated that green hydrogen performed poorly in various social indicators compared to traditional hydrogen production and attributed it to outsourcing essential equipment from countries with poor working conditions.

4.2.4 High Cost of Transportation

Transporting hydrogen may be more expensive and may even pose some challenges compared to other forms of fuels and therefore posing a threat to the overall cost-effectiveness of producing green hydrogen in Africa for exports (Cavana & Leone, 2021; Young, 2021). It requires advanced technology and infrastructure to transport which is less developed compared to other fuels. Although green hydrogen can be exported by ship as liquid hydrogen, it is more expensive than exporting it via pipeline (van Wijk & Wouters, 2021).

5.0 Conclusion and Policy Implications

In this study, the main potentials and pitfalls of producing green hydrogen in Africa was discussed using a systematic review of articles and conference papers from Web of Science and Scopus spanning from 2019 to 2023. The main objective was to identify factors informed as the key potentials and pitfalls of green hydrogen in Africa. This is to help recognise, in addition to the capabilities, the drawbacks or dangers to be able to address them appropriately and unlock the full potential of the production process in Africa.

Production of green hydrogen in Africa has significant advantages for the people on the continent, governments, as well as the environment. However, achieving these potentials requires a carefully considered strategy that takes into account all the possible obstacles and problems. The development of a sophisticated strategic framework, that includes favourable green hydrogen production regulations, financial incentives, subsidies, and a conducive investment environment, would make the sector attractive and boost partnerships.

It is crucial to develop the human capital in Africa, to support the green hydrogen sector. This can be done through educational initiatives and training programs that will build the capacity of individuals in green hydrogen production.

Commitments by governments in the form of prioritizing investment in research and development in green hydrogen production in Africa can help explore ways of improving the efficiency and cost-effectiveness of its production, storage, and transportation.

Finally, sustainable sourcing and management of raw materials need to be considered in the production of green hydrogen in Africa. This entails encouraging ethical work practices, and sourcing equipment if need be from countries with good working conditions.

References

AbouSeada, N., & Hatem, T. M. (2022). Climate action: Prospects of green hydrogen in Africa. *Energy Reports*, *8*, 3873–3890. https://doi.org/10.1016/j.egyr.2022.02.225

Afrane, S., Ampah, J. D., & Aboagye, E. M. (2022). Investigating evolutionary trends and characteristics of renewable energy research in Africa: A bibliometric analysis from 1999 to 2021. *Environmental Science and Pollution Research*, *29*(39), 59328–59362. https://doi.org/10.1007/s11356-022-20125-0

Agyekum, E. B., Ampah, J. D., Uhunamure, S. E., Shale, K., Onyenegecha, I. P., & Velkin, V. I. (2023). Can Africa Serve Europe with Hydrogen Energy from Its Renewables?—Assessing the Economics of Shipping Hydrogen and Hydrogen Carriers to Europe from Different Parts of the Continent. *Sustainability*, *15*(8), Article 8. https://doi.org/10.3390/su15086509

Akhtar, M. S., Khan, H., Liu, J. J., & Na, J. (2023). Green hydrogen and sustainable development – A social LCA perspective highlighting social hotspots and geopolitical implications of the future hydrogen economy. *Journal of Cleaner Production*, *395*, 136438. https://doi.org/10.1016/j.jclepro.2023.136438

AREI. (2018). *Africa Renewable Energy Initiative*. http://www.arei.org/wp-content/uploads/2016/09/AREI-Brochure-ENG_web.pdf

Ayodele, T. R., & Munda, J. L. (2019a). Potential and economic viability of green hydrogen production by water electrolysis using wind energy resources in South Africa. *International Journal of Hydrogen Energy*, *44*(33), 17669–17687. https://doi.org/10.1016/j.ijhydene.2019.05.077

Ayodele, T. R., & Munda, J. L. (2019b). The potential role of green hydrogen production in the South Africa energy mix. *Journal of Renewable and Sustainable Energy*, *11*(4), 044301. https://doi.org/10.1063/1.5089958

Beaucamp, L., & Nforngwa, E. (2022). *Green Hydrogen in Africa: Risks and benefits* (A Factsheet for Civil Society).

Bhandari, R. (2022). Green hydrogen production potential in West Africa – Case of Niger. *Renewable Energy*, *196*, 800–811. https://doi.org/10.1016/j.renene.2022.07.052

Cavana, M., & Leone, P. (2021). Solar hydrogen from North Africa to Europe through greenstream: A simulation-based analysis of blending scenarios and production plant sizing. *International Journal of Hydrogen Energy*, *46*(43), 22618–22637. https://doi.org/10.1016/j.ijhydene.2021.04.065

Collis, J., & Schomäcker, R. (2022). Determining the Production and Transport Cost for H2 on a Global Scale. *Frontiers in Energy Research*, *10*. https://www.frontiersin.org/articles/10.3389/fenrg.2022.909298

Dabar, O. A., Awaleh, M. O., Waberi, M. M., & Adan, A.-B. I. (2022). Wind resource assessment and techno-economic analysis of wind energy and green hydrogen production in the Republic of Djibouti. *Energy Reports*, *8*, 8996–9016. https://doi.org/10.1016/j.egyr.2022.07.013

Dunkley, C. (2021). North African nations vie for green opportunity. *Petroleum Economist*, 73.

Dyanti, N., & Ncanywa, T. (2022). Commercialization of green hydrogen production from kraal manure in the Eastern Cape, South Africa: A review. *Journal of Energy in Southern Africa*, *33*(4), 1–12. https://doi.org/10.17159/2413-3051/2022/v33i4a13116

Hamukoshi, S. S., Mama, N., Shimanda, P. P., & Shafudah, N. H. (2022). An overview of the socio-economic impacts of the green hydrogen value chain in Southern Africa. *Journal of Energy in Southern Africa*, *33*(3), Article 3. https://doi.org/10.17159/2413-3051/2022/v33i3a12543

Hyphen. (2022). Projects. *Hyphen Hydrogen Energy*. https://hyphenafrica.com/projects/

Imasiku, K., Farirai, F., Olwoch, J., & Agbo, S. N. (2021). A Policy Review of Green Hydrogen Economy in Southern Africa. *Sustainability*, *13*(23), Article 23. https://doi.org/10.3390/su132313240

IRENA, I. R. E. A. (2022). *Green hydrogen for industry: A guide to policy making*.

Jalbout, E., Genge, L., & Muesgens, F. (2022). H2Europe: An analysis of long-term hydrogen import-potentials from the MENA region. *2022 18th International Conference on the European Energy Market (EEM)*, 1–7. https://doi.org/10.1109/EEM54602.2022.9921055

Leiblein, J., Bär, K., Mörs, F., Hotz, C., & Graf, F. (2021). Techno-Economic Analysis of Green Hydrogen Production from Solar Energy in Mena and Transport to Central Europe. *Proceedings of the ISES Solar World Congress 2021*, 1–11. https://doi.org/10.18086/swc.2021.01.01

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: Explanation and elaboration. *BMJ*, *339*, b2700. https://doi.org/10.1136/bmj.b2700

Lindner, R. (2023). Green hydrogen partnerships with the Global South. Advancing an energy justice perspective on "tomorrow's oil." *Sustainable Development*, *31*(2), 1038–1053.

Mneimneh, F., Ghazzawi, H., Abu Hejjeh, M., Manganelli, M., & Ramakrishna, S. (2023). Roadmap to Achieving Sustainable Development via Green Hydrogen. *Energies*, *16*(3), Article 3. https://doi.org/10.3390/en16031368

MoE, M. of E. (2019, February). *Renewable-Energy-Masterplan-February-2019.pdf*. https://www.energycom.gov.gh/files/Renewable-Energy-Masterplan-February-2019.pdf

Osman Awaleh, M., Adan, A.-B., Assowe Dabar, O., Jalludin, M., Mahdi Ahmed, M., & Abdillahi Guirreh, I. (2022). Economic Feasibility of Green Hydrogen Production by Water Electrolysis Using Wind and Geothermal Energy Resources in Asal-Ghoubbet Rift (Republic of Djibouti): A Comparative Evaluation. *Energies*, *15*(1), Article 1. https://doi.org/10.3390/en15010138

Oyewo, A. S., Bogdanov, D., Aghahosseini, A., Mensah, T. N. O., & Breyer, C. (2022). Contextualizing the scope, scale, and speed of energy pathways toward sustainable development in Africa. *IScience*, *25*(9), 104965. https://doi.org/10.1016/j.isci.2022.104965

Panchenko, V. A., Daus, Yu. V., Kovalev, A. A., Yudaev, I. V., & Litti, Yu. V. (2023). Prospects for the production of green hydrogen: Review of countries with high potential. *International Journal of Hydrogen Energy*, *48*(12), 4551–4571. https://doi.org/10.1016/j.ijhydene.2022.10.084

Pek, A. (2021, March 4). Africa is only tapping into 0.01% of its wind power potential. *Global Wind Energy Council*. https://gwec.net/africa-is-only-tapping-into-0-01-of-its-wind-power-potential/

Ravikumar Bhagwat, S., & Olczak, M. (2021). *Green hydrogen: Bridging the energy transition in Africa and Europe*. European University Institute. https://doi.org/10.2870/126402

Razi, F., & Dincer, I. (2022). Renewable energy development and hydrogen economy in MENA region: A review. *Renewable and Sustainable Energy Reviews*, *168*, 112763. https://doi.org/10.1016/j.rser.2022.112763

Sadik-Zada, E. R. (2021). Political Economy of Green Hydrogen Rollout: A Global Perspective. *Sustainability*, *13*(23), Article 23. https://doi.org/10.3390/su132313464

Seada, N. A., & Hatem, T. M. (2022). Power to Hydrogen: The Prospects of Green Hydrogen Production Potential in Africa. In F. Tesfaye, L. Zhang, D. P. Guillen, Z. Sun, A. A. Baba, N. R. Neelameggham, M. Zhang, D. E. Verhulst, & S. Alam (Eds.), *REWAS 2022: Energy Technologies and CO2 Management (Volume II)* (pp. 153–159). Springer International Publishing. https://doi.org/10.1007/978-3-030-92559-8_16

Sens, L., Neuling, U., & Kaltschmitt, M. (2022, June 16). *Cost minimized hydrogen from solar and wind: Production and supply in the European catchment area*. Hamburger Energieforschungskolloquium, HEFK 2022. https://doi.org/10.15480/882.4396

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: Elaboration and explanation. *BMJ*, *349*, g7647. https://doi.org/10.1136/bmj.g7647

Touili, S., Alami Merrouni, A., El Hassouani, Y., Amrani, A., & Rachidi, S. (2020). Analysis of the yield and production cost of large-scale electrolytic hydrogen from different solar technologies and under several Moroccan climate zones. *International Journal of Hydrogen Energy*, *45*(51), 26785–26799. https://doi.org/10.1016/j.ijhydene.2020.07.118

UNFCCC. (2018). The Paris Agreement—Publication. *Policies and Measures*, 27. https://unfccc.int/documents/184656 van Wijk, A., & Wouters, F. (2021). Hydrogen–The Bridge Between Africa and Europe. In M. P. C. Weijnen, Z. Lukszo, & S. Farahani (Eds.), *Shaping an Inclusive Energy Transition* (pp. 91–119). Springer International Publishing. https://doi.org/10.1007/978-3-030-74586-8_5

Young, T. (2021). Imports to compete with EU production. *Trade Journal*, *June*, 67.

Zgheib, N. (2022, November 15). *EBRD supports first green hydrogen facility in Egypt*. https://www.ebrd.com/news/2022/ebrd-supports-first-green-hydrogen-facility-in-egypt-.html

Inclusive and Sustainable Development in the Green Hydrogen Value Chain: A Focus on Africa's Unique Perspective and Adoption Potentials.

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Abstract

From abundant renewable resources to a bustling population and consumer market, Africa exists as a strategic and promising powerhouse in green hydrogen production. It is essential to engage in inclusive discussion to develop effective strategies. Given the limited attention on the issue, the present study examines Africa's involvement in the green hydrogen value chain, highlighting its complex energy landscape and adoption potential based on political, economic, social, technological, legal, and environmental (PESTLE) conditions. It also explores the possible scenarios for a green hydrogen future in Africa, using Ghana as a case. Results based on a PESTLE-Scenario Planning Model (P-SPM) are documented as follows: First, there is the need to assess and understand the overall picture of each country's conditions since it provides a more accurate representation of green hydrogen potentials. Second, top-performing countries like South Africa, Morocco, Nigeria, Egypt, and Ghana show well-rounded strengths in all conditions. Finally, Ghana's economic challenges and inconsistent government support create a constrained and risky environment for green hydrogen investment and promotion. The study recommends establishing a consistent policy framework beyond government changes, encouraging public-private partnerships, and investing in education and workforce development to promote green hydrogen adoption.

