Namibia Green Hydrogen Association

Frequently Asked Questions

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GREEN HYDROGEN FAQs

Part A – Understanding climate change, the energy transition and the role of green hydrogen

Section 1 – What is climate change and how do we combat its effects?

What is climate change, is it real and is it being caused by humans?

According to the United Nations, climate change is the long-term shift in global temperatures and weather patterns, mainly driven by human activities since the 1800s, particularly the burning of fossil fuels like coal, oil, and gas. This process releases greenhouse gases—such as carbon dioxide and methane—that trap heat in the Earth's atmosphere, leading to rising temperatures. Key sources of these emissions include transportation, industry, energy production, agriculture, and deforestation[1].

In November 1988, the United Nations established the Intergovernmental Panel on Climate Change (IPCC)[2] to summarize the state of scientific research on climate change for political decision-makers with the aim of providing a basis for science-based decisions. Through this extensive research work, key evidence of climate change was found:

- Global warming is man-made
    - The IPCC states that humans are the main driver of climate change. In particular, the burning of fossil fuels (coal, oil, gas), land use changes and industrial activities release a considerable amount of greenhouse gases, especially carbon dioxide (CO_2), which leads to global warming.
- Temperature rise
    - The global average temperature has already risen by around 1.2°C since the pre-industrial age. If current emission trends continue, warming could reach over 3°C by the end of the century, which would lead to significant climatic changes.
- More frequent and more intense extreme weather events
    - Climate change is already leading to more frequent and more intense extreme weather events such as heatwaves, heavy rainfall, droughts and hurricanes. These will be exacerbated by the further rise in global temperatures.

[1] https://www.un.org/en/climatechange/what-is-climate-change
[2] https://www.ipcc.ch/

- Sea level rise
    - Sea levels are rising because of warming, as glaciers and polar ice melt and the oceans become warmer and expand. By the end of the century, sea levels could rise by up to 1 meter or more, which would have a serious impact on coastal regions and island states.
- Danger to ecosystems and biodiversity
    - Many ecosystems are threatened by climate change. Species are dying out or migrating to cooler regions. This affects both terrestrial and marine habitats, especially coral reefs and Arctic habitats.
- Threat to human society
    - Climate change also poses a serious threat to human societies. It jeopardizes food and water supplies, increases health risks (e.g. through heat stress) and leads to economic damage. Poor and vulnerable communities are particularly at risk.
- Urgency of climate protection measures
    - The IPCC emphasizes the urgency of reducing global emissions quickly and drastically in order to achieve the goal of limiting global warming to 1.5°C. Rapid and comprehensive measure are necessary to keep global warming below 1.5°C, including cutting global emissions in half by 2030 and reaching net-zero by 2050.

What are fossil fuels’ contribution to climate change?

About 90% of global CO_2 emissions, which make up the largest contribution to global warming, come from the use of fossil fuels for energy production, transportation, industry and heating[3].

Important aspects of the influence of fossil fuels:

- Carbon dioxide (CO_2):
    - CO_2 is the most significant greenhouse gas and is released in large quantities through the combustion of coal, oil and gas.
    - Around 75% of global greenhouse gas emissions come from the release of CO_2 from the combustion of fossil fuels alone.
- Methane (CH_4):
    - Fossil fuels also contribute to the release of methane, particularly through leaks during natural gas extraction and distribution.
    - Methane is a particularly potent greenhouse gas, although it is released in smaller quantities. However, it is a major contributor to global warming (methane is around 25 to 30 times more harmful as a greenhouse gas than CO_2 measured over a period of 100 years).
- Further emissions:
    - The extraction, transportation and processing of fossil fuels also cause indirect emissions.

[3] https://www.un.org/en/climatechange/science/causes-effects-climate-change#:~:text=Fossil%20fuels%20%E2%80%93%20coal%2C%20oil%20and,they%20trap%20the%20sun's%20heat

What is the Paris Agreement and what is its main objective?

The Paris Agreement[4] is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016.

Its overarching goal is to cap "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels." However, in recent years, world leaders have stressed the need to limit global warming to 1.5°C by the end of this century. That was after IPCC's warnings that crossing the 1.5°C threshold risks unleashing far more severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall.

Moreover, to limit global warming to 1.5°C, greenhouse gas emissions must peak before 2025 at the latest and decline 43% by 2030.

The Paris Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations together to combat climate change and adapt to its effects.

These objectives are to be achieved through national climate protection plans such as the Nationally Determined Contributions (NDCs), which the countries are required to update every five years and make more ambitious.

[4] https://unfccc.int/process-and-meetings/the-paris-agreement

Is the world really committed to achieving the objectives of the Paris Agreement?

196 out of 198 parties have adopted the Paris Agreement, which means that they are legally bound by its obligations. That is almost 100 percent of the world's population. The total CO_2 emissions of the parties to the Paris Agreement represents 98% of all global CO_2 emissions. The Paris Agreement is significant because it unites all nations in the fight against climate change and its adaptation efforts. [5] & [6] Imperatively, nations are gearing up for a 2050 net zero target by introducing policies and regulation that support innovation, research and investment in renewable technology.

We are witnessing how these policies and regulations are being localised to cities and regions[7], leading to advancement in renewable energy technology and environmental protection. The European Union recently passed the Renewable Energy Directive (RED III)[8] which focuses on mainstreaming renewable energy in the industry sector. The RED III is supported by policies such as the European Union carbon border adjustment mechanism (CBAM)[9] and emission trading systems (ETS)[10]. The CBAM will ensure that all products that enter the EU are certified and taxed according to their level of carbon intensity during their production. The ETS is a market tool to reduce greenhouse gas emissions by capping total emissions for certain sectors and issuing permits. Companies need permits to cover their emissions, incentivizing reductions or cleaner technologies. Those with lower emissions can sell extra permits, promoting overall emissions cuts to meet climate targets[11].

Japan has set aside USD 19 bn[12] to provide support for the adoption of low carbon hydrogen and lowering the cost of production through contracts of difference.

On August 16, 2022, President Biden signed the Inflation Reduction Act (IRA) into law. The Inflation Reduction Act in the USA (IRA)[13] aimed to encourage investment in the domestic energy production while promoting clean energy, amongst others. Unfortunately, due to the change in policy by President Trump, the newly elected party has suspended all funding disbursements under the Inflation Reduction Act (IRA).

China and India are investing heavily in renewable generation technologies and green hydrogen production.

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5 https://unfccc.int/process/the-paris-agreement/status-of-ratification
6 https://treaties.un.org/pages/viewdetails.aspx?src=treaty&mtdsg_no=xxvii-7-d&chapter=27&clang=_en
7 UNFCCC
8 https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en
9 https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en
10 https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en
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12 https://www.meti.go.jp/shingikai/enecho/shoene_shinene/suiso_seisaku/pdf/20230606_4.pdf
13 https://www.energy.gov/lpo/inflation-reduction-act-2022#:~:text=The%20President's%20Inflation%20Reduction%20Act,energy%20manufacturing%2C%20and%20putting%20the

How does the world decarbonise its energy systems?

There are four key measures to decarbonisation[14]:

- Improvements in energy efficiency.
- Replacing fossil fuels with CO_2-free renewable energies with direct electrification. Everything that can be directly electrified should be directly electrified, e.g. cars, heating systems, industrial processes.
- In areas that cannot be directly electrified (so called hard-to-abate or hard-to-decarbonise sectors or countries with insufficient renewable resources to decarbonize on their own), hydrogen and hydrogen derivatives produced from renewable energy are used (indirect electrification).
- In the end, residual emissions remain, mainly from agriculture (approx. 11% of total current emissions, see Figure 1)[15]. These emissions must be compensated for, e.g. through carbon capture and sequestration, policy and incentive to encourage farmers to adopt low-emission practices, etc.

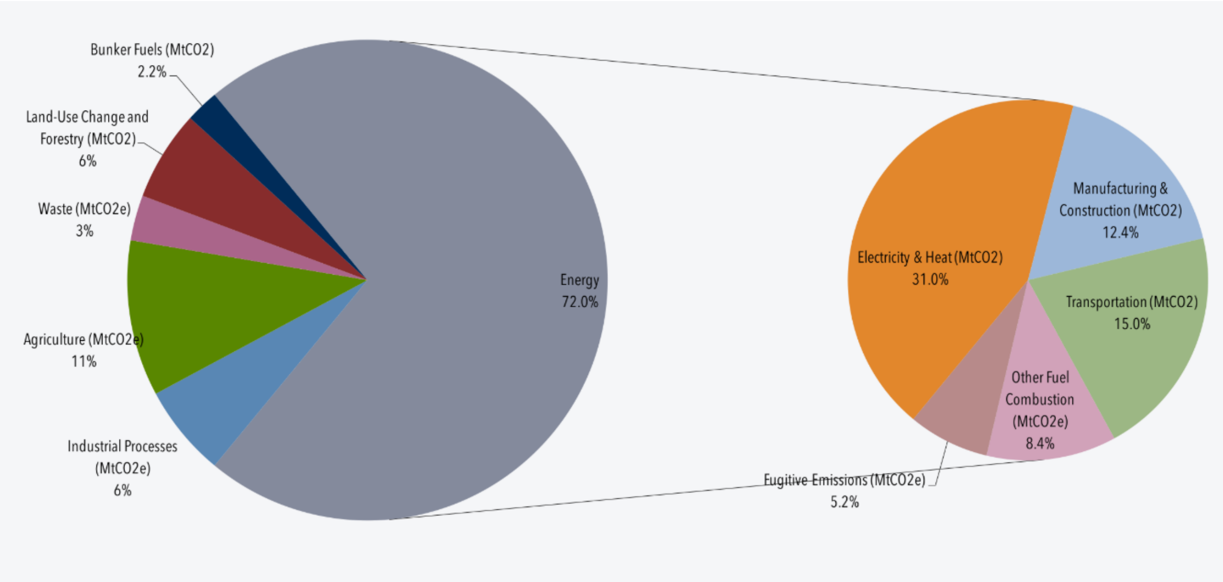

Figure 1: Globally, the primary sources of greenhouse gas emissions are electricity and heat (31%), agriculture (11%), transportation (15%), forestry (6%) and manufacturing (12%). Energy production of all types of accounts for 72 percent of all emissions[16].

[14] https://www.industrialdecarbonizationnetwork.com/leadership-strategy/articles/the-4-pathways-to-industrial-decarbonization

[15] https://www.c2es.org/content/international-emissions/#:~:text=Globally%2C%20the%20primary%20sources%20of,72%20percent%20of%20all%20emissions

[16] https://www.c2es.org/content/international-emissions/#:~:text=Globally%2C%20the%20primary%20sources%20of,72%20percent%20of%20all%20emissions

Section 2 – How is the world planning to decarbonise, where are we today and what does the future hold?

What would a net zero world look like in 2050 compared to today?

The 2024 IPCC assessment report[17] "assumes that the energy trinity challenges – sovereignty, security, and sustainability – are addressed in time and at the necessary pace and scale, driven by new technologies and global cooperation". The report calls for urgent action, building on policies like REPowerEU[18] and the Inflation Reduction Act[19]. Likewise, the IEA's report, *Net Zero by 2050: A Roadmap for the Global Energy Sector*[20], calls for these energy and climate policies to be strengthened and supported by a strong political will.

Equally, improved trade relationships will drive demand for technologies such as carbon capture utilisation and storage (CCUS), low or no--carbon hydrogen, and green ammonia. Therefore, governments, businesses, industries, and consumers should collaborate to create interconnected, electrified, and circular economies where resources are optimized.

By 2050, fossil fuels are projected to account for only 20% of the energy supply, down from 80% today, as solar, wind, nuclear, geothermal, and hydrogen drive rapid electrification. For this to happen, IPCC suggest that the world will need to invest an average of US$2.7 trillion annually between 2023 and 2050, with 79% of this investment going to renewable energy[21].

To help achieve the above targets, the world will need to produce and consume around 500 – 600 million tonnes per annum (MTPA) of low- or no-carbon hydrogen. This scenario is projected to be achieved with a carbon price averaging USD 163t/ CO_2[22]. Additionally, 90% of road transport is projected to be electrified through the sale of new electric vehicles (EVs)[23]. Figure shows 2050 projections by Woodmac through a net zero scenario.

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17 *Energy Transition Outlook: Net Zero 2050 Scenario*

18 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

19 https://www.energy.gov/lpo/inflation-reduction-act-2022#:~:text=The%20President's%20Inflation%20Reduction%20Act,energy%20manufacturing%2C%20and%20putting%20the

20 https://www.iea.org/reports/net-zero-by-2050

21 *Energy Transition Outlook: Net Zero 2050 Scenario*

22 https://www.woodmac.com/market-insights/topics/energy-transition-outlook/net-zero-by-2050/#:~:text=In%20our%20net%20zero,79%25%20of%20the%20overall%20investment.