Keywords: Africa; Ghana; Green Hydrogen; PESTLE- Scenario Planning Model; Policy

Introduction

An expected surge in demand for green hydrogen and its derivatives squarely positions Africa as a potential producer and net exporter in the global energy market (Lenivova, 2022). This opportunity, however, comes with the need for considerable investments in knowledge, training, and logistics, presenting future challenges for many African nations (World Economic Forum, 2022). Interestingly, a complex energy landscape further complicates these challenges.

First, Africa still struggles with limited electricity access, clean water, and an urgent need for industrialization and economic growth (Yohannes and Diedou, 2022). Second, despite abundant related resources, renewable energy development has been disappointingly slow (Ankrah et al., 2022). Third, many African nations exhibit a lack of focus on renewable energy due to their low-emission status. Consequently, the primary objective for many African countries is not to reduce their carbon footprint but rather to utilize their resources to meet the rising energy demand for economic growth (Yohannes and Diedou, 2022). As the inclusiveness of Africa in the green hydrogen value chain remains essential, it is crucial to understand these issues, especially in relation to the adoption potentials, based on political, economic, social, technological, legal, and environmental (PESTLE) conditions in respective local economies (Mukelabai, 2022). Despite the implied relevance, little information about green hydrogen in Africa is known.

Moreover, the existing scholarships are primarily review studies based on expert opinions and techno-economic analyses. The related analysis ignores the uniqueness and complexity of the continent's energy situation, including critical uncertainties that might influence hydrogen technology adoption. It follows that none of the extant studies provides plausible scenarios for the future development of green hydrogen in Africa.

Following the above exposition, this study examines the potential of green hydrogen to drive inclusive and sustainable development in local African economies and societies, considering the continent's distinct perspective. Through a PESTLE-Scenario Planning Model (P-SPM), the study also uses Ghana as a case to explore different scenarios of green hydrogen in Africa, allowing stakeholders to anticipate and prepare for future changes in their operating environment.

The applied model augments the traditional PESTLE analysis with a scenario planning technique to explore various scenarios of green hydrogen in Africa. The approach involves a consideration of the continent's unique perspective and challenges, including critical uncertainties that may influence hydrogen technology adoption. This offers constructive and significant insights beyond the current literature, which primarily relies on review studies, expert opinions, and techno-economic analyses. Moreover, by creating plausible scenarios for green hydrogen production in Africa, which can be used as a basis for strategic planning and decision-making by policymakers, the study contributes to the existing literature by bridging the gap between the current state of knowledge and the future needs of the emerging green hydrogen industry on the continent.

The remaining study details are organized as follows: Section 2 presents a brief background and literature. Section 3 profiles Africa's complex energy landscape in the green hydrogen adoption discussion. Sections 4, 5, and 6 depict the methodology, results, and conclusion.

Brief background and literature review

Green hydrogen involves splitting water molecules through electrolysis using renewable electricity (Brack et al., 2015). The technology has been gaining traction as a viable solution for the energy transition and decarbonization efforts of the global energy industry. According to World Energy Council (WEC), hydrogen demand in the European Union is expected to hit 60 million tons per year by 2050. However, the region is projected to produce less than half, necessitating the import of the remainder (Van der Zwaan, 2021). Africa has emerged as a suitable producer and potential net exporter of green hydrogen owing to its abundant renewable energy sources, such as wind and solar power (AbouSeada and Hatem, 2022).

Reports suggest the continent has about 60% of the world's best solar resources but only 1% of current solar generation capacity (World Economic Forum, 2022). In particular, country-specific studies such as Mandel (2019) and Ayodele and Munda (2019) advance how renewable energy resources are the most encouraging factor for hydrogen development in South Africa and that renewable-sourced hydrogen brings a positive outlook to the South African energy sector. Despite the potential for green hydrogen in Africa, there are numerous challenges that need to be addressed. Imasiku et al. (2021) and Ballo et al. (2022) both highlighted the need for policy frameworks specific to hydrogen development in each country and the need for regulatory reform and alignment of policies to introduce green hydrogen production. Hamukoshi et al. (2022) noted that green hydrogen has the potential to revolutionize agricultural and industrial sectors, but also highlights the need for corresponding investments and policy reforms, as well as the potential for job losses in fossil fuel-based industries. Barreto (2003) provides a long-term scenario for a global hydrogen-based energy system, illustrating the critical role of hydrogen in transitioning toward a clean and sustainable energy future. A recent study by Mukelabai (2022) evaluated the political, economic, social, technological, legal, and environmental (PESTLE) conditions that can be instrumental in adopting hydrogen technologies most effectively.

While these studies provide valuable insights into the opportunity, challenges, and potential of green hydrogen in Africa, most are qualitative and based on reviews and expert opinions. It can be observed that none of these scholarships provides plausible scenarios for the future development of green hydrogen in Africa. The present study fills such an existential gap in the literature.

Africa's complex energy landscape and green hydrogen development

Africa's complex energy environment, shaped by a set of challenges, offers a unique perspective for the green hydrogen adoption discussion. This section profiles three-pronged factors that define this distinct perspective, shedding light on how they can affect green hydrogen development across the region.

Slow renewable energy growth despite overt support

Africa is endowed with abundant renewable energy resources, including solar, wind, hydropower, and geothermal, which could play a significant role in producing green hydrogen (Ankrah et al., 2023). The continent's vast solar potential, particularly in the Sahel region and northern African countries, can be harnessed for large-scale solar energy production. Similarly, wind resources along the coastlines and in highland areas could contribute to generating renewable electricity. Despite these abundant resources, the development of renewable energy projects in Africa has been unimpressive, mainly due to inadequate infrastructure, insufficient investment, lack of supportive policies, and limited technical capacity (Ankrah and Lin, 2019). This slow progress in renewable energy development can hinder the region's large-scale adoption of green hydrogen production (Mutezo and Mulopo 2021).

Low contribution to global greenhouse gas emissions

Another complex issue relates to Africa's relatively low contribution to greenhouse gas emissions. With less than 4% of total global emissions, Africa's carbon footprint is small compared to developed countries (Wesseh and Lin, 2016). This situation presents a significant challenge as the continent seeks to adopt green hydrogen technologies. The argument is that most African countries lack renewable energy focus because of their low emission status (Yohannes and Diedou, 2022). To be precise, the predominant belief that Africa's future energy development depends on conventional energy sources, coupled with skepticism about the potential of renewable energy, has contributed to many unsuccessful clean energy projects across the continent over the past decades (Block, 2008). While the continent's low emissions could be leveraged to attract investments and support from developed countries, addressing the lack of clean energy focus induced by the low global emission status is crucial for the success of green hydrogen development in the region.

Balancing sustainable development and economic growth

Energy policy objectives can generally be divided into three main aspects: energy access, economic growth, and environmental protection (Lin et al., 2017). Energy access refers to a country's efforts to ensure that most of its population can access affordable, reliable, and sustainable energy. Economic growth involves recognizing energy as a vital component of economic development. On the other hand, environmental protection addresses the mitigation of adverse effects of energy consumption on the environment. As a growth and industrialized-oriented continent, striking a balance between sustainable development and economic growth has been a critical challenge (Lin and Ankrah, 2019). Many African nations often prioritize energy access and consumption to meet the energy demands of a growing population over environmental concerns. For instance, Nigeria has struggled to diversify its energy mix, remaining heavily dependent on oil revenues (Lin and Ankrah, 2018). Ghana is gradually shifting from renewable energy toward fossil fuels (Ankrah et al., 2023). Stakeholders of green hydrogen must be on the look for this complex phenomenon as far as Africa's involvement in the value chain is concerned.

The issues discussed above make Africa's energy economy complex, presenting a distinctive outlook for the future of green hydrogen development. Therefore, finding solutions to these issues is essential for Africa's success as a global powerhouse in the green hydrogen market.

Methods

PESTLE

The PESTLE framework exists as an essential method of assessing the implications of present and potential external factors on a technology, including the related impact of the technology on the environment in which it is used (Basu, 2004). It is suitable for analyzing problems and evaluating qualitative variables (Thomas, 2021). The PESTLE conditions are based on indicators important to major stakeholders, in this case, from the green hydrogen producers to consumers. They include:

I. **Political:** indices measuring corruption control, political stability, government effectiveness, and fragile states.

II. **Economics:** the cost of beginning a firm, the simplicity of conducting business, private partnership energy investment, and loan interest rate.

III. **Social:** unemployment rate, human development index, and adult and female literacy rates.

IV. **Technological:** grants for technological collaboration, R&D expenditures, patent applications, and high technology exports.

V. **Legal:** property rights index, strength of legal rights index, regulatory quality index, and rule of law index.

VI. **Environmental:** availability of electricity, electricity use, CO_2 emissions, and overall greenhouse gas emissions.

Following Mukelabai et al. (2022), a quantitative component is incorporated to the PESTLE framework, which involves the selection, collection, and ArcGIS Pro mapping of publicly available PESTLE factors.

PESTLE-Scenario Planning Model

It is important to note that the traditional PESTLE analysis alone may not be sufficient to capture the complexity and uncertainty of today's business environment (Song et al., 2017). This signals the need for a model incorporating scenario planning techniques to explore multiple possible prospects and develop more robust strategies better suited to a range of potential outcomes (Chermack, 2001). By combining traditional PESTLE analysis with scenario planning techniques, the P-SPM is better for exploring different possible futures for a given technology, industry, or sector. The model considers six key factors: political, economic, social, technological, legal, and environmental (PESTLE), as well as the uncertainties associated with each factor. It selects two critical factors from the PESTLE indicators based on the uncertainties to construct the scenarios. This approach allows stakeholders to anticipate and prepare for future changes in their operating environment. In this case, potential risks and opportunities can be identified by considering multiple possible scenarios and developing strategies to remain competitive in a rapidly changing world. A block diagram of the modeling procedure is shown in Fig.1

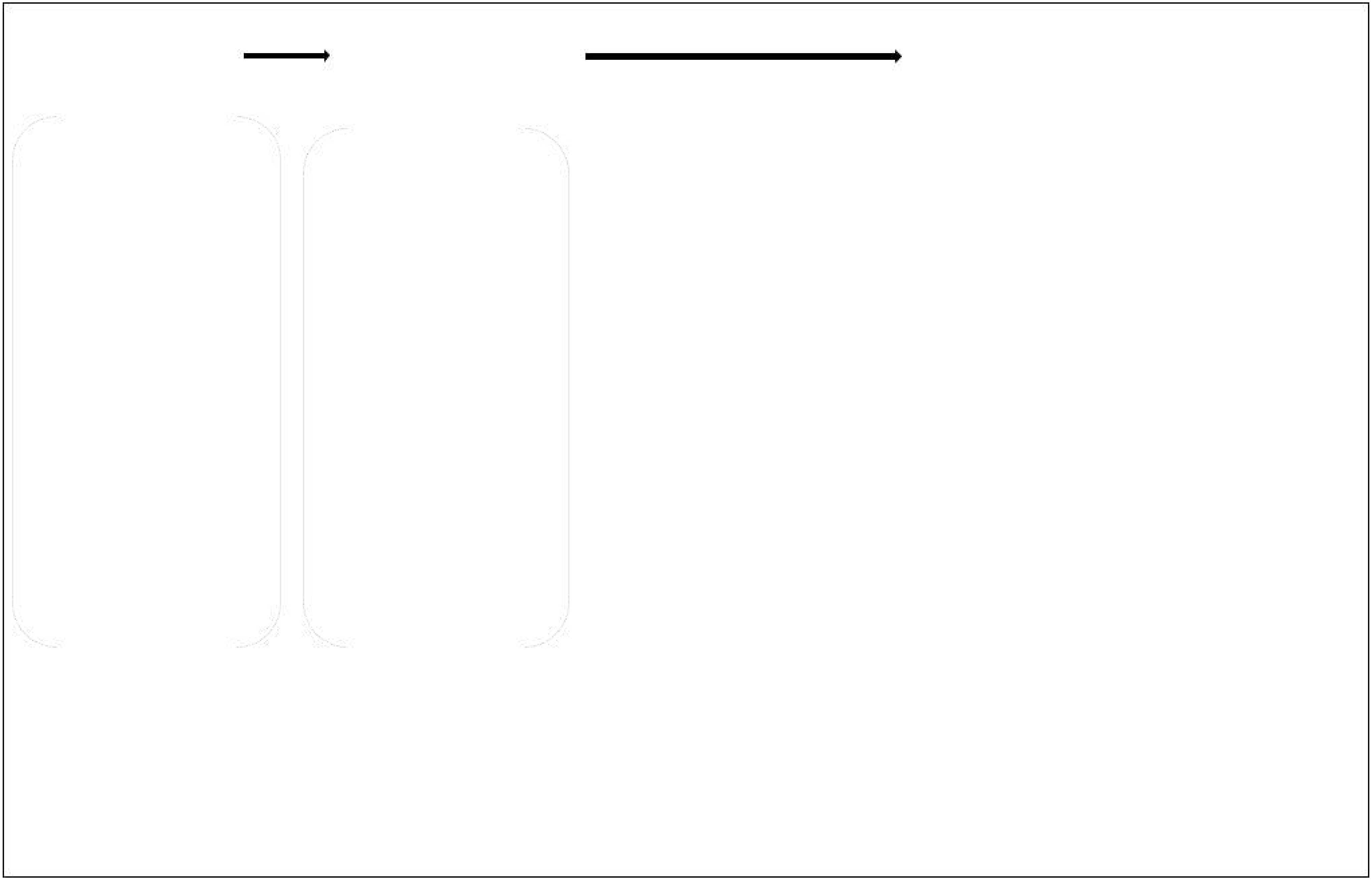

Fig 1. A block diagram of the modeling procedure
Note: description of scenarios depends on the choice of indicators

Results and discussion

PESTEL Analysis

Political

The political indicator that can impact the adoption of hydrogen technology under the PESTLE framework constitutes four significant indicators: the fragile State index, government effectiveness index, political stability index, and control of corruption index (The Global Economy, 2022). Fragile State Index depicts the vulnerability of nations in pre-conflict, active conflict, and post-conflict conditions. Investing in nations with low fragile state indexes is always advisable as it is one way to reduce risk. The government effectiveness index represents perceptions of the quality of public services, civil service, and independence from political interference. It also indicates the quality of policy formulation and implementation and the credibility of a government in formulating policies (Mukelabai, 2022). The political stability index measures the risk that the government would be overthrown by violent or illegal means, such as terrorism and acts of political violence. Political stability has a significant impact on how risk-averse hydrogen developers are. Despite having enormous renewable hydrogen potential, certain African nations might find it challenging to achieve it because of political instability and fragility (Mukelabai, 2022). The control of corruption index reveals public power being perceived as being utilized for private gain, encompassing several types of corruption and elite state capture. The overall political index based on these respective indicators can be seen in **Fig. 2**

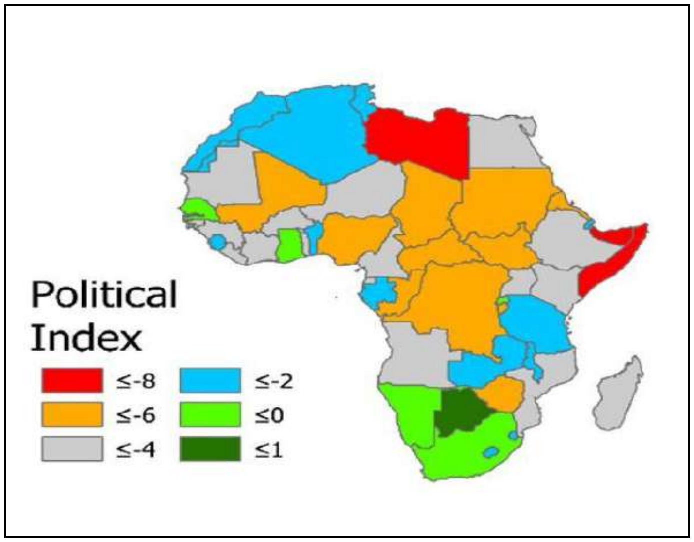

Fig 2. Political index (data mapped from The Global Economy via Mukelabai (2022))

In general, the lower the score on the political index, the higher the risk of political instability and its adverse impacts on various aspects such as investment, policy formulation and implementation, and overall economic development. A political index of ≤ 1 means that the country has a low level of political stability, indicating a high risk of political instability. A score of ≤ 0 indicates an even higher risk of political instability. A ≤ -2 indicates a very high risk of political instability, while a ≤ -4 indicates an extremely high risk. A score of ≤ -6 indicates that the country is in a critical situation with regard to political stability, and a score of ≤ -8 indicates that the country is in a highly critical situation.

Economic

Economic parameters that affect the uptake of hydrogen technology in Africa include the economic globalization index, ease of doing business, investments in energy in private partnerships, and robust financial systems indicators (Mukelabai, 2022). The ease of doing business evaluates a nation's economic health by taking into account elements that influence regular commercial activities (The World Bank, 2022). The economic globalization index accounts for actual economic flows, including capital and trade limitations (Gygli et al., 2019). This indicator is crucial considering Africa's ability to export hydrogen-based renewable energy, with southern African nations dominating trade attractiveness (Dreher, 2006). Increasing infrastructure service efficiency, decreasing financial constraints, and developing hydrogen technologies all depend on energy investment through private partnerships (The World Bank, 2022). The aggregate economic index with thresholds for various African states is shown in Fig 3.

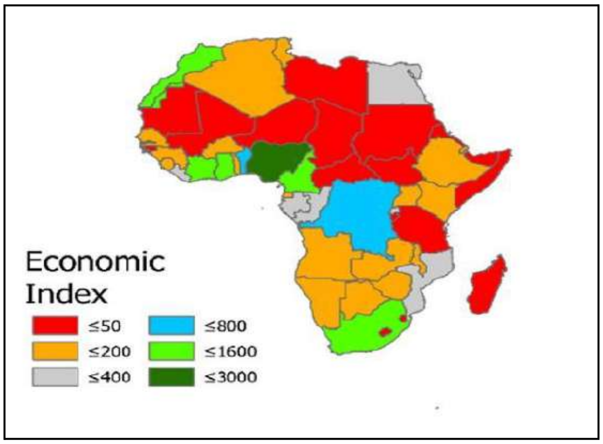

Fig 3. Political index (data mapped from The Global Economy via Mukelabai (2022))

In particular, a country with an index value of ≤50, for example, suggests poor performance, while a score of ≤3000 may indicate strong performance. Countries that fall within the thresholds (≤200, ≤400, ≤800, and ≤1600) represent a variety of performance levels, from low to high. Based on their respective economic realities, this category might assist stakeholders in identifying potential opportunities and difficulties for hydrogen technology adoption in African countries.

Social

Fig.4 highlights an evaluation of countries based on social indicators affecting hydrogen technology adoption in Africa. These include the human development index, unemployment rate, and literacy rates. The index values represent a range of performance levels in social parameters, which can help stakeholders identify opportunities and challenges for hydrogen technology development (The World Bank, 2022). For example, countries with high human development indices may be more attracted to hydrogen technology due to better knowledge and living standards (Mukelabai, 2022). High unemployment rates, though undesirable, can signal a readily available labor force, while high literacy rates indicate a sustained education system and a workforce receptive to essential skill training (The Global Economy, 2022). Understanding these social indices can aid developers in creating a safe and inclusive hydrogen economy in African countries. Generally, a country with a social index value of ≤100 may indicate poor performance in these social parameters, while a ≤400 may signify strong performance.

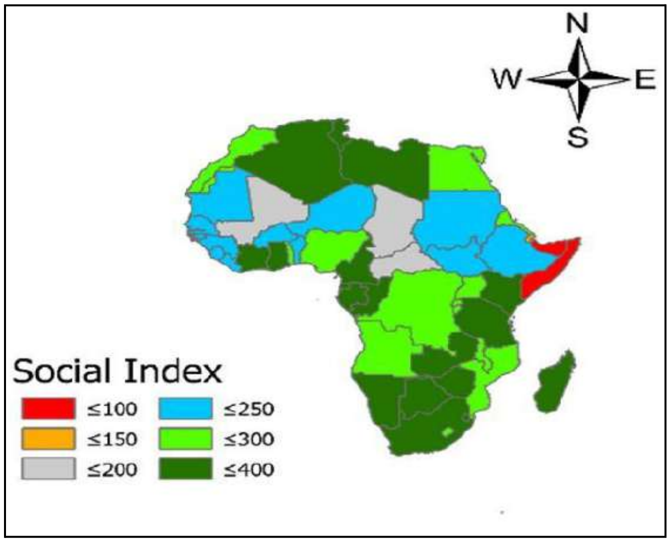

Fig 4. Political index (data mapped from The Global Economy via Mukelabai (2022))

Technological

Crucial factors such as domestic expenditures on research and development (R&D), patent data, high technology exports, and technical cooperation grants play an instrumental role in determining a country's potential in the hydrogen economy (Mukelabai, 2022).

At the outset, R&D expenditures signal a country's commitment to gaining a competitive advantage in science and technology. Specifically, in Africa, R&D is essential to adapt hydrogen technologies to local environmental conditions, which may differ significantly from their origin countries (Mukelabai, 2022). Furthermore, patent data offers valuable insights into a nation's inventiveness, cooperation during innovation, and technological strategies. Therefore, countries with strong patent portfolios in hydrogen technology, such as South Africa, Morocco, and Egypt, become attractive for forming strategic partnerships with global players like Germany and Japan (The Global Economy, 2022). Additionally, high-technology exports indicate a nation's capacity to develop competitive hydrogen trade markets, while technical cooperation grants reveal the ability to build hydrogen production capacities (IRENA, 2022). By establishing hydrogen trade relations, countries can enhance technology accessibility, skilled workforce development, information sharing, and investment. For instance, memorandums of understanding between governments and investors can facilitate the transfer of skilled workers in the hydrogen service industry. This collaboration offers benefits such as employment generation, workforce training, and accelerated growth of the hydrogen economy.

The technological index for African countries based on these technical indicators is shown in Fig 5. Each category in the index represents a range of scores, where a higher score indicates a more favorable environment for hydrogen technology adoption. For instance, a country with an index score of ≤10 would have a minimal investment in R&D, a limited number of patents, low high-technology exports, and scarce technical cooperation grants. On the other hand, a country with an index score of ≤70000 would demonstrate a substantial commitment to R&D, an impressive patent portfolio, strong high-technology exports, and numerous technical cooperation grants, signifying a more conducive environment for hydrogen technology development.

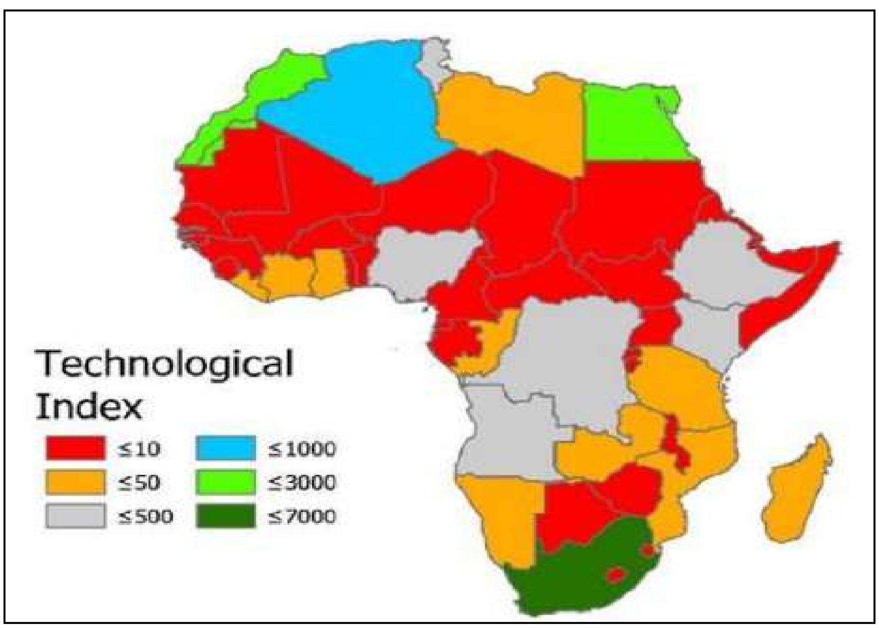

Fig 5. Political index (data mapped from The Global Economy via Mukelabai (2022))

Legal

Overall, the legal index offers valuable insights into the legal landscape for hydrogen technology adoption in Africa. It is based on four key indicators: the rule of law index, regulatory quality index, the strength of legal rights, and property rights index (Mukelabai, 2022). The rule of law index measures confidence in societal rules, including contract enforcement and the quality of police and courts. The regulatory quality index reflects a government's capacity to establish policies and regulations that promote private sector development (The Global Economy, 2022). Implementing hydrogen technologies requires systematic and transparent rules and standards, but varying standards may hinder progress and lead to market fragmentation. Finally, the strength of legal rights measures the protection of borrowers and lenders, affecting the expansion and accessibility of credit (The Global Economy, 2022).

A higher legal index indicates a stronger rule of law, regulatory quality, legal rights, and property rights protection (Fig 6). These factors contribute to a favorable environment for investment, private sector development, and technology implementation. Countries like South Africa, Morocco, Kenya, Zambia, and Rwanda exhibit strong legal frameworks and have become attractive for hydrogen technology developers (See Fig 6).