23 https://www.woodmac.com/market-insights/topics/energy-transition-outlook/net-zero-by-2050/#:~:text=In%20our%20net%20zero,79%25%20of%20the%20overall%20investment.

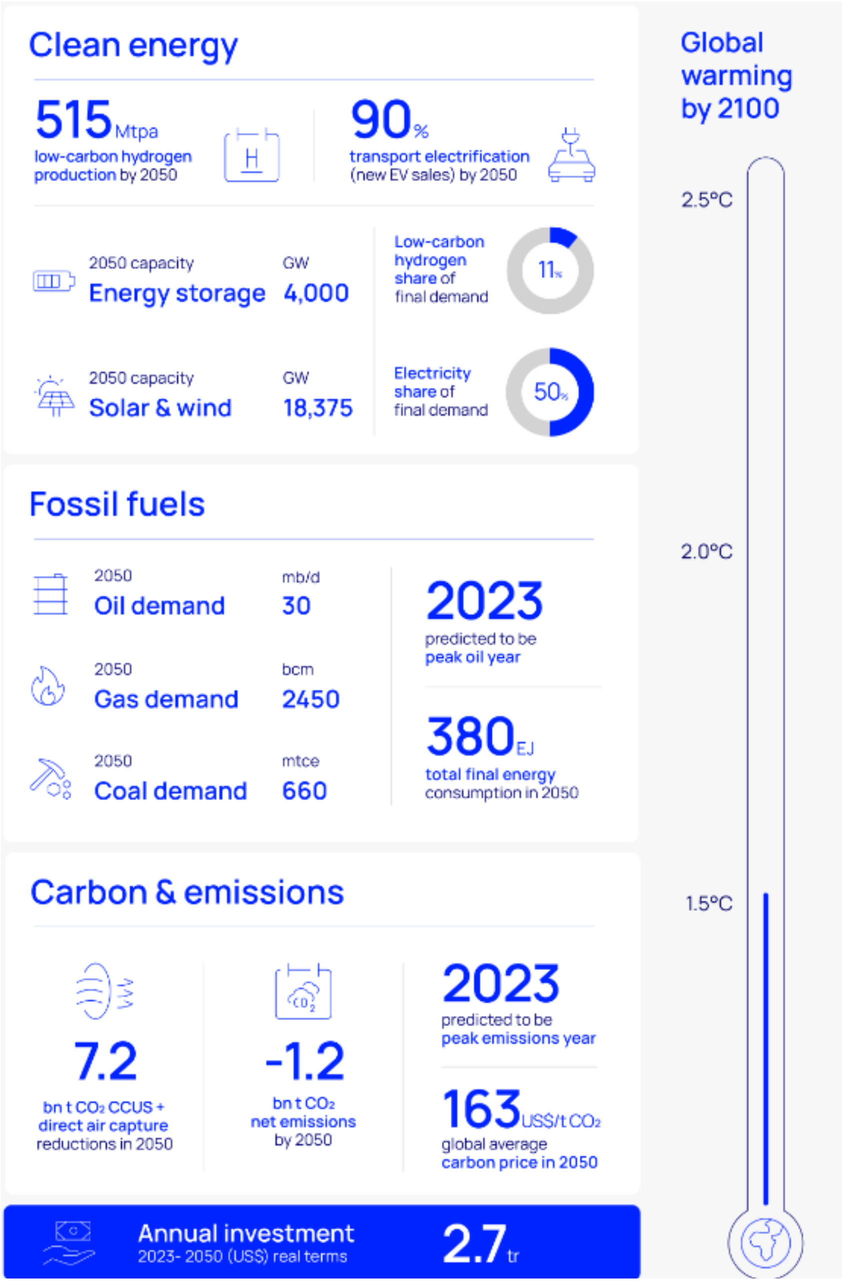


Figure 2: The 2050 net zero scenario shows that low carbon hydrogen will need to peak to over 500 million tons per annum (MTPA). And making up 11% of the energy mix[24]

While current commitments are acknowledged, they fall short of what's needed for net-zero pathways. Achieving net-zero emissions requires the immediate and large-scale deployment of all available clean and efficient energy technologies, alongside continued innovation. In the International Energy Agency (IEA)'s scenario, the global economy in 2030 would be 40% larger than today but would use 7% less energy.

[24] https://www.woodmac.com/market-insights/topics/energy-transition-outlook/net-zero-by-2050/#:~:text=In%20our%20net%20zero,79%25%20of%20the%20overall%20investment.

How are we doing in achieving the world's decarbonisation goals?

The IEA[25] reports that certain clean energy technologies, such as solar power, electric vehicles, and energy-efficient lighting, are progressing well towards meeting 2030 emissions reduction targets. However, several sectors, notably heavy industry and long-distance transport, are lagging due to incomplete technological development and slow deployment at scale.

Of the over 50 components tracked in the 2023 edition, 3 are evaluated as fully "on track" with the Net Zero by 2050 Scenario trajectory – solar PV, electric vehicles and lighting. Solar PV's annual growth in generation in 2022 of 26% is now aligned with the average compound annual growth rate needed from now to 2030 in the Net Zero Scenario.

Some noticeable progress in decarbonisation:

- Electrolyser – 165GW production expected by 2030, more than the actual expected production of 116GW
- International Maritime Organisation (IMO) targets up to 80% (Figure 2) reduction in greenhouse gas (GHG) emission by 2040[26]
- European Union's RED III, CBAM, ETS, USA IRA, Japanese and Korean hydrogen support programmes, etc., will support low carbon production and usage
- More than 50 countries have released their national hydrogen strategies
- Wind, solar, and battery prices have fallen significantly since 2010
- Electric vehicles sales grew by 55%, on track to 2030 Net Zero Scenario

Unfortunately, the overall progress is still not fast enough to achieve net-zero emissions by 2050, highlighting the need for stronger government action and increased international collaboration to accelerate the adoption of clean technologies.

[25] https://www.iea.org/reports/tracking-clean-energy-progress-2023
[26] https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx

How is the world progressing in the roll out of new renewables generation capacity?

The world has rapidly scaled the implementation of renewable energy generation technologies over the last 20 years, with wind and solar generation now being the cheapest form of adding new generation capacity, with around 65% of new capacity added in 2023 being in China[27]. Figure 3 illustrates global installed renewable energy capacity additions and total installed capacity at the end of 2023.

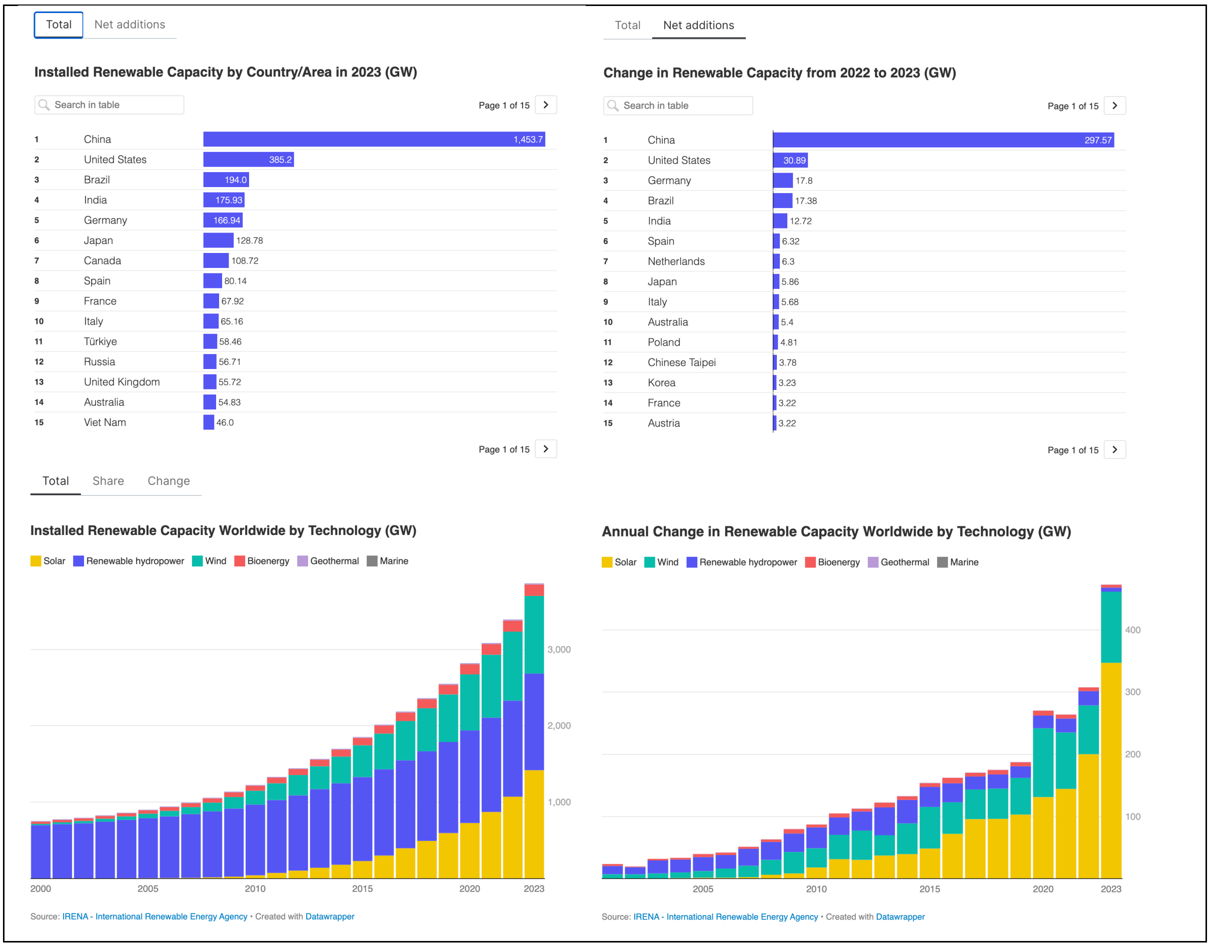


Figure 3: A combination of different graphs showing progress in the roll-out of renewable energy technology

Moreover, despite a rapid acceleration in recent years, clean electricity has not yet grown fast enough to meet rising demand, leaving space for fossil-fuelled power to continue expanding.

Global solar capacity is now 40-times larger than it was in 2010 and wind six times larger, the outlook notes, and a record 560 gigawatts (GW) of renewables were added in 2023.[28]

[27] https://qery.no/renewable-energy-capacity-tracker/
[28] https://www.carbonbrief.org/analysis-solar-surge-will-send-coal-power-tumbling-by-2030-iea-data-reveals/#:~:text=Along%20with%20a%20doubling%20of,2030%20and%2034%25%20by%202035

Yet growth in clean electricity supplies has still fallen short of rising demand, meaning coal power has climbed 23% since 2010 and gas by 36%, raising emissions in the sector by 20%. Renewables are only on track to expand 2.7-fold from 2022 to 2030 – short of the tripling target set at COP28 – but clean electricity will still outstrip rising demand, out to 2030 and beyond.

The IEA data shows that the amount of electricity generated from solar power alone is set to quadruple from 2023 levels by 2030 – and to climb more than nine-fold by 2050. This means that solar will overtake nuclear, hydro and wind in 2026, gas in 2031 – and then coal by 2033 – to become the world's largest source of electricity, as shown in Figure 4 below.

**Along with a doubling of wind generation and more modest gains for nuclear and hydro by 2030, clean electricity will push coal power into reverse, declining 13% by 2030 and 34% by 2035.