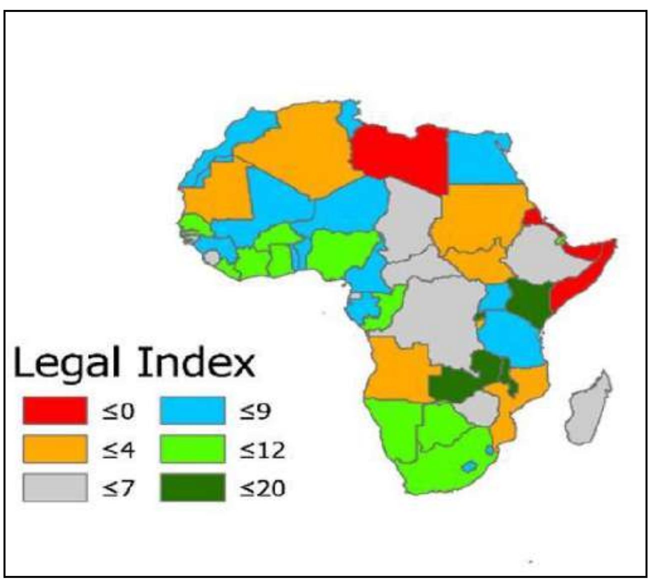

Fig 6. Political index (data mapped from The Global Economy via Mukelabai (2022))

Environmental

The environmental index ranging from ≤10 to ≤700 serves as a tool to evaluate the impact of environmental factors on hydrogen technology adoption in Africa (see Fig 7). A higher index value implies better performance in terms of electricity access, lower air pollution levels, and reduced greenhouse gas emissions. In this context, countries with higher index values are considered more suitable for adopting hydrogen technology, as they demonstrate a more sustainable and environmentally friendly approach to energy production and consumption. Developers can use this index to prioritize countries where hydrogen technology can be introduced and scaled effectively while addressing environmental concerns.

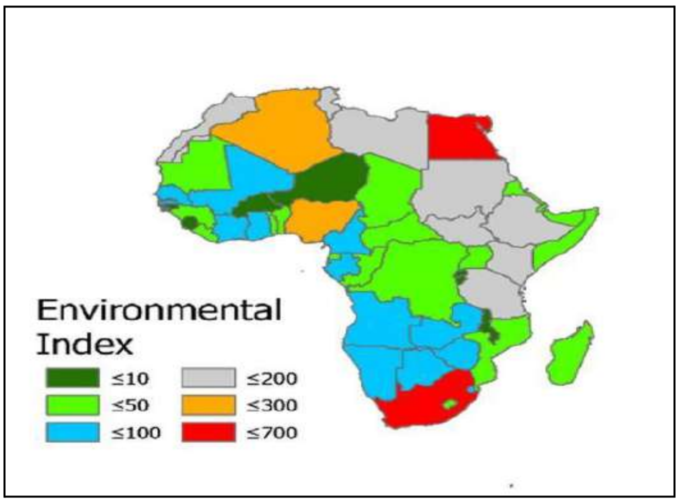

Fig 7. Political index (data mapped from The Global Economy via Mukelabai (2022))

The index is based on indicators such as electricity access, electric power consumption, air pollution exposure, and greenhouse gas emissions (Mukelabai, 2022). Electrification of the population without access to electricity in developing countries should be prioritized before producing hydrogen using renewable energy sources for local consumption or export. Countries with substantial renewable energy potential, such as solar and wind power, may be better suited for hydrogen production using renewable sources. Since most current research on hydrogen technologies is based on European and Asian environmental and climatic conditions, developers must understand how these technologies will perform in different environments, such as Africa's hotter and dustier conditions. Water availability is also critical, as hydrogen production requires large amounts of water, posing challenges for countries with limited water resources. Moreover, countries with strong environmental regulations may be more attractive to hydrogen technology developers who aim to produce hydrogen using renewable sources while minimizing negative environmental impacts (The Global Economy, 2022). In summary, these environmental indicators are vital in determining the feasibility and sustainability of hydrogen technology adoption in Africa.

Overlaid PESTLE factors and country ranking

To provide a clearer overall picture of each country's progress in developing a green hydrogen economy, overlaid PESTLE indicators and country ranking are presented in Fig 8. The characterization was applied, assuming all analyzed parameters were equal. However, weighting can be considered if a factor can be identified as more important than others (Mukelabai, 2022). The figures underscore the need to assess and understand the overall picture of the PESTLE conditions rather than individually. For instance, countries like Kenya and Malawi exhibit strong political and legal conditions but underperform in other aspects. Interestingly, it could be seen that the top five countries, including South Africa, Morocco, Nigeria, Egypt, and Ghana, display well-rounded strengths across all conditions compared to other nations. This holistic analysis provides a more accurate representation of each country's potential for hydrogen technology adoption.

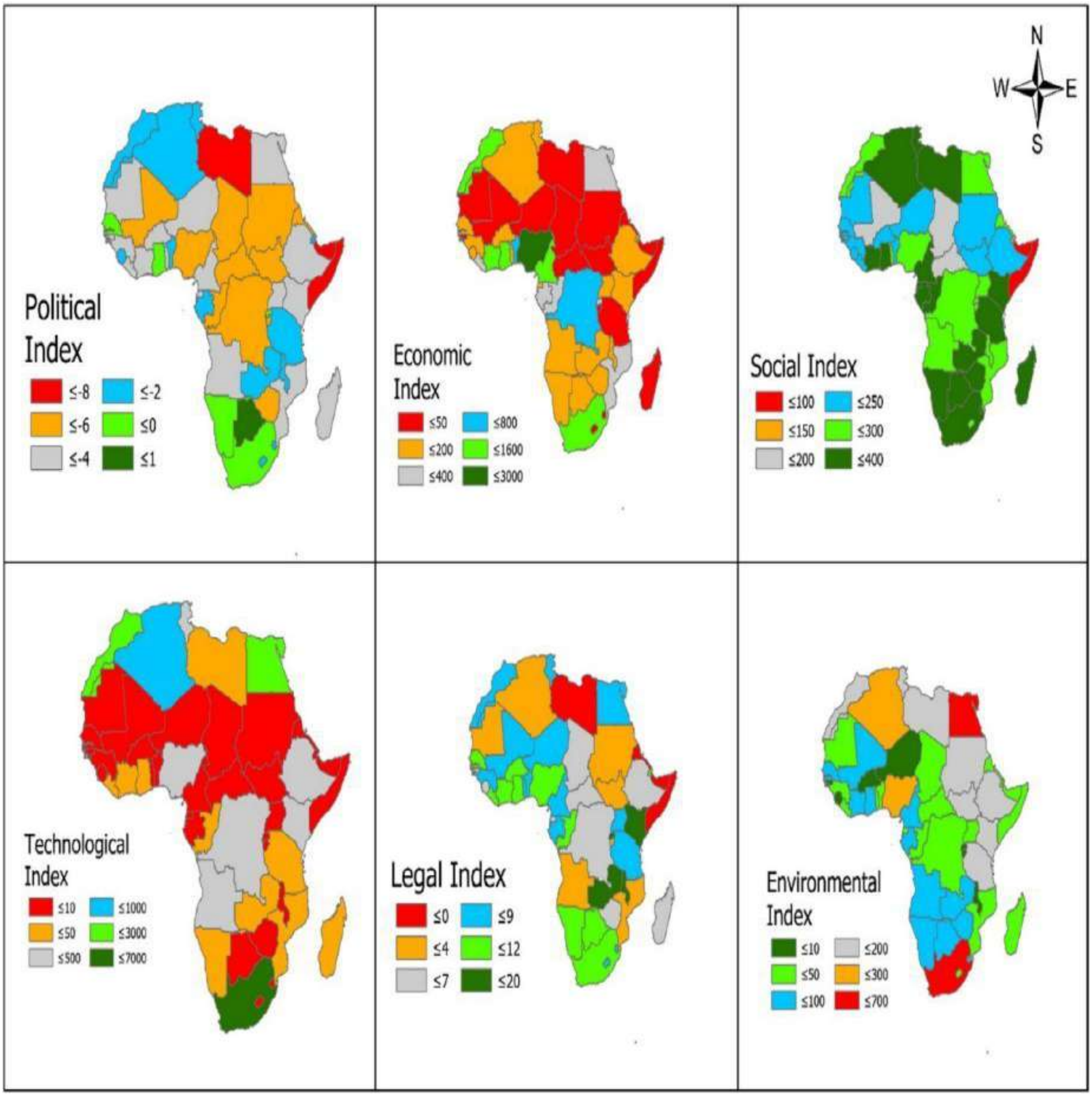

Fig 8. Overlaid PESTLE indicators

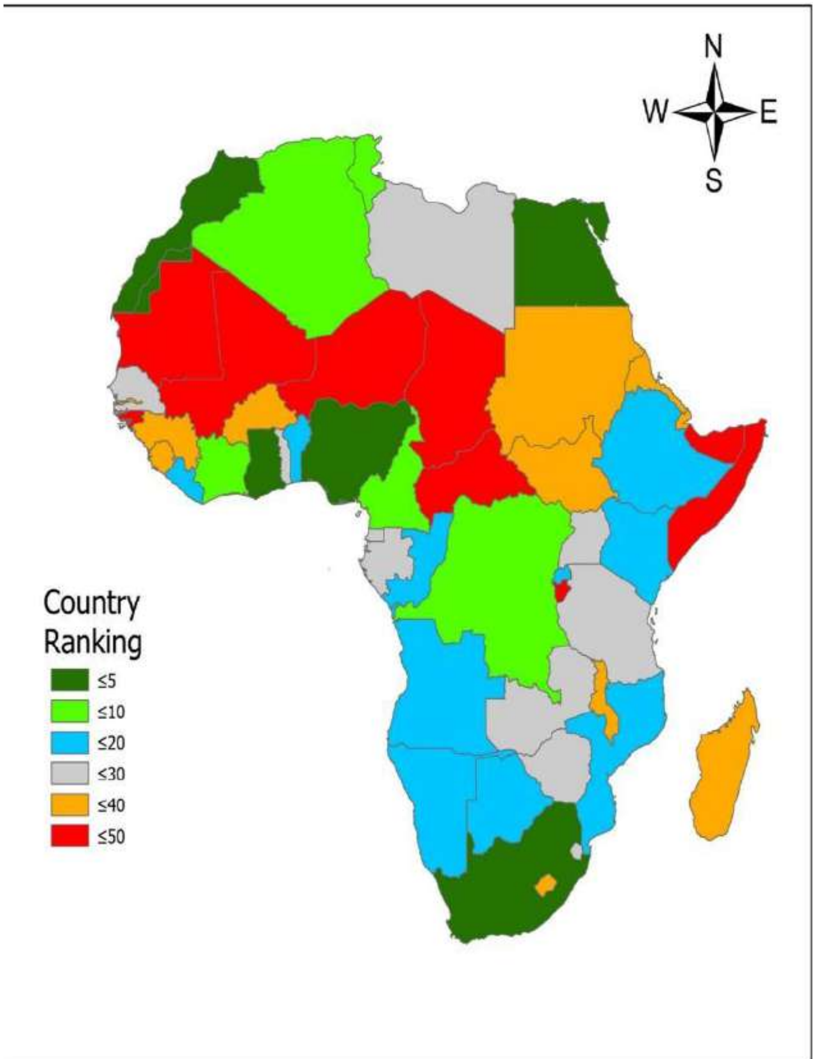

Fig 9. PESTLE country ranking

A case study of Ghana's Green Hydrogen Potential

While the traditional PESTLE analysis provides valuable insights into Africa's green hydrogen development, it fails to fully account for the uniqueness and complexity of the continent's energy economy. In particular, the analysis overlooks critical uncertainties arising from this distinct context, making it difficult to identify potential risks and opportunities and formulate strategies to address or capitalize on them. Therefore, this section analyzes Ghana's green hydrogen potential using the PESTLE-Scenario Planning Model.

Determining uncertainties and time horizon

Following the P-SPM (see Fig 1), we chose political and economic indicators from the PESTLE framework as the two critical factors/uncertainties that have the greatest potentials to shape the future of green hydrogen in Ghana.

Politics in Ghana is extensive and interestingly impacts the legal environment, stability, and overall direction of the country's energy policy. Political stability, government support, and the commitment of policymakers to promote green hydrogen development are essential for the successful implementation of hydrogen projects. In addition, economic conditions directly influence the availability of financial resources, market opportunities, and incentives necessary for the growth of the green hydrogen sector. Based on these drivers/uncertainties, the study creates four plausible scenarios representing disparate viable expectations of Ghana's hydrogen economy. The scenarios include complex, favorable, Risky, and Constrained (Fig 9). It is worth noting that these scenarios are based on a time horizon of 4 years (a term in office for any political government in Ghana).