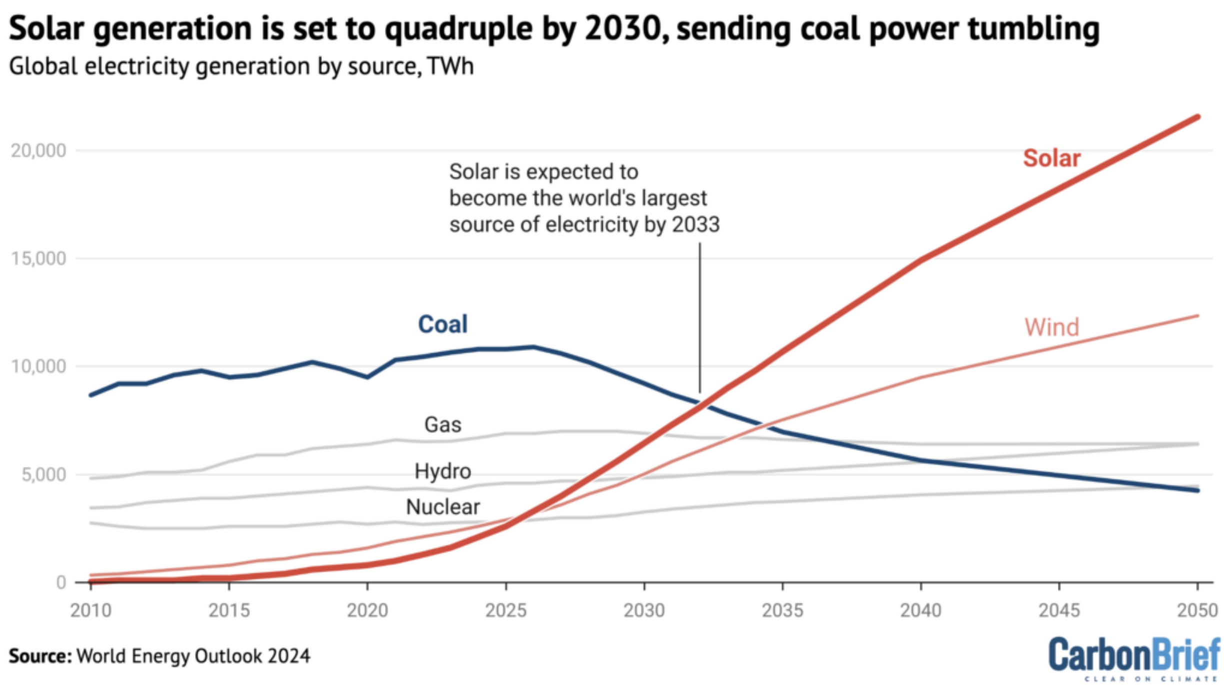


Figure 4: Global electricity generation by source, TWh, 2010-2050. Source: World Energy Outlook 2024.

China accounted for 60% of global renewable energy installations last year and is expected to contribute the same share of new capacity additions through 2030, according to the IEA. By the early 2030s, China's solar power generation alone is projected to surpass the current total electricity demand of the United States.

This year's IEA report highlights a significant upward revision in solar energy projections under existing policies. The agency now estimates that global solar capacity will exceed 16,000GW by 2050—a 30% increase from last year's forecast and nearly 11 times higher than its 2015 projection.

By 2023, the world had already installed 1,610GW of solar capacity, far surpassing the 1,405GW the IEA had initially predicted for 2050 under its 2015 World Energy Outlook—a forecast made before the Paris Agreement was adopted later that year.[29]

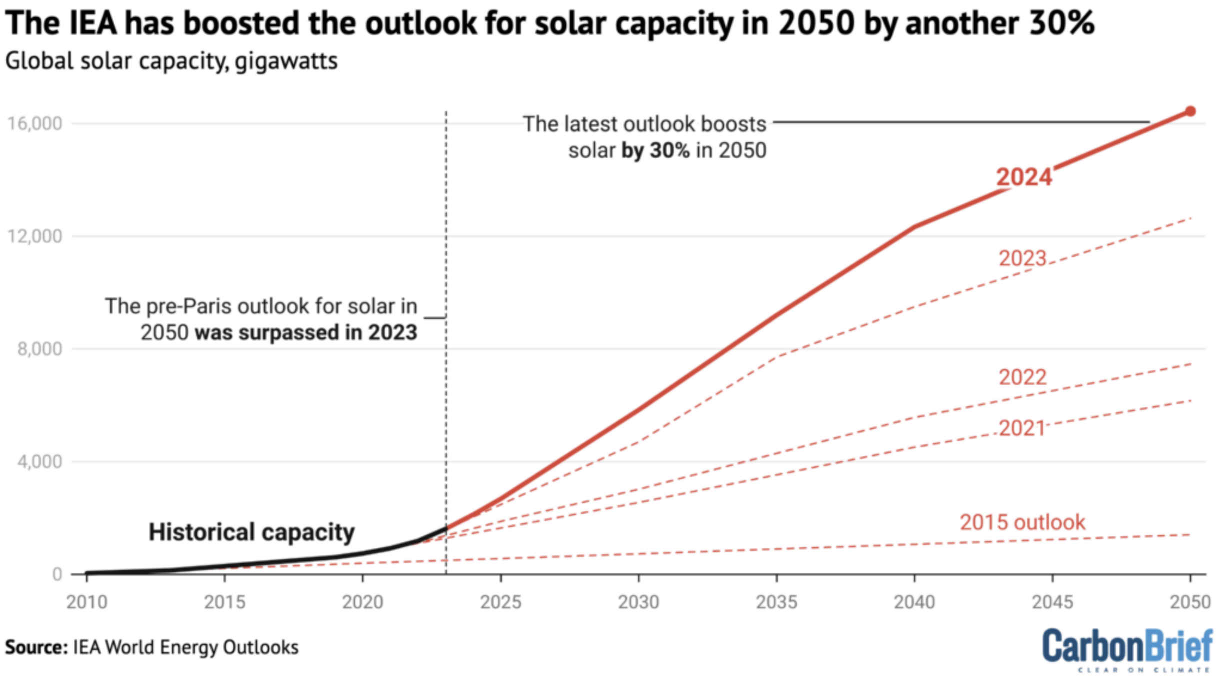


Figure 5: Past and expected future global solar capacity, gigawatts, 2010-2050, in IEA world energy outlooks from 2015 ("new policies scenario"), 2021, 2022, 2023 and 2024 ("stated policies scenario") [30].

What are the projections for future scale up of green technologies?

Global green technology investments are projected to increase 6-fold between 2022 and 2030, up from US$1 trillion in 2022 to US$5.7 trillion in 2030 per annum[31]. This is in line with the Organisation for Economic Co-operation and Development's (OECD) estimates that an average annual investment of US$500 billion – US$2.5 trillion per annum is required in developing countries alone. To help achieve these targets, developed countries provided and mobilised US$116 billion in climate finance for developing countries in 2022 alone, exceeding commitments by 15%[32].

[29] https://www.carbonbrief.org/analysis-solar-surge-will-send-coal-power-tumbling-by-2030-iea-data-reveals/#:~:text=Along%20with%20a%20doubling%20of,2030%20and%2034%25%20by%202035

[30] https://www.carbonbrief.org/analysis-solar-surge-will-send-coal-power-tumbling-by-2030-iea-data-reveals/#:~:text=Along%20with%20a%20doubling%20of,2030%20and%2034%25%20by%202035

[31] https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/accelerated-investment-renewables-and-energy-efficiency-key-15degc-target-2024-01-12_en#:~:text=Global%20annual%20investment%20in%20clean,largest%20investment%20in%20clean%20technologies

[32] OECD COP29 Virtual Pavilion

Moreover, the global market value for the 6-key mass-manufactured clean energy technologies – solar PV, wind, electric vehicles (EVs), batteries, electrolysers and heat pumps – grew nearly fourfold between 2015 and 2023, when it surpassed USD 700 billion, Under today's policy settings, the market for these clean technologies is set to nearly triple by 2035 to more than USD 2 trillion.[33]

- Global investment in clean technology manufacturing rose by 50% in 2023, reaching USD 235 billion. This increase is equal to nearly 10% of the growth in investment across the entire world economy. Four-fifths of the clean technology manufacturing investment in 2023 went to solar PV and battery manufacturing, with EV plants accounting for a further 15%.

- Clean technology supply chains heavily rely on global trade and will continue to do so in the future. The total trade value of clean technologies is approximately USD 200 billion, accounting for nearly 30% of their global market value.[34]

- China is currently the cheapest location for manufacturing the key clean energy technologies. The door of the new energy economy is still open to emerging markets. Emerging and developing economies in Latin America, Africa and Southeast Asia currently only account for less than 5% of the value generated from producing clean technologies today.[35]

[33] https://www.linkedin.com/feed/update/urn:li:ugcPost:7279902878268350464/?commentUrn=urn%3Ali%3Acomment%3A%28ugcPost%3A7279902878268350464%2C7279903127330279424%29&dashCommentUrn=urn%3Ali%3Afsd_comment%3A%287279903127330279424%2Curn%3Ali%3AugcPost%3A7279902878268350464%29

[34] iea.blob.core.windows.net/assets/93db951b-afae-48fd-a2f8-bce22f24c625/EnergyTechnologyPerspectives2024.pdf

[35] iea.blob.core.windows.net/assets/93db951b-afae-48fd-a2f8-bce22f24c625/EnergyTechnologyPerspectives2024.pdfhttps://www.linkedin.com/feed/update/urn:li:ugcPost:7279902878268350464/?commentUrn=urn%3Ali%3Acomment%3A%28ugcPost%3A7279902878268350464%2C7279903127330279424%29&dashCommentUrn=urn%3Ali%3Afsd_comment%3A%287279903127330279424%2Curn%3Ali%3AugcPost%3A7279902878268350464%29

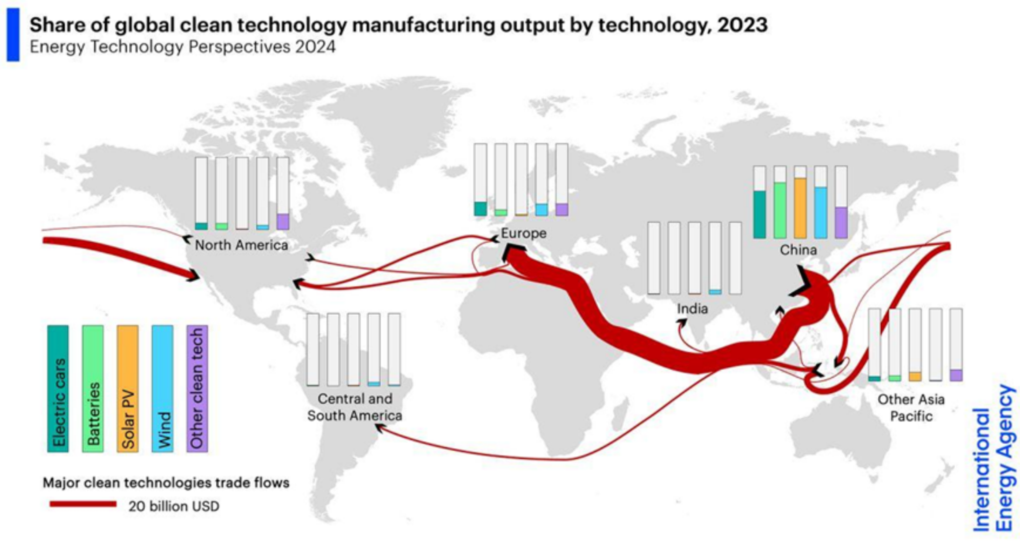


Figure 6: Share of global clean technology manufacturing output by technology, 2023[36].

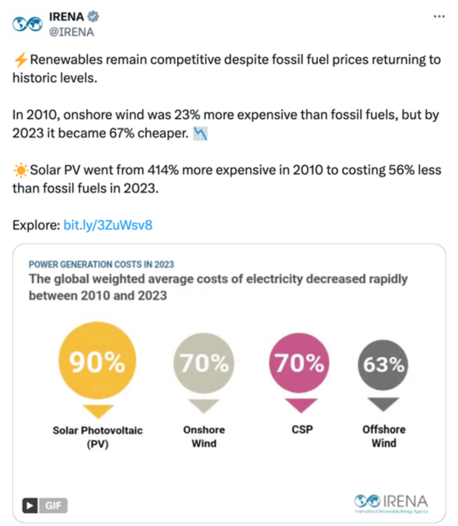
Between 2010 and 2023, the prices of solar, wind and battery storage have dramatically decreased by 90%, 70% and 90% respectively (see Figure 8), driven by technological advancements and economies of scale. This has made solar and wind generation the cheapest and fastest ways of adding generation capacity compared to any other technology. It also expected that proton exchange membrane (PEM) electrolysers will fall by 40% by 2040[37] and up to over 50% by 2050.

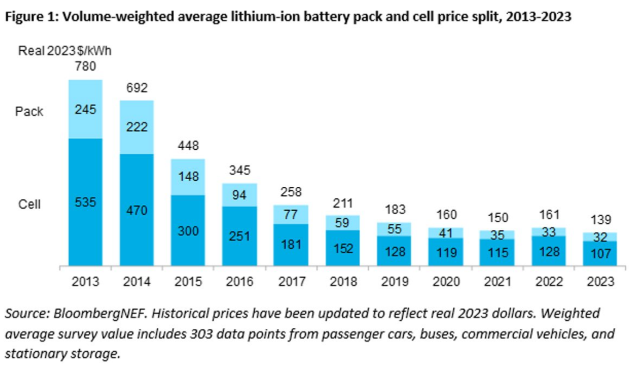
Between 2010 and 2023, the prices of solar, wind and battery storage have dramatically decreased by 90%, 70% and 90% respectively (see Figure 7), driven by technological advancements and economies of scale. This has made solar and wind generation the cheapest and fastest ways of adding generation capacity compared to any other technology. It also expected that proton exchange membrane (PEM) electrolysers will fall by 40% by 2040[38] and up to over 50% by 2050.

[36] https://www.linkedin.com/feed/update/urn:li:ugcPost:7279902878268350464/?commentUrn=urn%3Ali%3Acomment%3A%28ugcPost%3A7279902878268350464%2C7279903127330279424%29&dashCommentUrn=urn%3Ali%3Afsd_comment%3A%287279903127330279424%2Curn%3Ali%3AugcPost%3A72799028782683504644%29

[37] https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

[38] https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction





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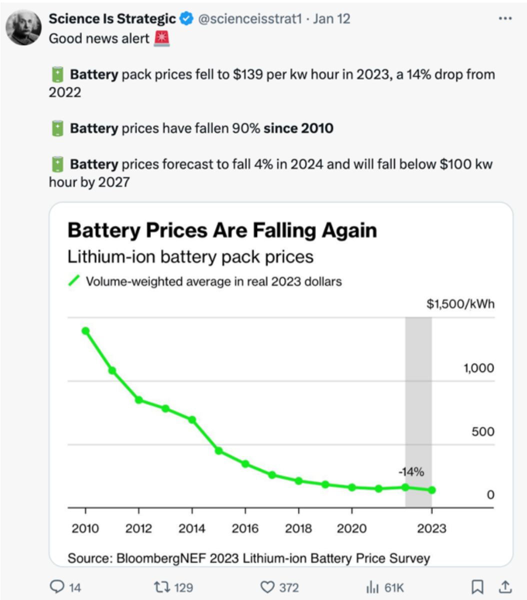

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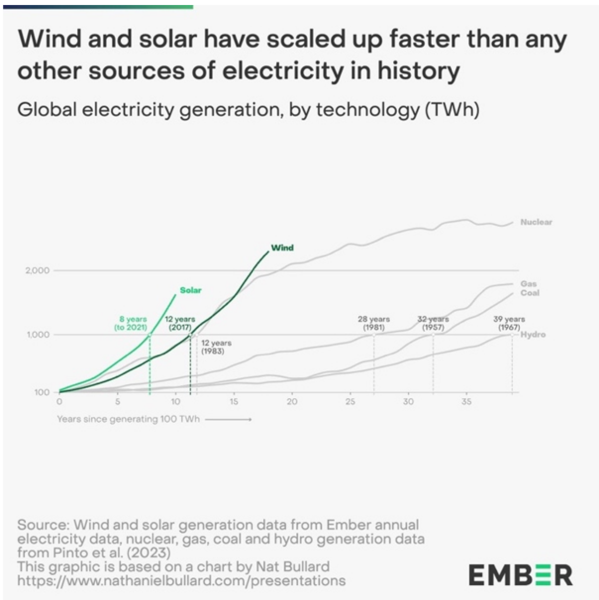


39 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Sep/IRENA_Renewable_power_generation_costs_in_2023.pdf

40 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Sep/IRENA_Renewable_power_generation_costs_in_2023.pdf

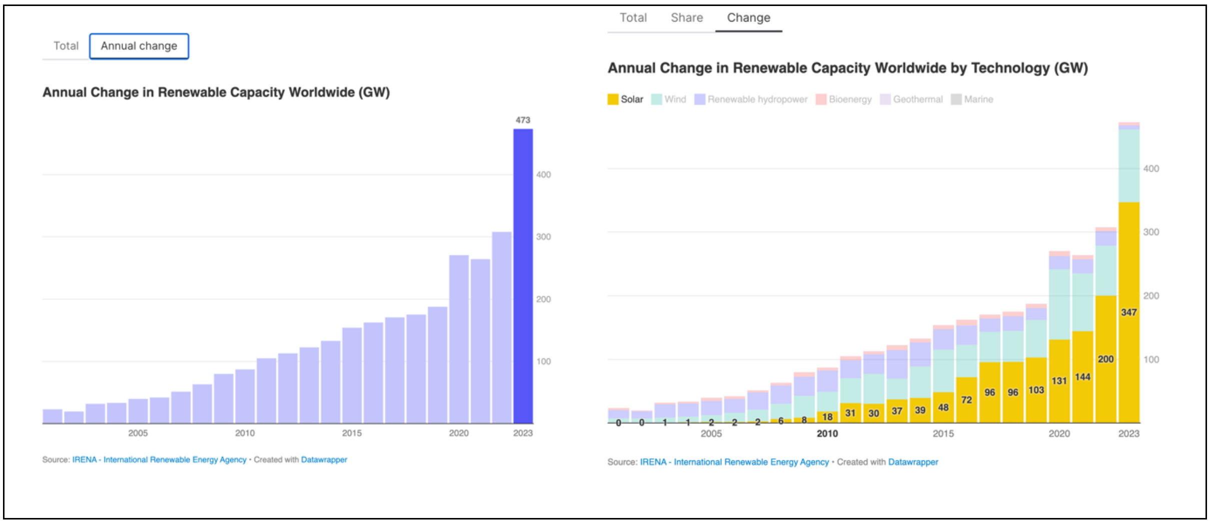


Figure 7: A compilation of green technology scale-up and decreasing costs through the years

Indeed, the outlook data shows global energy supply growing 34EJ (5%) by 2030, with this growth easily outpaced by clean-energy expansion of 48EJ (44%)[41]. As a result, fossil fuels in aggregate will be pushed into decline, as shown in the Figure 9 below.

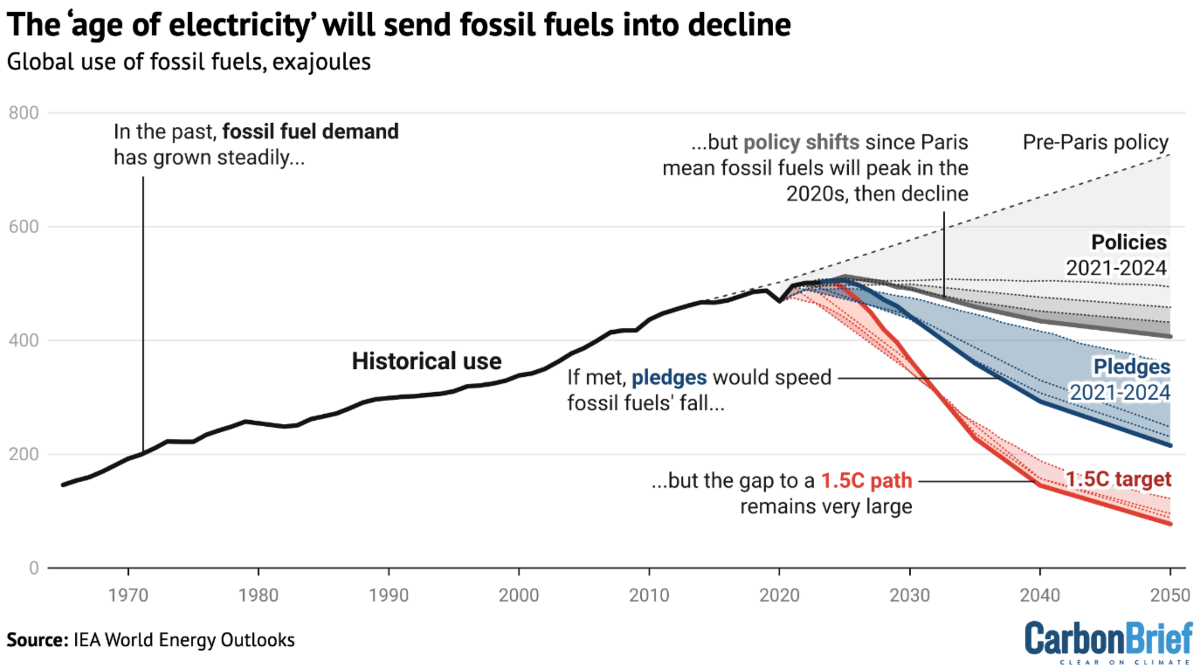


Figure 8: Global use of fossil fuels, exajoules, 1965-2050. Chart shows historical use (black), the pre-Paris policy baseline (dashed line, 2015 "current policies scenario"), policy in 2021-2024 (shades of grey, "stated policies scenarios"), as well as

[41] https://www.carbonbrief.org/analysis-solar-surge-will-send-coal-power-tumbling-by-2030-iea-data-reveals/#:~:text=Along%20with%20a%20doubling%20of,2030%20and%2034%25%20by%202035

pledges in 2021-2024 (blue, "announced pledges scenarios") and the IEA's suggested paths to staying below 1.5C in 2021-2024 (red, "net-zero emission by 2050 scenarios") [42].

Is the world committed to using green hydrogen?

Over 50 countries (Figure 9) have already released their own hydrogen strategies, with another 20 countries in the process of drafting their hydrogen strategies, setting targets for a projected electrolyser capacity of 113.5 gigawatts (GW) by 2030 and 287 GW by 2050. Namibia is amongst these countries.

Namibia has several projects that have already commenced construction and a pipeline of projects in the planning phase, for both local use and export markets. Namibia has equally developed its own green hydrogen strategy to position the country as a major global producer and exporter of green hydrogen and its derivatives, linked to a broader green industrialisation strategy[43].

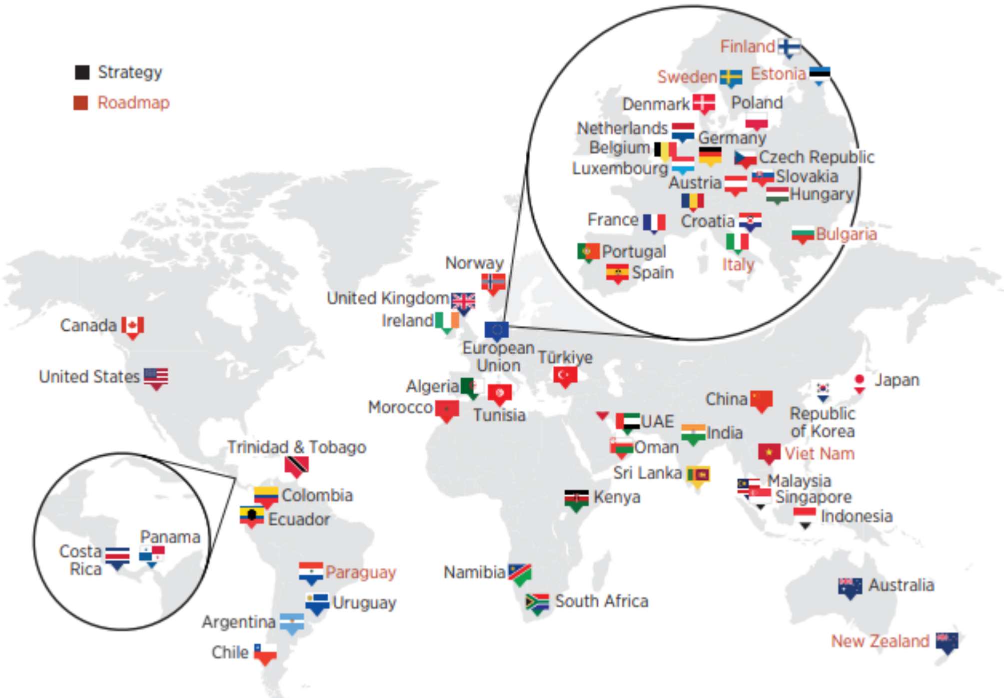


Figure 9: Map of counties with national hydrogen strategies published (as of May 2024)[44]

Every major eastern economy has its own green hydrogen strategy, and not only does China have a national green hydrogen strategy, so too do 21 of China's 23 provinces (see Figure 10). China is rapidly investing and scaling up in the production of critical components required in the manufacture of green

42 https://www.carbonbrief.org/analysis-solar-surge-will-send-coal-power-tumbling-by-2030-iea-data-reveals/#:~:text=Along%20with%20a%20doubling%20of,2030%20and%2034%25%20by%202035
43 https://gh2namibia.com/media-downloads/
44 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Jul/IRENA_Green_hydrogen_strategy_design_2024.pdf

hydrogen, electrolysers, as China tries to cement itself across the entire hydrogen value chain (China already accounts for around 75% of all renewables equipment globally)[45].