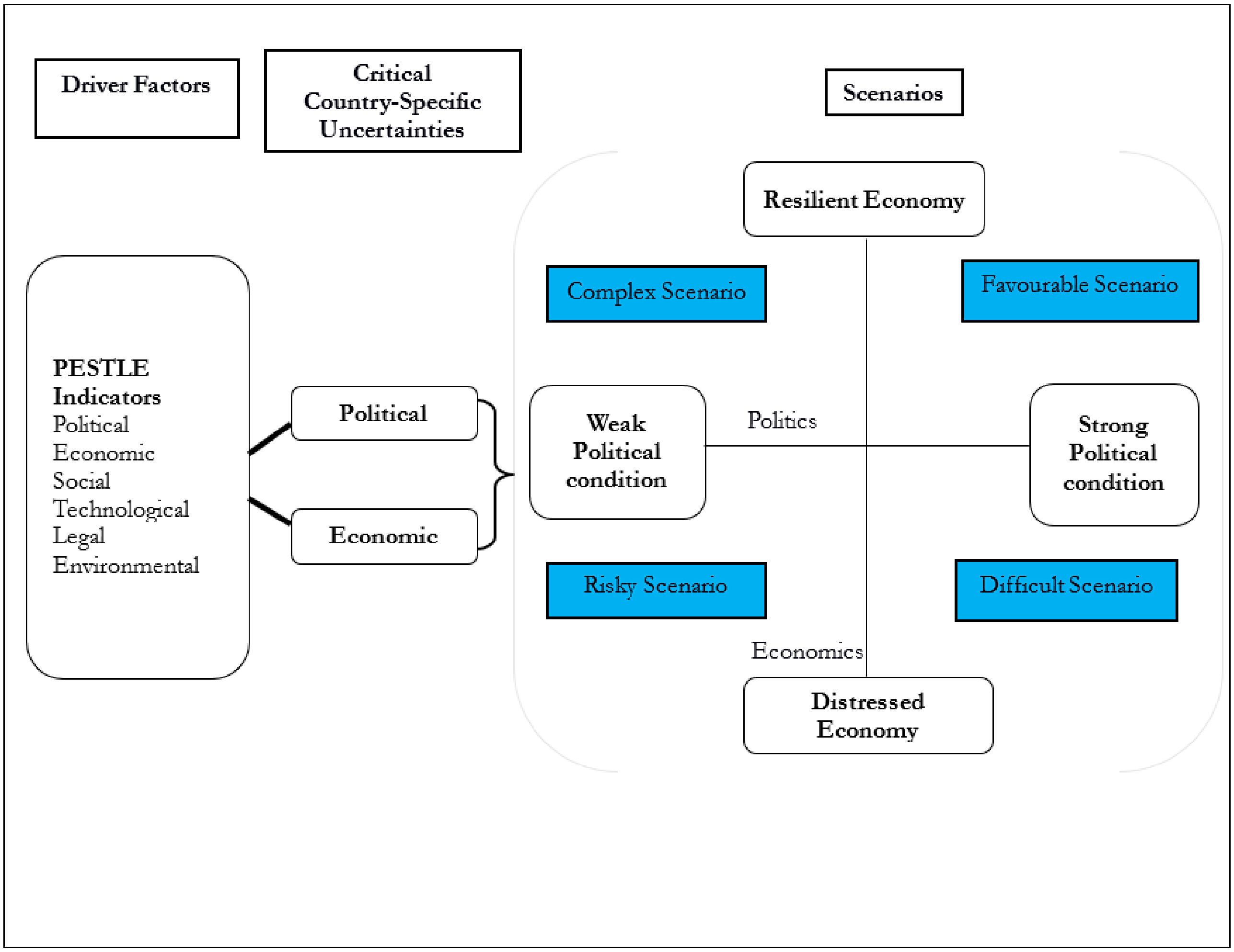

Fig 10. A block diagram of the P-SPM for green hydrogen adoption

Favorable Scenario

In this scenario, a resilient and growing economy, combined with strong government support, fosters a thriving green hydrogen market in the country. Government policies, incentives, and funding boost infrastructure development, technology advancements, and international collaboration, paving the way for integrating green hydrogen into various sectors. The well-developed hydrogen infrastructure, competitive production technologies, and strategic partnerships contribute to a cleaner, more sustainable energy mix, reduced greenhouse gas emissions, and significant economic benefits. This favorable environment enables the successful development and adoption of green hydrogen as a key component of the country's energy landscape.

Complex Scenario

This situation is multifaceted, with various interrelated factors, such as a resilient and growing economy, weak political conditions, and limited government support for green hydrogen. The lack of favorable policies and incentives results in slow progress in infrastructure development, technology advancements, and international collaboration. Consequently, navigating and developing strategies for the green hydrogen industry is challenging. This unfavorable environment stifles the potential growth of the green hydrogen industry and prevents it from becoming a key component in the country's energy landscape. The missed opportunities for economic benefits and environmental improvements highlight the importance of strong political support for the successful development and adoption of green hydrogen technologies.

Constrained scenario

In this scenario, the economy faces significant challenges, with high unemployment, inflation, and widespread financial instability. Despite these economic hardships, the political landscape is stable, and the government is committed to promoting green hydrogen development. Strong political leadership and favorable policies help foster collaboration between the public and private sectors. Incentives, such as tax breaks and subsidies, are provided to attract investments and encourage innovation in green hydrogen technologies. While the struggling economy poses a barrier to large-scale implementation, the government's support gradually enables the industry to gain traction. Grassroots movements and local initiatives also contribute to the growth of the green hydrogen sector, fostering job creation and slowly contributing to the economy's recovery. As a result, committing to green hydrogen becomes a beacon of hope and a potential catalyst for long-term economic revitalization.

Risky Scenario

This situation is "risky" for green hydrogen development because it involves a struggling economy characterized by high unemployment and low living standards. Simultaneously, the political landscape is marred by instability, weak governance, and limited government support for green hydrogen initiatives. Key players in the energy sector are hesitant to invest due to the uncertain environment and lack of incentives for renewable energy projects. Public opinion on green hydrogen remains divided, as many citizens prioritize immediate economic relief over long-term sustainable solutions. Furthermore, the weak political situation undermines international confidence, making it difficult to attract foreign investments and forge strategic partnerships. The lack of government support hinders research and development in the hydrogen sector, limiting the country's ability to adopt innovative technologies and keep up with global advancements in green hydrogen. Generally, this scenario paints a bleak picture of the future of green hydrogen in a nation burdened by economic and political challenges. The potential for a thriving hydrogen economy remains untapped as the country struggles to address its immediate concerns and lacks the necessary support to pursue sustainable energy solutions.

Plausible Scenario and policy implications

Ghana's economy is presently struggling with high inflation, rising unemployment, and pervasive financial instability. Although the political landscape is stable, clean energy development has not been impressive, even though successive governments continue to publicly express their support (Ankrah and Lin, 2020). Green hydrogen may encounter a similar scenario. In other words, varying government support depending on the administration creates an unpredictable environment for the development of green hydrogen projects. As a result, Ghana's situation can be described as "constrained" or even "risky" for green hydrogen investment and promotion.

For such a situation, this study recommends the following for future green hydrogen projects. First, there is the need to establish a consistent policy framework that transcends changes in administration. The framework should outline long-term goals, targets, and incentives for green hydrogen development, providing investors and project developers with a stable environment. Second, a collaboration between the public and private sectors in the green hydrogen spaces. By fostering public-private partnerships, the government can leverage private sector expertise and investment to drive innovation, create jobs, and scale up hydrogen projects. These collaborations can also help to overcome financial constraints and mitigate risks associated with green hydrogen investment. Finally, investing in education and workforce development is essential for ensuring a skilled workforce for the emerging green hydrogen sector. The government should promote STEM education, offer technical and vocational training, and support research initiatives at universities and research institutions focused on clean energy and hydrogen technologies. A well-trained workforce will not only support the development of green hydrogen projects but also contribute to addressing the broader economic challenges of high unemployment and financial instability.

Conclusion

Africa's unique energy landscape, abundant renewable resources, and bustling population position the continent as a promising player in the green hydrogen market. This study sheds light on the importance of understanding each country's PESTLE conditions and potential for green hydrogen adoption. Notably, top-performing countries like South Africa, Morocco, Nigeria, Egypt, and Ghana demonstrate well-rounded strengths in this area. However, challenges remain, as exemplified by Ghana's constrained environment for green hydrogen investment. Consistent policy frameworks, public-private partnerships, and investment in education and workforce development are crucial to overcome these hurdles and capitalize on the continent's immense potential. By addressing these challenges, Africa can unlock its full potential in the green hydrogen sector, driving sustainable economic growth and contributing to global climate goals.

Reference

AbouSeada, N., & Hatem, T. M. (2022). Climate action: Prospects of green hydrogen in Africa. Energy Reports, 8, 3873-3890. https://doi.org/10.1016/j.egyr.2022.02.225

Ankrah, I., Dogah, K., Twumasi-Ankrah, S., Sackey, F. G., Asravor, R., Donkor, D. O., Lamptey, C., & Arthur, L. (2023). Is energy transition possible for oil-producing nations? Probing the case of a developing economy. Cleaner Production Letters, 4, 100031. https://doi.org/10.1016/j.clpl.2023.100031

Ankrah, I., Sackey, F. G., & Twumasi-Ankrah, S. (2022). Towards a cleaner energy system: Estimating the odds of transitioning to an energy-efficient state. Cleaner Energy Systems, 2, 100006.

Ayodele, T.R., Munda, J.L. (2019). The potential role of green hydrogen production in the South Africa energy mix. Journal of Renewable and Sustainable Energy 11 (4): 044301. doi.org/10.1063/1.5089958

Ballo, A., Valentin, K. K., Korgo, B., Ogunjobi, K. O., Agbo, S. N., Kone, D., & Savadogo, M. (2022). Law and Policy Review on Green Hydrogen Potential in ECOWAS Countries. Energies, 15(7), 2304. https://doi.org/10.3390/en15072304

Basu R, 2004. Implementing quality: a practical guide to tools and Techniques: enabling the power of operational excellence. Thomson Learning.

Block, B., 2008. African Renewable Energy Gains Attention. WorldWatch Institute. Retrieved from: <https://web.archive.org/web/20080924193119/http://www.worldwatch.org:80/node/5884 >

Brack, P., Dann, S.E., Upul, Wijayantha, K.G. (2015). Heterogeneous and homogenous catalysts for hydrogen generation by hydrolysis of aqueous sodium borohydride (NaBH4) solutions. Energy Sci 3(3):174e88. https://doi.org/10.1002/ese3.67

Chermack, T. J., Lynham, S. A., Ruona, W. E. (2001). A review of scenario planning literature. Futures research quarterly, 17(2), 7-32.

Dreher A (2006). Does globalization affect growth? Evidence from a new index of globalization. Appl Econ, 38(10):1091e110. <https://doi.org/10.1080/00036840500392078>

Gygli, S., Haelg, F., Potrafke, N., Sturm, J.E. (2019). The KOF globalization index revisited. Rev Ind Organ;14(3):543e74. <https://doi.org/10.1007/s11558-019-09344-2>

Hamukoshi, S. S., Mama, N. ., Shimanda, P. P. ., & Shafudah, N. H. (2022). An overview of the socio-economic impacts of the green hydrogen value chain in Southern Africa. Journal of Energy in Southern Africa, 33(3), 12–21. https://doi.org/10.17159/2413-3051/2022/v33i3a12543

Imasiku, K., Farirai, F., Olwoch, J., & Agbo, S. N. (2021). A Policy Review of Green Hydrogen Economy in Southern Africa. Sustainability, 13(23), 13240. https://doi.org/10.3390/su132313240

IRENA (2022). "The geopolitics of energy transformation: the hydrogen factor," Abu Dhabi. Retrieved from: <https://www.irena.org//media/Files/IRENA/Agency/Publication/2022/Jan/IRENA_Geopolitics_Hydrogen_2022.pdf >

Lenivova, V., 2022. Potential development of renewable hydrogen imports to European markets until 2030. Oxford Institute for Energy Studies. Retrieved from: <https://a9w7k6q9.stackpathcdn.com/wpcms/wp-content/uploads/2022/03/Potential-development-of-renewable-hydrogen-imports-to-European-markets-until-2030-ET08.pdf>

Mukelabai, M. D., Wijayantha, K., Blanchard, R. E. (2022). Hydrogen technology adoption analysis in Africa using a Doughnut-PESTLE hydrogen model (DPHM). International Journal of Hydrogen Energy, 47(74), 31521-31540. https://doi.org/10.1016/j.ijhydene.2022.07.07

Mutezo, G., Mulopo, J., 2021. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. G. Renew. Sustain. Energy Rev. 137, 110609 https://doi.org/10.1016/j.rser.2020.110609.

Song, J., Sun, Y., Jin, L., 2017. PESTEL analysis of the development of the waste-to-energy incineration industry in China. Renew Sustain Energy Rev, 80:276e89. https://doi.org/10.1016/j.rser.2017.05.066

The Global Economy, 2022. Business and economic indicators for 200 countries. <https://www.theglobaleconomy.com/indicators_list.php>

The World Bank, 2022. Indicators 2022. Retrieved from: <https://data.worldbank.org/indicator>.

Thomas, PJM, Sandwell, P., Williamson, SJ., Harper, PW. (2021). A PESTLE analysis of solar home systems in refugee camps in Rwanda. Renew Sustain Energy Rev, 143:110872. https://doi.org/10.1016/j.rser.2021.110872.