Figure 10: Distribution of existing hydrogen demand, industrial clusters, and renewable hydrogen projects in China[46]

Although large-scale deployment of green hydrogen is not necessarily a prerequisite for the achievement of each country's 2030 announced pledges, green hydrogen is an essential component in the 2050 net zero roadmaps of most developed nations (see Figure 12).[47]

45 https://energypolicy.columbia.edu/publications/national-hydrogen-strategies-and-roadmap-tracker/
46 https://www.energypolicy.columbia.edu/publications/chinas-hydrogen-strategy-national-vs-regional-plans/
47 https://www.crugroup.com/en/communities/thought-leadership/sustainability/energy-from-green-hydrogen-will-be-expensive-even-in-2050/

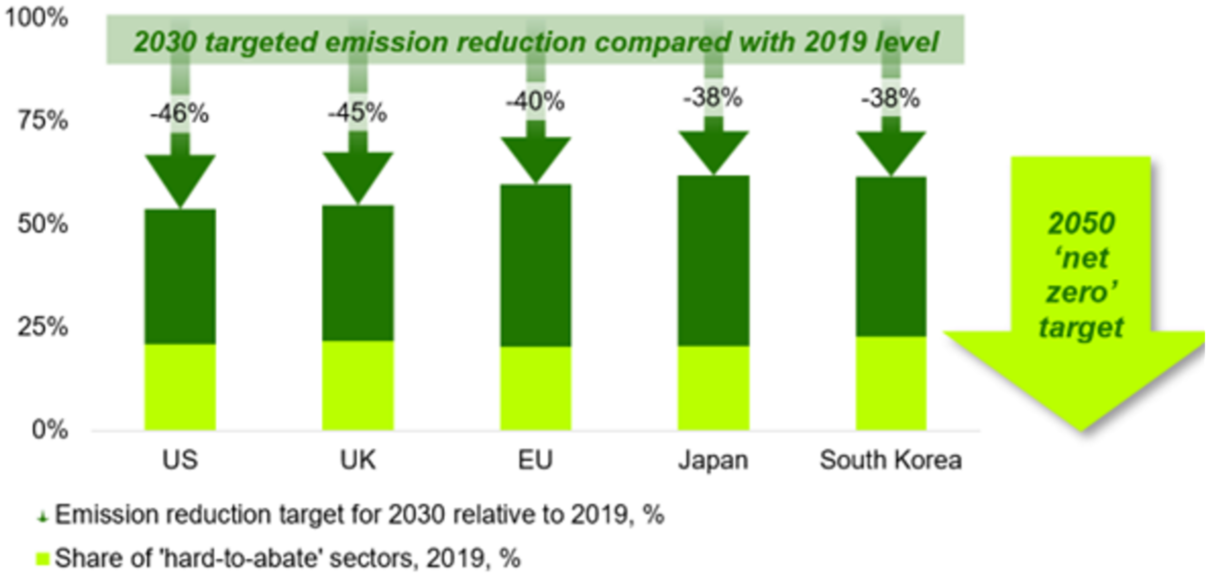


Figure 11: 2030 targets do not need large H2 capacity, but 2050 net-zero goals do48

Who will produce their own hydrogen and who is likely to want to buy Namibia's green hydrogen?

North America (USA and Canada) have sufficient renewable resources to meet their demand for direct electrification and for the production of hydrogen and hydrogen derivatives (indirect electrification). For example, in September 2022, the United States Department of Energy (DOE) identified opportunities for 10 Mt/y of clean hydrogen production by 2030 and 50 Mt/y by 2050 in its draft National Clean Hydrogen Strategy and Roadmap.[49] China and India are expected to meet their own demand from domestic production. These large economic regions are not expected to be dependent on imports of green hydrogen.

The regions and countries of the European Union, Japan and South Korea do not have the renewable energy resources required to achieve their decarbonisation objectives and will need to import green energy. As a result, all three have developed hydrogen strategies to support imports.

To achieve climate neutrality, the 27 EU member states will be able to cover their significantly higher demand for electricity from renewable energies compared to today, and they will also be able to produce a considerable amount of hydrogen from it, but not enough to achieve their decarbonisation goals. The EU will have to import around 50% of its demand for hydrogen and hydrogen derivatives. This is equivalent to 10 million tons of hydrogen per annum by 2030[50]. Japan targets low carbon

[48] https://www.crugroup.com/en/communities/thought-leadership/sustainability/energy-from-green-hydrogen-will-be-expensive-even-in-2050/
[49] https://www.crugroup.com/en/communities/thought-leadership/sustainability/energy-from-green-hydrogen-will-be-expensive-even-in-2050/
50 https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en#:~:text=The%20priority%20for%20the%20EU,10%20million%20tonnes%20by%202030

hydrogen use of 3 million tons per annum by 2030, 12 million tons per annum in 2040 and 20 million tons per annum by 2050 in a quest to decarbonize its economy[51]. South Korea targets 4 million tons per annum by 2030 and about 30 million tons per annum by 2040, which will comprise of a mixture of locally produced and imported low carbon hydrogen[52].

Namibia is well positioned to produce and export green hydrogen to Europe, Japan and South Korea. Firstly, Namibia has abundant solar and wind resources that are co-located is a sparsely populated country. Secondly Namibia is geographically well placed to export to these markets. Thirdly, Namibia has a stable political environment, democratically elected government and low risk of civil unrest which is critical when consumer nations look at long term energy security.

[51] https://resourcehub.bakermckenzie.com/en/resources/hydrogen-heat-map/asia-pacific/japan/topics/hydrogen-developments#:~:text=The%20Strategy%20stipulates%20a%201,20%20million%20tons%20in%202050

[52] https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/112621-s-korea-to-provide-279-mil-mtyear-of-clean-hydrogen-by-2050

Section 3 – What is green hydrogen and why is it required to decarbonise hard-to-abate sectors?

What is green hydrogen?

Green hydrogen is produced through electrolysis, a process that uses electricity from renewable energy sources like wind, solar and hydro to split water molecules into hydrogen and oxygen. During this process, hydrogen is retained and stored for use. There are no other energy storage methods that have such a high density of energy per unit of mass (i.e. batteries are still 100x less energy dense).

Moreover, hydrogen is often categorized according to its production pathways, using colours to distinguish them (see Figure 12). Most relevant colours are **Grey, Blue, Pink and Green Hydrogen. Grey hydrogen** is produced from natural gas or coal, emitting significant amounts of CO_2. **Blue hydrogen** is similarly produced but uses carbon capture technology to reduce CO_2 emissions. **Pink hydrogen** is produced using nuclear energy. **Green hydrogen** is produced by means of electrolysis that makes use of electricity generated by wind, solar or hydro. **Natural hydrogen** (also called white, or geologic hydrogen) is hydrogen found naturally in the Earth's crust. Extraction of natural hydrogen could potentially lead to a significant amount of methane leakage. More hydrogen 'colours' are in use though, for example for hydrogen produced with electricity coming from biomass gasification namely, **turquoise hydrogen**.

Green hydrogen is considered critical in achieving net-zero emissions, particularly in hard-to-decarbonize sectors like heavy industry and transport. Figure illustrates some of the hydrogen uses in different sectors. The IEA equally has emphasised the critical role of hydrogen in reducing global decarbonisation, especially as countries ramp up production capacity and investments in clean hydrogen technologies. [53] & [54]

[53] https://www.weforum.org/agenda/2021/12/what-is-green-hydrogen-expert-explains-benefits/
[54] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_hydrogen_policy_2020.pdf

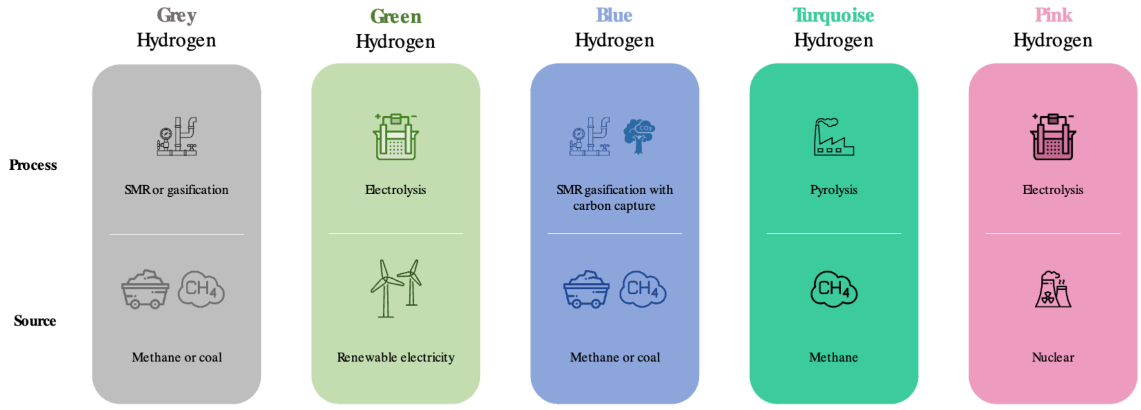


Figure 12: Different shades of hydrogen[55]

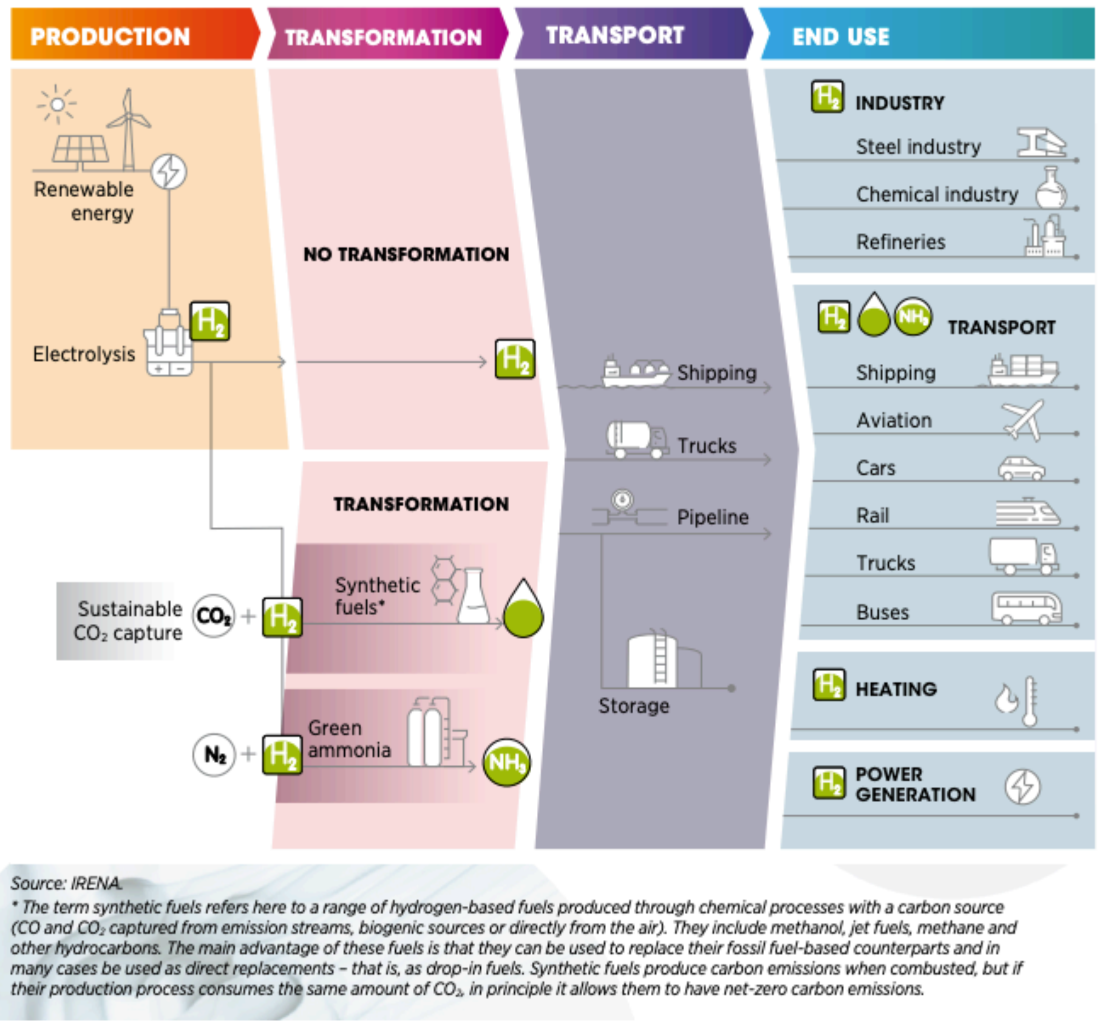


Figure 13: Green hydrogen production, conversion and end use across the energy system.56

[55] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Jul/IRENA_Green_hydrogen_strategy_design_2024.pdf
[56] https://www.weforum.org/agenda/2021/06/4-technologies-accelerating-green-hydrogen-revolution/

What green products can be produced from green hydrogen?

Green hydrogen is the base chemical that can be used to produce a variety of clean fuels.