Van der Zwaan, B., Lamboo, S., Dalla Longa, F. (2021). Timmermans' dream: an electricity and hydrogen partnership between Europe and North Africa. Energy Pol 159:112613.

Wesseh Jr., P.K., Lin, B., 2016. Can African countries efficiently build their economies on renewable energy? Renew. Sustain. Energy Rev. 54, 161–173.

World Economic Forum, 2022. How Africa could become a global hydrogen powerhouse. Retrieved from: <https://www.weforum.org/agenda/2022/07/africa-hydrogen-iea/>

Yohannes, B., Diedou, A. (2022). Green hydrogen: A viable option for transforming Africa's energy sector. Africa Renewal. Retrieved from: <https://www.un.org/africarenewal/magazine/july-2022/green-hydrogen-viable-option-transforming-africas-energy-sector>

Involving African Local economy and society in Green Hydrogen Value Chain

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Abstract
Green hydrogen is a critical component of the shift towards a low-carbon energy system. As the global community increases its efforts towards decarbonization, the demand for green hydrogen is expected to surge. This study aims to investigate the potential for involving African local economies and societies in the green hydrogen value chain using a mixed-method approach that integrates qualitative and quantitative methods. The study examines five African countries, namely Nigeria, South Africa, Egypt, Ghana, and Kenya, with 220 participants selected from these countries, 44 from each. The research findings reveal several approaches that could be employed to involve the local population in the green hydrogen value chain, such as education and training programs, partnerships with local suppliers, and the establishment of local cooperatives. Nevertheless, various challenges must be tackled to facilitate their participation, including safety concerns, regulatory frameworks, financial incentives, and effective communication and public engagement strategies. Moreover, economic growth, improved energy security and access, carbon emissions reduction, environmental benefits, and enhanced social and community development are significant factors that influence African participation in the hydrogen value chain. The involvement of local communities in the green hydrogen value chain will not only promote the adoption of green hydrogen but also ensure equitable distribution of benefits among the population, reducing inequality and promoting social development. This study provides context-specific research to determine the most effective approaches to involving the local population in the green hydrogen value chain in different African countries and how this can impact social and environmental sustainability. It identifies the need for policymakers and industry stakeholders to develop sustainable and equitable green hydrogen value chains in African countries. The findings highlight the importance of international cooperation and partnerships, investment in research and development, regulatory frameworks and policies, and public education and outreach efforts in promoting the adoption of green hydrogen

Keywords: green hydrogen, local economies, local societies, Africa, social sustainability, environmental sustainability, equitable value chains, community involvement.

1.0 Introduction

To defeat energy poverty, encourage vigorous development, and increase sustainability, Africa desperately needs a clean energy revolution. Clean energy may empower women and children to lead more productive lives and can generate sustainable economic growth. It can also enhance human health and well-being. Access to clean energy would increase human security and foster resilience in states and communities in addition to providing immediate economic and social benefits, which will help reduce the likelihood of widespread migration throughout the African continent (Rigaud et al., 2018). The ability of a nation to generate renewable hydrogen depends on a variety of technical, socioeconomic, and environmental considerations, including the availability of land, freshwater, and RE resources. Africa has a large pool of human resources and a young, expanding population that is looking for employment. This shows great potential for an electric economy powered by hydrogen.

Africa's rich and varied RE potential offers possibilities for producing affordable green hydrogen. Additionally, in theory, Africa's large landmass might support the growth of RE initiatives like wind and solar for the production of environmentally friendly hydrogen. Land use and tenure rights are frequently ill-defined in Africa, since it is a strongly contested resource. Similar to this, Africa has a large supply of water that might be utilized for electrolysis, including lakes, rivers with catchment areas, and water basins. These resources will, however, become scarcer and more susceptible as temperatures rise because of their immense value to nearby populations, culture, and wildlife. Africa as a whole is currently home to many nations creating their own hydrogen policies. This development is being pioneered by South Africa and Morocco, and many countries are anticipated to follow. For instance, South Africa has created its National Hydrogen Strategy, which fosters and directs innovation along the fuel cell and hydrogen value chain, particularly in the platinum group metals sector, which the country is richly endowed with.

The green hydrogen economy, which uses green hydrogen as a synthetic fuel and energy source, has attracted a lot of attention in recent years. As seen in nations with fully developed hydrogen infrastructures, including Japan and Australia, green hydrogen will play an important role in the future of the transportation and industrial sectors (Jensterle et al., 2019). To our knowledge, no country in Africa is currently engaged in the production or use of green hydrogen, despite the continent having a large amount of potential. However, it has been noted that some sections of Africa are paying attention to the construction of green hydrogen infrastructure. It is possible for many African nations to create and transport green hydrogen due to their abundance of natural resources, such as wind, sun, and long coastlines (Custers and Matthysen, 2009).

Numerous regions of Africa have an abundance of energy resources, making the continent a potential site for the production and export of climate-friendly hydrogen, which would be powered by either renewable electricity (green hydrogen) or natural gas combined with carbon capture and storage technologies (blue hydrogen). Blue hydrogen is created by splitting natural gas into hydrogen and CO2, after which the CO2 must be recovered and stored. Green hydrogen is created by electrolyzing water molecules to separate them into their component parts using renewable electricity. Decentralized solar energy fueled by green hydrogen is one of the available solutions for generating electricity. However, policies and financing need to advance significantly in terms of funding and domestic capability if they are to be implemented at the level required for Africa to have universal access to electricity. The groundwork for more efficient public investment and to encourage private investment must be laid through domestic leadership, policy reforms, and capacity. Massive political efforts from both local and international actors will be necessary to raise the necessary funding and scale up domestic capabilities to manage these changes. To redirect existing public and private resources into new technologies and new markets, better planning and coordination with the local African economy and society in the green hydrogen value chain would be necessary.

2.0 Literature

2.1 Hydrogen Production

There are currently efforts underway in the African Development Community to build a green hydrogen economy. Positively, there is a resurgence of interest, particularly in Ghana, Morocco, Namibia and South Africa. There are many ways to create green hydrogen, but according to some authors, electrolysis of water is the most responsible method (Wang, Lu, and Zhong, 2021). Water electrolysis fueled by renewable energy is thus the preferred technique of producing clean, or green, hydrogen, taking into account all factors. Since it emits less carbon dioxide and it is therefore considered "green," producing hydrogen from renewable energy sources is preferred (Noussan et al., 2021). Green hydrogen may be used to power everything from tiny to large industrial uses as well as heavy-duty vehicles using fuel cells or hydrogen engines. Renewable energy sources can currently produce hydrogen that is both economically competitive and technically feasible. The declining cost of renewable energy and the difficulties in integrating renewable electricity into systems are driving the increased interest in this supply alternative.

In addition, grey hydrogen and blue hydrogen can be produced from non-renewable energy sources including fossil fuel and natural gas. These two methods are not thought to be environmentally friendly, particularly the grey method, which releases carbon dioxide into the atmosphere, as opposed to the blue hydrogen production, which captures carbon dioxide but also increases the cost of the process (Atilhan et al., 2021; Navas-Anguita et al., 2021).

Water electrolysis, in which water is split into hydrogen and oxygen using electricity, is the main method used to produce hydrogen from renewable sources. Anode and cathode electrodes are typically dipped in water and separated by a semipermeable separator in water electrolyzers. The electrodes are connected to a power source by an external electrical circuit. The electrolyzer receives water, which is then divided into hydrogen and oxygen by an electrical current. H2 is produced through a reduction at the cathode, and O2 is created by an oxidation at the anode. These two processes, which are known as the oxygen evolution reaction (OER) and the hydrogen evolution reaction (HER), respectively, take place in acidic media. The ultimate products, hydrogen and oxygen, have the extra advantage of not releasing carbon or other GHGs. By adsorbing reactants on their surface to create intermediates that facilitate charge transfer in the electrolyzer, electrocatalysts, which are typically platinum group metals, are required to lower the overpotential of the electrochemical processes. To create H2 from water, these chemical principles can be used in a variety of electrolyzer designs. Alkaline electrolyzers (AEs), proton exchange membrane electrolyzers (PEMEs), and solid oxide electrolyzers (SOEs) are the three main technologies of interest for industrial applications.

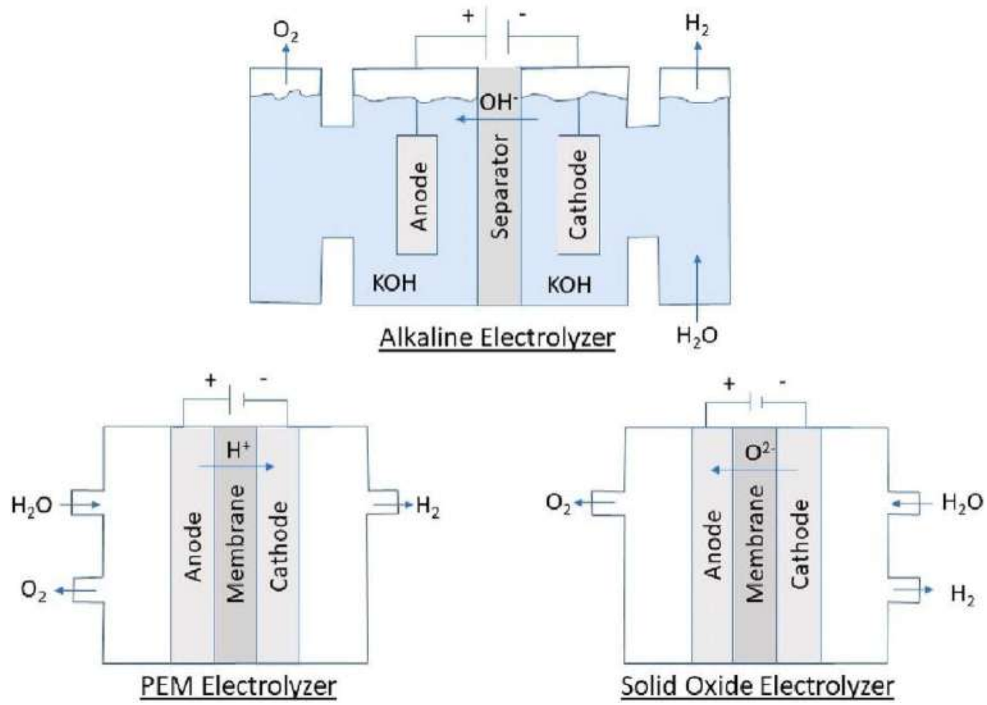

Figure 1. Electrolyzer configurations of interest for application.

Due to the development of new materials, the price of electrolysis components has been decreasing recently. The price of renewable energy must be taken into serious consideration. Thus, a high sun irradiation, a good wind capacity factor, and hydropower are advantageous for creating green hydrogen more affordably. Due to its abundant renewable energy source, many developers are drawn to Africa as a possible center for the manufacturing of green hydrogen. Increased usage of renewable energy sources, especially variable renewables, in the power sector presents a chance to electrolyze excess renewable electricity to create green hydrogen. The region could profit from an early adoption of hydrogen for numerous applications across end-use industries in addition to meeting the worldwide need for green hydrogen.

2.2 Empirical Review

Despite the enormous and expanding body of research on the interaction between hydrogen and power systems, in this article we analyzed a number of papers that were directly relevant to our work. Ren et al. (2020) summarized China's transition to a hydrogen economy. Despite significant advancements, there were still a number of obstacles standing in the way of China establishing a hydrogen economy, including addressing the high costs associated with providing hydrogen infrastructure. Ren et al. specifically concluded that hydrogen will not be an exclusive energy carrier but will complement and compete with electricity and biofuels in the future energy system. They also highlighted hydrogen technologies as facilitators of large-scale development of renewable energy and decarbonization within the economy. A more thorough literature assessment of the motivations and challenges for a hydrogen economy was conducted by Maggio et al. (2019). Positive influences on the development of a hydrogen economy included the need for increased energy storage and electrical grid balancing, as well as policy and regulatory frameworks aimed at lowering greenhouse gas emissions. However, the interaction with the power system, and more notably electricity costs, were recognized as significant elements determining the commercial sustainability of hydrogen electrolyzers. The high cost of hydrogen and fuel cell technologies were among the challenges facing hydrogen development.

Maggio et al. (2019) examined how the markets for fuels might be impacted by the production of hydrogen from renewable energy sources. According to their research, electrolysis-based hydrogen production will have a large economic impact, notably in the field of transportation. This will result in the development of new supply chains and markets, which will alter the properties of the energy market. Hanley et al. (2018) reviewed the various integrated energy system models for low-carbon hydrogen production. Their goal was to pinpoint the political contexts and elements that promoted hydrogen above other low-carbon technologies. Along with high renewable electricity scenarios and higher electrification, they found that bioenergy might act as a driver and rival for hydrogen energy. However, it was noted that the main rival in the passenger vehicle market was electric automobiles.