Green hydrogen can be combined with nitrogen from the air to produce green ammonia, which is crucial for creating sustainable fertilizers, for use in the chemicals industry and for use as a clean fuel in shipping and electricity generation.

Green hydrogen can also react with carbon dioxide to produce synthetic fuels, such as green methanol and e-fuels, which are considered key for decarbonizing hard-to-abate sectors like aviation and shipping.

In the steel industry, green hydrogen can replace coal in the Direct Reduced Iron (DRI) process to create green steel, significantly reducing CO_2 emissions.

Additionally, green hydrogen or green ammonia, depending on the electricity generation technology, can substitute or be co-fired in coal or natural gas in power plants for electricity and heat generation. This provides a cleaner alternative to fossil fuels, offering pathways to decarbonize power production. Green hydrogen can be used in passenger vehicles, trucks, trains and other forms of mobility either with hydrogen fuel cells or combustion within internal combustion engines[57]. Figure provides some insights on some of the uses and advantages of green hydrogen.

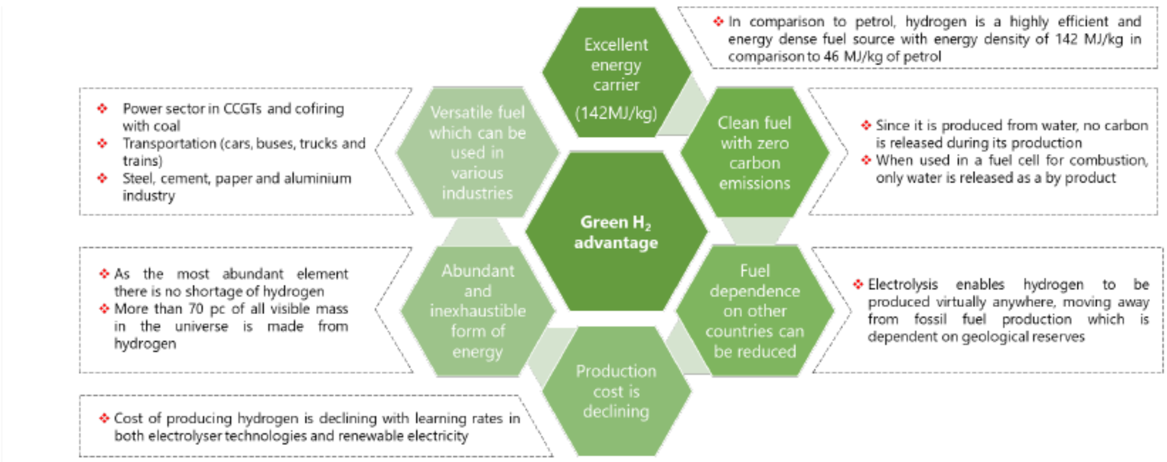


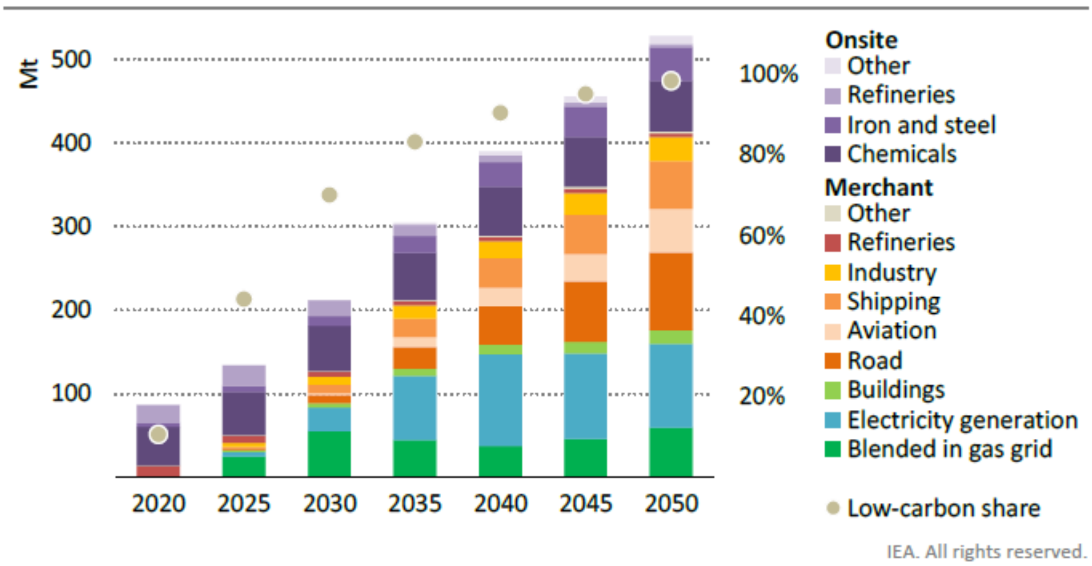
Figure 14: Why hydrogen (source, Argus)

[57] https://www.iea.org/reports/tracking-clean-energy-progress-2023

How much green hydrogen is required to achieve net zero?

Industrial sectors such as steel manufacturing, shipping, road transport, chemical production, and power generation are large CO_2 emitters, are energy intensive and are hard-to-abate (i.e. hard to decarbonise). There are also few alternatives (and in some cases no alternatives) to replace fossil fuels in these sectors and eliminate CO_2 emissions. Introducing green hydrogen or green ammonia as direct replacement or co-firing (i.e. power generation) to these industries is necessary in reducing GHG emissions and decarbonisation (Figure).

The IEA estimates that by 2050, a total of over 500 – 600 million tonnes per annum (MTPA) of low-carbon hydrogen will be required to meet global decarbonization goals, up from the current 100 MTPA produced today, which is predominantly produced from fossil fuels (see Figure). Green hydrogen is considered the most viable option to achieve net zero for these hard-to-abate sectors, as other hydrogen colours (production pathways) have serious downsides or limitations. For example, a major concern with blue hydrogen is around methane leakage in the upstream system (methane having up to 30 times the GHG impact of CO_2) and CO_2 emissions that remain after the deployment of carbon capture, utilization, and storage (CCUS) technologies. [58] Low carbon hydrogen is expected to make up about 11% of the power mix by 2050 [59].



The initial focus for hydrogen is to convert existing uses to low-carbon hydrogen; hydrogen and hydrogen-based fuels then expand across all end-uses

Figure 9: Global hydrogen and hydrogen-based fuel use in the net zero. Source IEA

[58] https://www.iea.org/reports/tracking-clean-energy-progress-2023
[59] https://www.woodmac.com/market-insights/topics/energy-transition-outlook/net-zero-by-2050/#:~:text=In%20our%20net%20zero,79%25%20of%20the%20overall%20investment.

Section 4 – Why green hydrogen compared to other forms of low carbon hydrogen?

What is grey hydrogen?

Today most hydrogen is still mainly produced from natural gas using a process known as steam reformation, where methane (CH4) is split with steam resulting in the emission of CO_2– (the main culprit for climate change) – and H_2, hydrogen.[60] Grey hydrogen can also be produced from coal, with significantly higher CO_2 emissions per unit of hydrogen produced. When grey hydrogen is used to produce ammonia, which is what around 35 million tonnes of the annual 100 million tonnes of hydrogen produced is used for, about 3.2 tons of CO_2 is emitted per ton of grey ammonia produced. [61] & [62] Another of the key issues with the use of methane as a feed stock for grey hydrogen production, is that a large amount of methane is released during the extraction process into the atmosphere, with methane being around 30 times more potent than CO_2 as GHG.

What is low carbon hydrogen?

The European Union and Japan define low carbon hydrogen as hydrogen produced with 70% or more emission reductions, compared to hydrogen produced using fossil fuels. The following colours of hydrogen are regarded as low carbon hydrogen based on CO_2 emission during their production[63]:

- Green – zero or extremely low CO_2 emission
- Blue – includes the use of carbon capture utilisation and storage (CCUS)
- Pink – produced using nuclear energy and emits near zero CO
- Turquoise - produced using methane pyrolysis

[60] https://www.iea.org/reports/global-hydrogen-review-2024/hydrogen-production
[61] https://www.weforum.org/agenda/2021/12/what-is-green-hydrogen-expert-explains-benefits/
[62] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_hydrogen_policy_2020.pdf
[63] https://www.nationalgrid.com/stories/energy-explained/hydrogen-colour-spectrum#:~:text=Green%20hydrogen%2C%20blue%20hydrogen%2C%20brown,between%20the%20types%20of%20hydrogen.

Why is green hydrogen preferred over other types of low carbon hydrogen?

Green hydrogen production does not emit CO_2, making it the cleanest form of hydrogen. In contrast, blue hydrogen, produced from natural gas with CCUS, raises concerns about carbon leakage—where captured CO_2 could escape during transportation or storage. Additionally, blue hydrogen production relies primarily on natural gas, of which the wells and pipelines can release methane, a potent greenhouse gas (GHG) with a global warming potential approximately 30 times greater than CO_2. Methane emissions during extraction and production of blue hydrogen exacerbate its negative environmental impact, contributing to climate change and air pollution, which harms both human and animal health. The 2023 methane releases were estimated at an unprecedented 120 million tonnes per annum (MTPA) [64].

Pink hydrogen, which is produced with nuclear energy, has its own challenges. Not only does the technology generate radioactive waste but the development of the power plant is expensive, complex and fraught with cost over runs and time delays. Nuclear energy now accounts for less than 10% of global electricity production despite the first nuclear power plant starting 70 years ago. In 2023, more wind and solar renewable energy were installed than the entire installed nuclear capacity in the whole world today.

Yellow hydrogen, which uses electricity from the existing electricity grid, is not guaranteed to meet carbon reduction targets because the energy mix from the grid often includes both fossil fuels and renewables, making "greenality" difficult to trace, while also potentially put a strain on national energy systems.

These are not the only types of hydrogen however, all other types of hydrogens carry social and environmental implications, which are likely to outweigh their benefits.

From a production perspective, green hydrogen is likely to win out over time due to the anticipated cost reductions following the trends seen in solar, wind, and battery storage, which have experienced drastic price declines over the past decade. The price of electrolysers, one of the key technological inputs in the green hydrogen production, is expected to fall by 40% by 2030[65]. Figure illustrates the projected prices of the levelized cost of hydrogen production by 2030.

As green hydrogen production scales up and benefits from technological advancements, it is projected to become increasingly cost-competitive. Moreover, as policies like carbon pricing and emissions trading systems (ETS) become more widespread, the cost of producing fossil-fuel-derived hydrogen, such as grey or blue hydrogen, is projected to rise.

Under the EU Renewable Energy Directive (RED III), only Renewable Fuels of Non-Biological Origin (RFNBOs) qualify as green hydrogen, and to meet the European Union's stringent standards, electricity used for green hydrogen production must be sourced from renewable infrastructure that is less than three years old, which means that only green hydrogen qualifies under this definition, not any other forms of low carbon hydrogen.

[64] https://www.iea.org/reports/global-methane-tracker-2024/key-findings
[65] https://www.irena.org/publications/2020/Dec/Green-hydrogen-cost-reduction

From a policy perspective, the EU RED III mandates that 42.5% of all hydrogen used in Europe by 2030 must be RFNBOs, including green hydrogen. This creates a significant market for green hydrogen and limits the viability of blue and grey hydrogen as long-term solutions due to their higher emissions profiles and failure to meet renewable energy standards. [66]

Both Korea and Japan now consider the "well-to-gate" philosophy as the measurement of the carbon intensity for low carbon hydrogen alternatives, effectively including the effects of methane leakage for blue hydrogen in the calculation of the carbon intensity of the hydrogen produced.