Additionally, a succinct summary of hydrogen as an energy carrier was provided by Abe et al. (2019). The study highlighted hydrogen storage as a barrier to the growth of hydrogen and offered some suggestions for its development. Various hydrogen generating technologies were also examined by Hosseini and Wahid (2016). According to their research, the most significant obstacles to the commercialization of solar-based hydrogen production are the high cost of photovoltaic cells and their low efficiency. The economic, technological, and environmental elements of hydrogen generation were also examined by El-Emam and Ozcan (2019). They noticed that geothermal and nuclear energy were the best sources for producing hydrogen at a low cost due to their reduced cost of power.

3.0 METHODOLOGY:

3.1 Study Design

This study is a mixed-methods research that utilized both quantitative and qualitative data collection and analysis methods to examine the involvement of African local economies and societies in the green hydrogen value chain (Creswell, 2014). The study was conducted between 1st to 20th April 2023, and it involved a survey of five African countries: Nigeria, South Africa, Egypt, Ghana, and Kenya. The study followed a sequential exploratory design, where the quantitative data was collected first, followed by qualitative data collection and analysis.

3.2 Sampling:

The sampling method for this study was purposive sampling, where the participants were selected based on their knowledge and experience in the green hydrogen industry (Palinkas et al., 2015). The participants included government officials, private sector actors, and civil society organizations. A total of 220 participants were sampled from the five African countries, with 44 participants from each country.

3.3 Data Collection:

The study utilized both primary and secondary sources of data. The primary sources of data were collected through an online survey on SurveyHeart.com (Kvale & Brinkmann, 2009). The survey consisted of 25 questions, which were divided into four sections: demographics, awareness and perception of green hydrogen, involvement in the green hydrogen value chain, and factors influencing involvement in the green hydrogen value chain. The survey was administered in English and French, the two official languages used in most African countries. The secondary sources of data were collected through a review of academic and non-academic literature on the green hydrogen value chain and related topics. The literature review was conducted using online databases such as Google Scholar, ScienceDirect, and JSTOR.

3.4 Data Analysis:

The quantitative data collected from the survey was analyzed using descriptive statistics such as frequencies and percentages. The qualitative data collected from the open-ended questions in the survey and the literature review was analyzed using thematic analysis. The themes that emerged from the analysis were used to develop the findings and conclusions (Braun & Clarke, 2006).

3.5 Ethical Considerations:

The study adhered to ethical principles such as informed consent, confidentiality, and anonymity. Participants were informed about the purpose of the study, and their consent was sought before the survey was administered. The data collected was kept confidential, and the participants' identities were anonymized.

3.6 Limitations:
Some of the limitations of this study included the small sample size and the limited generalizability of the findings to other African countries. Additionally, the study may have been affected by the biases of the researchers and participants.

4.0 RESULTS
4.1 Demographic Characteristics
Table 2: ***Gender***

Items	Frequency	Percentage
Male	148	67.3
Female	72	32.7
Total	220	100.0

Source: Field Data, 2023

The analysis of gender in the sample population can provide insights into the potential gendered impacts of the value chain. The Table 1 shows that out of the total sample of 220 individuals, 67.3% were male and 32.7% were female. This suggests that there may be a gender imbalance in the participation and benefits of the green hydrogen value chain. Furthermore, the gendered impacts of the value chain may extend beyond employment opportunities. For example, if the production of green hydrogen requires the displacement of local communities or the use of natural resources that are traditionally managed by women, this could have negative impacts on women's livelihoods and well-being.

Table 3: ***Occupation***

Levels	Freq	Percentage
Student	42	19.1 %
Entrepreneur	43	19.5 %
Government official	34	15.5 %
Academic researcher	59	26.8 %
Industry professional	42	19.1 %
Total	**220**	**100.0**

Source: Field Data, 2023

The majority of the participants are academic researchers, accounting for 26.8% of the total respondents, followed by entrepreneurs and industry professionals, each accounting for 19.5% and 19.1% of the total respondents, respectively. Government officials and students account for 15.5% and 19.1% of the total respondents, respectively. The high representation of academic researchers in the study is indicative of a strong interest in the topic of involving African local economy and society in the green hydrogen value chain. Their participation in the study suggests a willingness to engage with the topic and contribute to the body of knowledge on the subject. The presence of entrepreneurs and industry professionals also indicates a practical interest in the topic and a potential for practical application of the research findings. The presence of government officials suggests a possible interest in policy development related to the green hydrogen value chain in African countries. The high representation of students suggests an interest in the topic among younger generations, and their participation could provide valuable insights into the potential for future engagement with the green hydrogen value chain. Overall, the biodata of the respondents suggests a diverse group of participants with a range of experiences and perspectives, which could lead to a comprehensive understanding of the topic of involving African local economy and society in the green hydrogen value chain.

Table 4: Age of the Respondents

Levels	Counts	% of Total
20-30 years	14	6.4 %
31-40 years	73	33.5 %
41-50 years	76	34.9 %
51-60 years	55	25.2 %
Total	**220**	**100.0**

Source: Field Data, 2023

The majority of respondents fall within the age range of 31-50 years, with a combined total of 67.8%. This indicates that the study population is relatively mature and experienced in their respective fields, which could potentially impact their understanding and perception of the green hydrogen value chain. The relatively small percentage of respondents in the 20-30 age range suggests a need for further outreach and engagement with younger individuals to raise awareness and promote involvement in this emerging industry.

4.2 Approaches Used to Involve the Local Population in the Green Hydrogen Value Chain

*Table 5: **Familiarity with green hydrogen***

Items	Frequency	Percentage
Very familiar	123	55.9
Somewhat familiar	52	23.6
Not familiar at all	45	20.5
Total	**220**	**100.0**

Source: Field Data, 2023

Table 4 shows the respondents familiarity with green hydrogen, it can be observed that the majority of the respondents (55.9%) are very familiar with green hydrogen, while 23.6% are somewhat familiar and 20.5% are not familiar at all. This indicates that a significant proportion of the respondents have a good understanding of green hydrogen, which could be attributed to increasing awareness and interest in renewable energy sources. It is also possible that some of the respondents may have a professional or academic background related to energy or environmental science, which could have contributed to their familiarity with the subject matter. Overall, the high level of familiarity with green hydrogen among the respondents is a positive sign for the development and adoption of green hydrogen technologies in the African region. It suggests that there is a potential market for green hydrogen and that efforts to promote and raise awareness of this technology could be well-received by the public.

Table 6: Potential of green hydrogen in Africa

Responses	Frequency	Percentage
High potential	148	67.2
Moderate potential	58	26.4
Low potential	9	4.1
Don't know	5	2.3
Total	**220**	**100.0**

Source: Field Data, 2023

The analysis of the potential of green hydrogen in Africa is based on the responses of 220 participants. Out of these, 148 participants (67.2%) believed that green hydrogen has high potential in Africa, while 58 participants (26.4%) considered the potential to be moderate. Only 9 participants (4.1%) thought that the potential of green hydrogen in Africa is low, and 5 participants (2.3%) did not have any knowledge about the potential. This results indicates that a significant number of participants have a positive outlook towards the potential of green hydrogen in Africa. The majority of participants believed that green hydrogen has high potential in Africa, which suggests that they consider it to be a promising source of energy for the continent.

The moderate potential response indicates that some participants believe that while green hydrogen has potential, there may be limitations that need to be addressed. The small percentage of participants who thought that the potential of green hydrogen in Africa is low suggests that there is a need to educate people about the benefits and potential of green hydrogen. The fact that some participants did not have any knowledge about the potential of green hydrogen further emphasizes the need for awareness and education. Overall, the responses indicate that there is a general belief in the potential of green hydrogen in Africa, and this can be a positive factor in encouraging the development and adoption of green hydrogen technologies on the continent.

Table 7: Specific approaches for involving local economy and society in green hydrogen value chain

Approaches	Mean	St. Dev
Joint ventures with local businesses and industries	3.00	0.797
Investment in local infrastructure	5.00	0.00
Providing technical support and resources to local communities	3.63	1.14
Capacity building and training programs	3.45	1.14

Source: Field Data, 2023

Table 6 shows the approach with the highest mean score is "investment in local infrastructure" with a mean of 5.00 and a standard deviation of 0.00. This indicates that the respondents strongly agree that investing in local infrastructure is a specific approach for involving local economy and society in the green hydrogen value chain.

The approach with the second highest mean score is "providing technical support and resources to local communities" with a mean of 3.63 and a standard deviation of 1.14. This indicates that the respondents generally agree that providing technical support and resources to local communities is a specific approach for involving local economy and society in the green hydrogen value chain.

The approach with the lowest mean score is "joint ventures with local businesses and industries" with a mean of 3.00 and a standard deviation of 0.797. This indicates that the respondents are neutral about joint ventures with local businesses and industries as a specific approach for involving local economy and society in the green hydrogen value chain. Overall, the data suggests that investment in local infrastructure and providing technical support and resources to local communities are perceived as important specific approaches for involving local economy and society in the green hydrogen value chain.

Table 8: Role of Governments and Stakeholders in Involving Local Economy and Society in Green Hydrogen Value Chain

Role	**Mean**	**St. Dev**
Providing financial support and incentives	5.00	0.00
Setting regulatory frameworks and policies	3.79	1.31
Collaborating with local communities and businesses	4.23	1.09
Raising awareness and promoting the benefits of green hydrogen	3.31	0.774

Source: Field Data, 2023

The respondents' views on the role of governments and stakeholders in involving local economy and society in the green hydrogen value chain can be summarized as follows: Providing financial support and incentives is considered the most important role, with a mean score of 5.00 and zero standard deviation, indicating that all respondents agreed on its importance. Collaborating with local communities and businesses received a high mean score of 4.23 with a relatively low standard deviation of 1.09, indicating a relatively high level of agreement among respondents. Setting regulatory frameworks and policies received a moderate mean score of 3.79 with a relatively high standard deviation of 1.31, indicating some variability in respondents' views.

Raising awareness and promoting the benefits of green hydrogen received a relatively low mean score of 3.31 with a low standard deviation of 0.774, indicating a moderate level of agreement among respondents. The result suggests that the respondents consider financial support and collaboration with local communities and businesses as important roles for governments and stakeholders in involving local economy and society in the green hydrogen value chain. The role of setting regulatory frameworks and policies received a more mixed response, while raising awareness and promoting the benefits of green hydrogen was considered less important.

4.3 Impacts of Involving Local Economy and Society in Green Hydrogen Value Chain

Table 9: The effect of African involvement on the economy and society

Variables	Coefficient	Std. Err.	T	P>|t|
Constant	2.8705	.113	25.478	.001
Job creation and economic growth	.6572	.284	2.314	.022
Improved energy security and access	.8380	.313	2.679	.008
Reduction in carbon emissions and environmental benefits	1.7274	.275	6.276	.001
Enhanced social and community development	1.0173	.306	3.322	.001
R^2=	0.281			
Adj R-squared	0.225			
F	4.97			
PROB>F=	0.001			

Mean VIF	1.265
Durbin-watson	1.06

***Significance at 1% level. **Significance at 5% level *significance at 10% level

The R-squared value of 0.281 indicates that the independent variables in the model explain approximately 28.1% of the variation in the dependent variable. The Breusch-Pagan test (Chi2) of 4.77 with a p-value of 0.008 suggests that there may be heteroscedasticity in the model (Table 8). The mean VIF of 1.265 indicates that there is low multicollinearity between the independent variables. The Durbin-Watson statistic of 1.06 suggests that there is no significant autocorrelation in the model.

The coefficient for job creation and economic growth suggests that a one-unit increase in job creation and economic growth is associated with a 0.6572 unit increase in African involvement in the hydrogen value chain. This suggests that economic growth and job creation have a positive impact on African involvement in the hydrogen value chain.

The coefficient for improved energy security and access suggests that a one-unit increase in improved energy security and access is associated with a 0.8380 unit increase in African involvement in the hydrogen value chain. This suggests that access to affordable and reliable energy is an important factor for African involvement in the hydrogen value chain.

The coefficient for reduction in carbon emissions and environmental benefits suggests that a one-unit increase in reduction in carbon emissions and environmental benefits is associated with a 1.7274 unit increase in African involvement in the hydrogen value chain. This indicates that environmental sustainability is an important factor for African involvement in the hydrogen value chain.

The coefficient for enhanced social and community development suggests that a one-unit increase in enhanced social and community development is associated with a 1.0173 unit increase in African involvement in the hydrogen value chain. This suggests that the development of social and community infrastructure, such as healthcare and education, can contribute to increased African involvement in the hydrogen value chain.