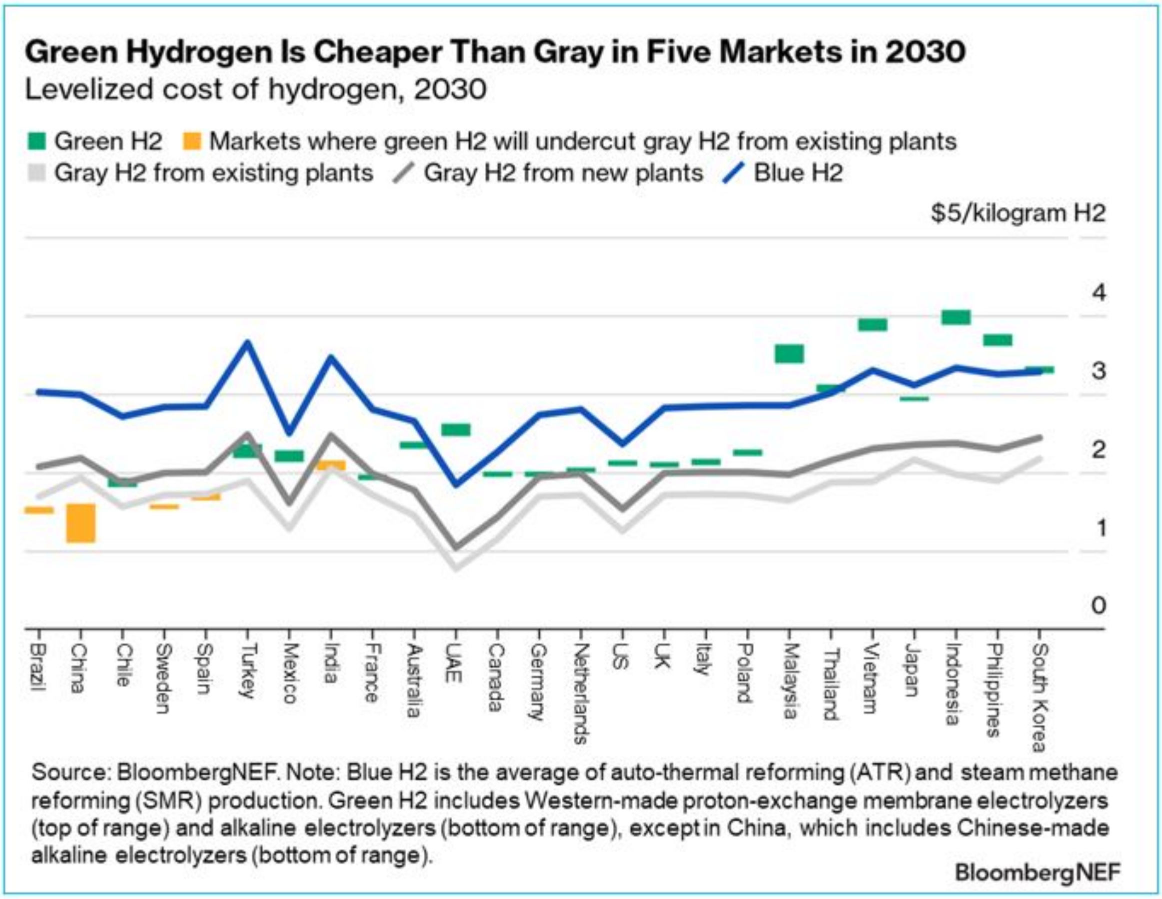


Figure 15: BNEF expect green hydrogen to become competitive against grey hydrogen in a long term[67]

Further, apart from the EU, the UK and China, which are expected to have access to low-cost renewable energy by 2050 and/or relatively high carbon prices, most countries exhibit green hydrogen costs above blue and grey hydrogen costs by 2050.[68]

[66] https://www.epa.gov/gmi/importance-methane
[67] https://about.bnef.com/blog/green-hydrogen-to-undercut-gray-sibling-by-end-of-decade/
[68] https://www.crugroup.com/en/communities/thought-leadership/sustainability/energy-from-green-hydrogen-will-be-expensive-even-in-2050/

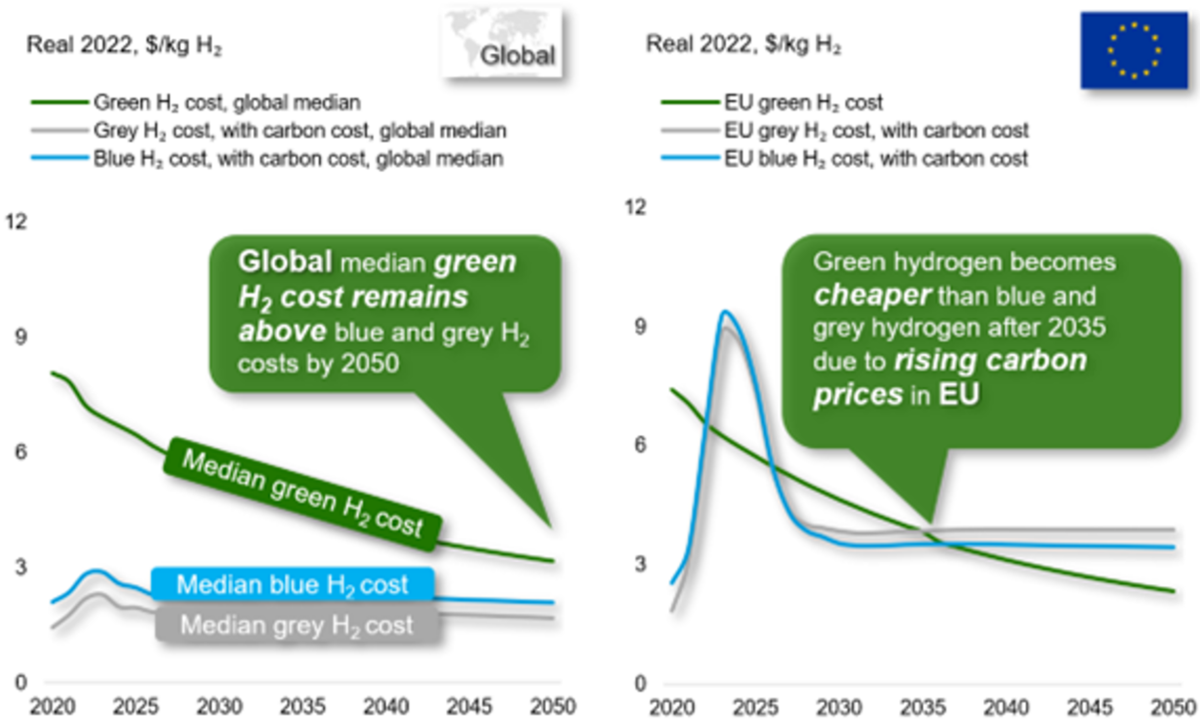


Figure 16: Globally, green hydrogen costs remain above grey and blue hydrogen production costs by 2050...but green hydrogen will gain cost-competitiveness over blue and grey hydrogen in late-2030.[69]

[69] https://www.crugroup.com/en/communities/thought-leadership/sustainability/energy-from-green-hydrogen-will-be-expensive-even-in-2050/s

Why are existing nuclear superpowers not investing in pink hydrogen?

Solar and wind energy, when combined with battery storage, are more cost-effective to build, operate and ultimately decommission than nuclear energy for new energy infrastructure and in addition substantially faster to build.

While nuclear energy can offer lower electricity costs once constructed due to its reliable and continuous generation of electricity, the initial investment for nuclear plants is substantially higher compared to solar and wind projects. Building a new nuclear plant involves significant financial, regulatory, and safety hurdles, which can take decades to complete, making it less attractive from a cost and time perspective compared to rapidly deployable renewables.[70] From 2009 to 2024 (see Figure – which shows the average cost of electricity per megawatt hour of various technologies), the cost of nuclear has gone up by 49% while those of wind and solar continue to drop significantly. [71] & [72]

Additionally, nuclear power accounts for less than 10% of the world's annual electricity production, with just 460GW of installed capacity today for an industry that saw the first nuclear reactor constructed 70 years ago. In contrast, just in 2023 alone the world built more solar and wind generation capacity than the entire nuclear capacity operational today (i.e. more wind and solar added in 2023 than the entire existing nuclear fleet). Wind and solar annual capacity installations are projected to double by 2030 to around 1,000 GW per year.

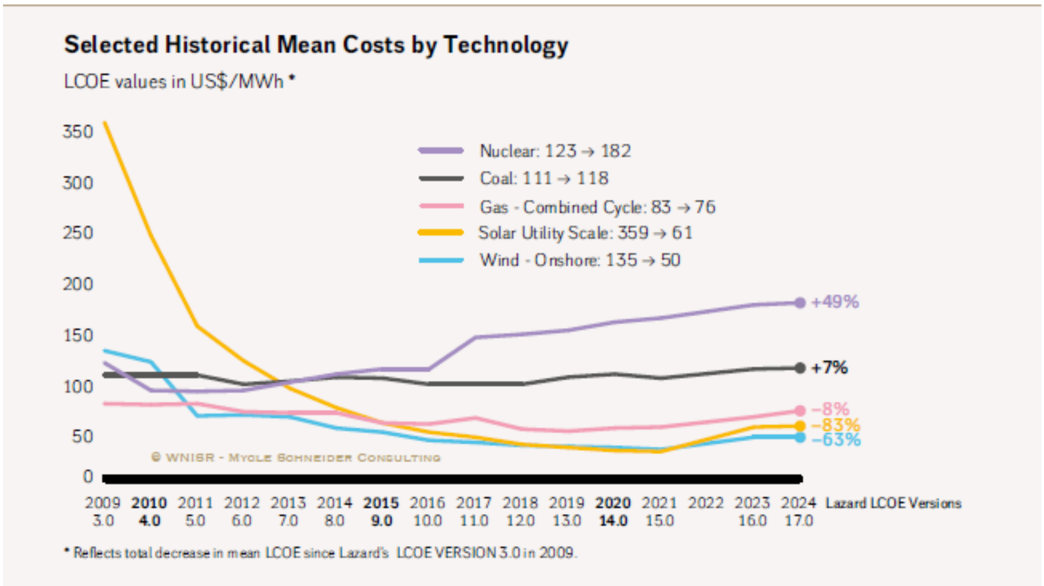


Figure 17: The declining costs of renewable vs traditional power [73] & [74]

[70] https://www.iea.org/reports/renewables-2023
[71] https://www.worldnuclearreport.org/World-Nuclear-Industry-Status-Report-2024-1046
[72] https://www.lazard.com/perspective/
[73] https://www.worldnuclearreport.org/World-Nuclear-Industry-Status-Report-2024-1046
[74] https://www.lazard.com/perspective/

Section 5 – What is the role of green hydrogen in decarbonisation?

What are hard-to-abate sectors and how much carbon do they emit?

Some key industries are hard-to-abate or hard-to decarbonise because they are energy intensive and rely heavily on fossil fuels for different processes of their operation. The hard-to-abate industries are responsible for about 70% of global carbon emissions. These industries contribute significantly to GHG emissions, making their decarbonization crucial in achieving climate goals.

There are four key sectors that require low carbon hydrogen to decarbonise (also see Figure):

- Steel production
- Parts of the chemical production industry
- Long-haul traffic, in particular air and sea traffic
- The power sector to cover for the few hours of the year when renewable energies are not sufficiently available

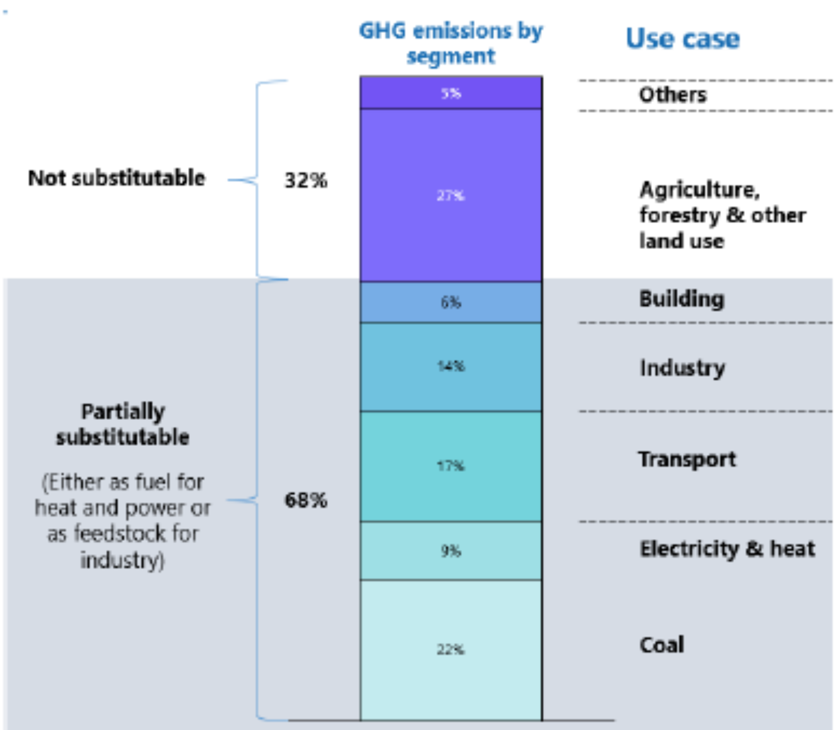


Figure 18: Greenhouse emission by sector (source, Argus)[75]

[75] Greenhouse emission by sector (source, Argus)

Why is green hydrogen required to decarbonise these hard-to-abate sectors?