Overall, these results suggest that a holistic approach that addresses economic, social, and environmental factors is important for promoting African involvement in the hydrogen value chain. By focusing on these factors, policymakers and stakeholders can create an enabling environment that encourages and supports African participation in the hydrogen value chain

4.4 Challenges and solutions for involving local economy and society in green hydrogen value chain

Table 10: One Sample T-Test on Challenges for Involving Local Economy and Society in Green Hydrogen

		Statistic	df	p
Lack of awareness and understanding of green hydrogen	Student's t	192.0	219	< .001
Limited access to resources and funding	Student's t	43.0	219	< .001
Resistance to change and adoption of new technologies	Student's t	57.7	219	< .001
Addressing social and environmental concerns	Student's t	63.5	219	< .001

Source: Field Data, 2023

The Table 9 shows the results of a one-sample t-test on the challenges and solutions for involving the local economy and society in the green hydrogen value chain (Table 14). The t-test was performed on four different challenges that were identified by the respondents: lack of awareness and understanding of green hydrogen, limited access to resources and funding, resistance to change and adoption of new technologies, and addressing social and environmental concerns. The results show that all four challenges were statistically significant ($p < .001$), indicating that they are significant obstacles for involving the local economy and society in the green hydrogen value chain. This suggests that there is a need for targeted interventions to address these challenges and facilitate the involvement of the local economy and society in the green hydrogen value chain.

4.5 Social Acceptance of Green hydrogen and economy

Table 11: Importance of enhancing social acceptance of green hydrogen

Response	Frequency	Percentage
Yes	198	90.0
No	20	9.1
Not sure	2	0.9
Total	**220**	**100.0**

According to the survey, 90% of the respondents believe that enhancing social acceptance of green hydrogen is important, 9.1% answered "No" and 0.9% were "Not sure". The high percentage of respondents (90%) who believe that enhancing social acceptance of green hydrogen is important highlights the critical role that public perception plays in the success of any technology (Table 10). Without public acceptance, it would be difficult to garner support from policymakers, investors, and other stakeholders necessary for the growth and adoption of green hydrogen. It is therefore essential to engage with communities, educate them about the benefits of green hydrogen, and address their concerns to build trust and increase acceptance. This underscores the need for effective communication and public engagement strategies in the development and deployment of green hydrogen technologies.

Table 12: The steps to Enhance Social Acceptance of Green Hydrogen in Africa

Steps	**Frequency**	**Percentages**
Increasing investment and funding for research and development	123	55.9
Promoting awareness and education on green hydrogen	97	44.1
Developing regulatory frameworks and policies to support adoption	102	46.4
Engaging with local communities and stakeholders	79	35.9
Encouraging international cooperation and partnerships	153	69.5
Offering financial incentives for the use of green hydrogen	36	0.16
Addressing safety concerns through regulation and certification	65	29.5

Multiple responses were allowed
Source: Field Data, 2023

The Table 11 presents the additional steps for promoting the adoption of green hydrogen in Africa and globally as perceived by the respondents. The most commonly cited step was encouraging international cooperation and partnerships, with 69.5% of respondents indicating its importance. The second most frequently mentioned step was increasing investment and funding for research and development, which was mentioned by 55.9% of respondents. Developing regulatory frameworks and policies to support adoption was mentioned by 46.4% of respondents, while promoting awareness and education on green hydrogen was mentioned by 44.1% of respondents. About 20.5% of respondents provided other unspecified steps. Also, engaging with local communities and stakeholders (35.9%) are effective ways to enhance social acceptance of green hydrogen. Respondents also believe that addressing safety concerns through regulation and certification (29.5%) is an important factor to consider. Interestingly, only a small percentage of respondents (0.16%) believe that offering financial incentives for the use of green hydrogen is an effective way to enhance social acceptance.

The results suggest that international cooperation and partnerships play a crucial role in promoting the adoption of green hydrogen, followed by investment and funding for research and development. Addressing safety concerns through regulation and certification is also important, but financial incentives may not be as effective in promoting social acceptance. The findings also highlight the importance of regulatory frameworks and policies in supporting the adoption of green hydrogen. Promoting awareness and education on green hydrogen was also mentioned as an important step, indicating the need for public education and outreach efforts.

Table 13: Effect of Social Acceptance of Green hydrogen and economy

Variables	Coefficient	Std. Err.	T	P>|t|
Constant	1.7454	0.6907	2.527	.012
Job creation	.4144	.0874	4.742	.001
Increased investment in green hydrogen infrastructure	.5433	.0841	6.462	.001
Reduced energy costs	0.1876	.0875	2.144	.033
Increased innovation and competitiveness	0.0283	.0841	0.337	.737
R^2=	0.242			
Adj R-squared	0.228			
F	17.1			
PROB>F=	0.001			
Breusch-Pagan test (Chi2)	4.33			
Prob>Chi2	0.001			
Mean VIF	1.05			
Durbin-watson	1.04			

***Significance at 1% level. **Significance at 5% level *significance at 10% level
Source: Field Data, 2023

The R-squared value of 0.242 indicates that the independent variables explain about 24.2% of the variation in the dependent variable. The adjusted R-squared value of 0.228 is slightly lower, which suggests that the model may be slightly overfit. The F-statistic of 17.1 with a probability value of 0.001 indicates that the model is statistically significant. The mean VIF value of 1.05 indicates that multicollinearity is not a concern in the model. The Durbin-Watson value of 1.04 suggests that there is no significant autocorrelation in the model residuals.

The coefficient of 0.4144 indicates that for every one-unit increase in job creation resulting from the use of green hydrogen, there is a corresponding increase of 0.4144 units in the perceived positive impact on the economy. The t-value of 4.742 indicates that this coefficient is statistically significant at the 0.001 level, meaning that there is a very low likelihood that this result occurred by chance.

The coefficient of 0.5433 suggests that for every one-unit increase in investment in green hydrogen infrastructure, there is a corresponding increase of 0.5433 units in the perceived positive impact on the economy. The t-value of 6.462 indicates that this coefficient is statistically significant at the 0.001 level, meaning that there is a very low likelihood that this result occurred by chance.

The coefficient of 0.1876 suggests that for every one-unit decrease in energy costs resulting from the use of green hydrogen, there is a corresponding increase of 0.1876 units in the perceived positive impact on the economy. The t-value of 2.144 indicates that this coefficient is statistically significant at the 0.033 level, meaning that there is a moderate likelihood that this result occurred by chance.

The coefficient of 0.0283 indicates that for every one-unit increase in innovation and competitiveness resulting from the use of green hydrogen, there is a corresponding increase of 0.0283 units in the perceived positive impact on the economy. However, the t-value of 0.337 suggests that this coefficient is not statistically significant at the 0.05 level, meaning that there is a high likelihood that this result occurred by chance.

Overall, the results suggest that job creation and increased investment in green hydrogen infrastructure have a statistically significant positive impact on the perceived positive impact of green hydrogen on the economy, while reduced energy costs have a moderately significant positive impact. However, increased innovation and competitiveness does not appear to have a significant impact on the perceived positive impact on the economy.

The Main Obstacles to Enhancing Social Acceptance of Green Hydrogen

Table 14:

One Sample T-Test on The Main Obstacles to Enhancing Social Acceptance of Green Hydrogen

			Statistic	**df**	**p**
a. Lack of public awareness about green hydrogen	a.. Lack of public awareness about green hydrogen	Student's t	33.1	219	< .001
b. Concerns about safety and reliability	b. Concerns about safety and reliability	Student's t	54.0	219	< .001
c. Resistance to change	c. Resistance to change	Student's t	55.7	219	< .001
d. Lack of political support	d. Lack of political support	Student's t	60.1	219	< .001

This table shows the results of One Sample T-Tests conducted on four variables related to green hydrogen. Each variable has a t-value, degrees of freedom (df), and p-value listed. The null hypothesis in each test is that the mean of the population for that variable is equal to zero. The alternative hypothesis is that the mean of the population is greater than zero.

For each variable, the t-value is much greater than 1.96, indicating that the sample mean is significantly different from zero at the 5% level of significance. The p-values for each variable are less than 0.001, indicating that the results are highly significant. Therefore, we can reject the null hypothesis and conclude that there is evidence to support the alternative hypothesis that the population means for each variable are greater than zero. In other words, there is strong evidence that lack of public awareness about green hydrogen, concerns about safety and reliability, resistance to change, and lack of political support are all significant barriers to the adoption of green hydrogen. This highlights the importance of addressing these barriers in order to promote the use of green hydrogen as a clean energy source.

Conclusions and Recommendations

The study shows that involving local businesses and industries in the green hydrogen value chain is a high priority for promoting the adoption of green hydrogen in Africa. Building local infrastructure and capacity, as well as engaging and empowering local communities, are also important factors for promoting involvement in the green hydrogen value chain. Additionally, developing policy frameworks and regulations can provide a clear framework for investment and development in the green hydrogen sector. The study also found that economic growth, improved energy security and access, environmental sustainability, and enhanced social and community development are all important factors for promoting African involvement in the hydrogen value chain. Overall, a holistic approach that addresses economic, social, and environmental factors is crucial for promoting African involvement in the hydrogen value chain. By focusing on these factors, policymakers and stakeholders can create an enabling environment that encourages and supports African participation in the hydrogen value chain.

Based on the results, here are some policy recommendations for promoting the involvement of the local population in the green hydrogen value chain in Africa:

Collaboration with Local Businesses and Industries: Governments and stakeholders should focus on developing partnerships with local businesses and industries to involve them in the green hydrogen value chain. This can be done through initiatives such as joint ventures, investment in local infrastructure, and providing technical support and resources.

Government Policies and Incentives: Governments should provide policy frameworks and incentives that encourage investment and development in the green hydrogen sector. This can include tax incentives, subsidies, and regulations that promote the adoption of green hydrogen technologies.

Education and Training Programs: Governments and stakeholders should invest in education and training programs to raise awareness and build capacity for the adoption and development of green hydrogen technologies. This can include initiatives such as vocational training programs, workshops, and seminars.

Local Community Engagement and Awareness: Efforts should be made to engage and empower local communities to raise awareness of the benefits of green hydrogen technologies and involve them in decision-making processes. This can be done through community outreach programs, public consultations, and stakeholder engagement initiatives.

Addressing Economic, Social, and Environmental Factors: Policymakers and stakeholders should take a holistic approach to promoting African involvement in the hydrogen value chain by addressing economic, social, and environmental factors. This can include initiatives that support job creation and economic growth, enhance social and community development, improve energy security and access, and reduce carbon emissions and promote environmental sustainability.

By implementing these policy recommendations, governments and stakeholders can create an enabling environment that encourages and supports African participation in the hydrogen value chain, ultimately contributing to the development of a more sustainable and prosperous future for the region.

References

Abe, J.O., Popoola, A.P.I., Ajenifuja, E., & Popoola, O.M. (2019). Hydrogen Energy, Economy and Storage: Review and Recommendation. International Journal of Hydrogen Energy, 44, 15072-15086.

Atilhan, S., Aktaş, B., Kılıç, M., & Karakaya, E. (2021). Green hydrogen as an alternative fuel for the shipping industry. Current Opinion in Chemical Engineering, 31, 100668.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77-101.

Creswell, J. W. (2014). Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications.

Custers, R., & Matthysen, K. (2009). Africa's natural resources in a global context.

El-Emam, R.S., & Özcan, H. (2019). Comprehensive review on the techno-economics of sustainable large-scale clean hydrogen production. Journal of Cleaner Production, 220, 593-609.

Hanley, E.S., Deane, J., & Gallachóir, B.Ó. (2018). The role of hydrogen in low carbon energy futures. A review of existing perspectives. Renewable and Sustainable Energy Reviews, 82, 3027-3045.

Hosseini, S.E., & Wahid, M.A. (2016). Hydrogen production from renewable and sustainable energy resources: Promising green energy carrier for clean development. Renewable and Sustainable Energy Reviews, 57, 850-866.

Jensterle, M., Pavič, P., & Kavčič, F. (2019). The role of clean hydrogen in the future energy systems of Japan and Germany, Berlin.

Kvale, S., & Brinkmann, S. (2009). Interviews: Learning the craft of qualitative research interviewing. Sage publications.

Maggio, G., Nicita, A., & Squadrito, G. (2019). How the hydrogen production from RES could change energy and fuel markets: A review of recent literature. International Journal of Hydrogen Energy, 44, 11371-11384.

Navas-Anguita, Z., Gómez-Navarro, M.V., Martínez-López, L.M., Moreno-Castilla, C., & García-García, A. (2021). Revisiting the role of steam methane reforming with CO2 capture and storage for long-term hydrogen production. Science of The Total Environment, 771, 145432.

Noussan, M., Belayachi, N., & Mohamed, A. (2021). The role of green and blue hydrogen in the energy transition, a technological and geopolitical perspective. Sustainability (Switzerland), 13(298), 1-26.

Palinkas, L.A., Horwitz, S.M., Green, C.A., Wisdom, J.P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. Administration and Policy in Mental Health and Mental Health Services Research, 42(5), 533-544.

Rigaud, K. K., A. de Sherbinin, B. Jones, J. Bergmann, V. Clement, K. Ober, J. Schewe, S. Adamo, B. McCusker, S. Heuser, A. Midgley (2018f), Groundswell: Preparing for Internal. Climate Migration. World Bank, Washington DC