Green hydrogen and green ammonia are the only true alternatives that do not emit CO_2 and pose no risk of GHG leakages, unlike other forms of hydrogen or ammonia alternatives. Green hydrogen and its derivatives have the potential to substitute fossil-fuels in sectors that are responsible for about 70% of global emissions.[76]

Carbon intensity of various sectors targeted to be decarbonised by green hydrogen:

- Producing 1 ton of grey hydrogen emits around 12 tons of CO_2, with 100 million tonnes per annum ("MTPA" of grey hydrogen produced annually.
- Grey ammonia production releases about 1.7 tons of CO_2 per ton of grey ammonia produced.
- Steel production uses 1 ton of coking coal to produce crude steel, resulting in approximately 2 tons of CO_2 emissions
- In the marine shipping industry, every 1 ton of heavy fuel oil (HFO) or very low sulphur fuel oil (VLSFO) consumed emits 3.2 tons of CO_2.
- In the power generation sector:
    - Every ton of liquefied natural gas (LNG) consumed results in the emission of 2.9 tons of CO_2; and
    - Every ton of coal consumed results in 2.6 tons of CO_2 emissions.
- The aviation industry accounts for about 2.5% of global CO_2 emissions, with 492 million metric tons (Mt CO_2) emitted by the aviation industry in 2023 (down from the 625 Mt CO_2 in 2019 before the COVID-19 pandemic).

[76] Argus Low Carbon Hydrogen Strategy Report Sample - Asia-Pacific and the Middle East

Part B – Environmental and safety considerations in the production and handling of green hydrogen

How much water do you require to make green hydrogen?

In the direct production of green hydrogen, around 9kg of water is required for every 1kg of green hydrogen produced. Considering various other water requirements in the entire green hydrogen value chain, up to 20kg of water can be required for every 1kg of green hydrogen produced.

If desalinated water is used, what happens to the brine?

Brine management is crucial because, if not properly handled, high salinity can adversely affect marine ecosystems, including changes to the seabed and harm to marine species.

The disposal process of brine will vary from project to project depending on specific site conditions. Generally, brine is disposed back into the ocean in accordance with local legislation and international best practice, which ensures that brine disposal is rapidly dispersed and that there is no concentration of salinity levels in any discharge location in excess of stipulated safe operating thresholds. Disposal methodologies and site-specific conditions consider factors such as the salinity of the brine, local water currents, and marine biodiversity to ensure that the brine disperses safely and does not cause harm to aquatic life or disrupt the balance of the marine environment. Continuous monitoring and adaptive management ensure that disposal remains within safe limits, mitigating any unforeseen consequences.

How much land is required to produce green hydrogen?

Namibia’s national green hydrogen strategy target an aggregated green hydrogen production of 15 million tonnes per annum (MTPA). This implies roughly 9,000 square kilometres of land footprint would be required to produce this amount of green hydrogen – equivalent to approximately 1 200 square kilometres per 1 MTPA of hydrogen production. This is equivalent to around 1% of Namibia’s land mass.

Is it safe to handle green hydrogen and ammonia?

When handling hazardous materials like ammonia (NH_3) and hydrogen (H_2), strict safety standards are essential to minimize risks to health, safety, and the environment. Both ammonia and hydrogen are highly reactive and require specific precautions to ensure their safe use in industry and laboratory settings.

Ammonia Safety Standards: Ammonia is a toxic and corrosive gas that can cause severe health effects if inhaled or exposed to the skin or eyes. Ammonia is typically stored and transported in pressurized cylinders, tanks, pipelines or ships and proper ventilation is essential when working with it to prevent the buildup of dangerous concentrations in confined spaces. With around 200 million tonnes of ammonia produced per annum, there is a comprehensive existing set of standards and safety measures for the safe handling of ammonia to draw upon.

Hydrogen Safety Standards: Hydrogen is an odourless, colourless, and highly flammable gas that can form explosive mixtures with air. Hydrogen is typically stored under high pressure or at very low temperatures as a cryogenic liquid. The primary safety concern with hydrogen is its flammability and the risk of explosion. Namibia will need to develop its own safety standards for the handling of hydrogen, but given its wide production and use globally, there is a long existing set of safety records and standards to draw upon. Standards for the safe handling of hydrogen typically cover aspects such as proper ventilation, the use of explosion-proof electrical equipment, and the implementation of leak detection systems. Since hydrogen can easily diffuse into confined spaces, these areas must be monitored to prevent an accumulation of flammable mixtures. Additionally, workers should be trained in the recognition of hydrogen leaks, the use of flame arresters, and the importance of grounding and bonding equipment to prevent electrostatic discharge. With around 100 million tonnes of hydrogen produced per annum, there is a comprehensive existing set of standards and safety measures for the safe handling of hydrogen to draw upon.

General Safety Practices for Both Gases: For both ammonia and hydrogen, the use of standardized procedures, proper labelling, and hazard communication (e.g., Material Safety Data Sheets, or MSDS) are crucial. Regular training of employees on emergency response procedures, including evacuation plans, fire extinguishing protocols, and first-aid measures, is a fundamental part of any safety program. Appropriate emergency response equipment, such as fire suppression systems and ventilation fans, should be readily accessible in areas where these gases are handled. Facilities must also be designed to minimize the risk of accidental releases by incorporating features like automatic shut-off valves and containment barriers.

Part C – Technologies in direct electrification

What role does nuclear energy play?

Nuclear energies share of global electricity production has been stagnant for the last 30 years in absolute terms and has declined as a percentage of total electricity generation, dropping from its peak of 17.5% in 1996 to 9.2% in 2023. During the same period, the global share of electricity production from renewables has grown to 30.2% of annual electricity production and is expected to reach 42% by 2028.[77] Moreover, the levelized cost of electricity (LCOE) for a new nuclear plant has risen by 49% from 2009 to 2023 at the same time that solar and wind have dropped by 83% and 63%, respectively (see Figure)[78], making wind and solar significantly cheaper than nuclear and all other fossil fuel technologies.

Global investment in nuclear energy is projected at around USD 80 billion in 2024 as compared to global investments in renewable energies estimated to reach almost 10 times this at USD 771 billion in 2024.[79] The differences in investment between these two electricity generation technologies is fundamentally due to the price of nuclear generation capacity being much more expensive than renewable energies and the speed at which renewable energy can be constructed.[80] Nuclear has 460GW of installed capacity today for an industry that saw the first nuclear reactor constructed 70 years ago. In contrast, just in 2023 alone the world built more solar and wind generation capacity than the entire nuclear capacity operational today (i.e. more wind and solar added in 2023 than the entire existing nuclear fleet). Wind and solar annual capacity installations are projected to double by 2030 to around 1,000 GW per year.

77 https://www.iea.org/reports/renewables-2023
78 https://www.worldnuclearreport.org/World-Nuclear-Industry-Status-Report-2024-1046
79 https://www.iea.org/reports/world-energy-investment-2024/overview-and-key-findings
80 https://www.lazard.com/media/typdgxmm/lazards-lcoeplus-april-2023.pdf

Can countries that want to decarbonize their electricity supply and switch completely to renewable energies manage without so-called base load power plants?

Yes, Germany, for example, is leading the way with 59.7% of its entire electricity supply in 2023 coming from renewables in the form of wind and solar.[81] Flexible generation capacity is still required in these energy systems, and the long term plan is for hydrogen fired flexible generation power plants to be built to replace their reliance on gas fired generational capacity where intermittency cannot be met by battery storage alone.

This transition will be achieved by the production and importation of green hydrogen, which is stored in caverns as hydrogen and transported to the power plants via pipelines or in ammonia form and combusted in ammonia fired power plants. The future power system will combine inexpensive renewable energies, available for most hours in a year, with relatively more expensive hydrogen-based electricity for periods of renewables intermittency or peak demand. Ideally, where forms of zero CO2 emission base load are available, e.g. hydropower, such base load options should be engaged.

[81] https://www.ise.fraunhofer.de/en/press-media/press-releases/2024/public-electricity-generation-2023-renewable-energies-cover-the-majority-of-german-electricity-consumption-for-the-first-time.html#:~:text=Public%20Net%20Electricity%20Generation%202023,Consumption%20for%20the%20First%20Time&text=In%202023%2C%20renewables%20accounted%20for,net%20electricity%20generation%20in%20Germany.

WHITE HYDROGEN FAQs

Part A – Understanding White Hydrogen and Its Global Context

Section 6: Introduction to White Hydrogen

What is White Hydrogen?

White hydrogen, also known as natural or geologic hydrogen, is hydrogen gas that is naturally produced within the Earth's crust through various geological and geochemical processes. Unlike other types of hydrogen that require industrial production, white hydrogen is found in underground deposits[82] It is believed to form through mineral and water reacting underneath the ground.[83]

[82] https://energyadvicehub.org/what-is-white-hydrogen/?utm_source=chatgpt.com.
[83] https://montel.energy/blog/what-is-white-hydrogen#:~:text=White%20hydrogen%20is%20almost%20pure,a%20viable%20source%20of%20energy.

Section 7: Extraction and Technological Aspects

How is White Hydrogen Extracted?

White hydrogen is extracted through drilling into underground reservoirs where it has accumulated, similar to natural gas extraction. SpecialiSed techniques are needed due to hydrogen's low molecular weight and high diffusivity[84]

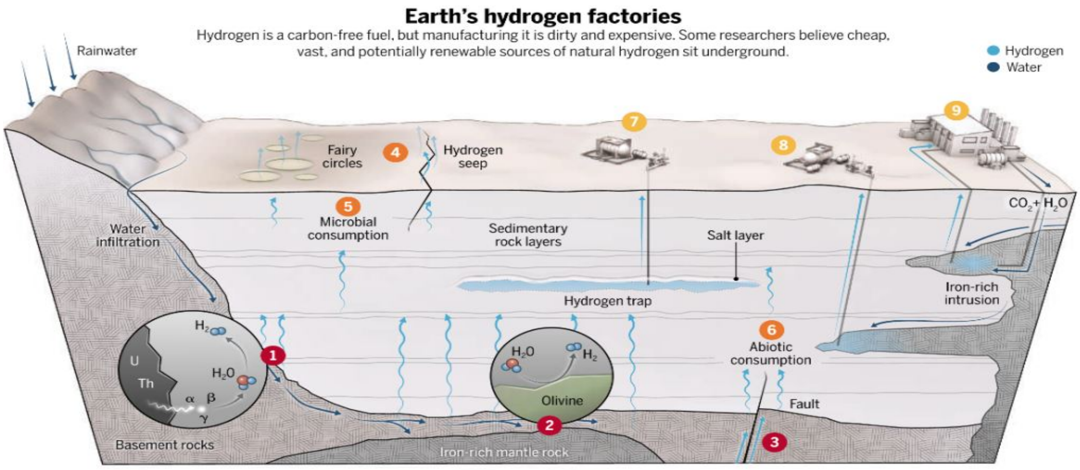


Figure 19: Earth's hydrogen factories[85]

What Challenges Exist in Extracting and Utilising White Hydrogen?

The key challenges include:

- *Exploration and Mapping* – Identifying viable deposits requires advanced geological surveys.
- *Technological Development* – Extracting and storing hydrogen safely remains a challenge. Additionally, technology to prevent and monitor leaking white hydrogen is lacking, which could create blind spots. [86&87]
- *Economic Viability* – Large-scale commercialiSation depends on infrastructure development and regulatory support[88]
- *Regulatory and Environmental Concerns* – Extracting white hydrogen caries a potential leakage of a significant amount of green house gases such as methane which are more potent than CO2, which could have negative environmental impacts.[89]

[84] https://energyadvicehub.org/what-is-white-hydrogen/?utm_source=chatgpt.com.
[85] White Hydrogen reserves discovered in France - Civilsdaily
[86] https://montel.energy/blog/what-is-white-hydrogen#:~:text=White%20hydrogen%20is%20almost%20pure,a%20viable%20source%20of%20energy.
[87] https://www.euronews.com/green/2023/11/05/what-is-white-hydrogen-the-pros-and-cons-of-europes-latest-clean-energy-source
[88] https://www.woodmac.com/news/the-edge/unlocking-the-potential-white-hydrogen/?utm_source=chatgpt.com .
[89] https://montel.energy/blog/what-is-white-hydrogen#:~:text=White%20hydrogen%20is%20almost%20pure,a%20viable%20source%20of%20energy.

Section 8: White Hydrogen vs. Other Hydrogen Types

How Does White Hydrogen Compare to Other Hydrogen Types?

- *Green Hydrogen* – Produced using renewable electricity to split water molecules via *electrolysis*. It is entirely carbon-free, making it the gold standard for sustainable hydrogen production. As advancements in renewable energy technologies continue to drive down costs, green hydrogen is emerging as the long-term solution for a zero-emission hydrogen economy.
- *Blue Hydrogen* – Produced from natural gas with carbon capture, lower emissions but still reliant on fossil fuels.
- *Grey Hydrogen* – Produced from natural gas without carbon capture, leading to high CO_2 emissions[90]

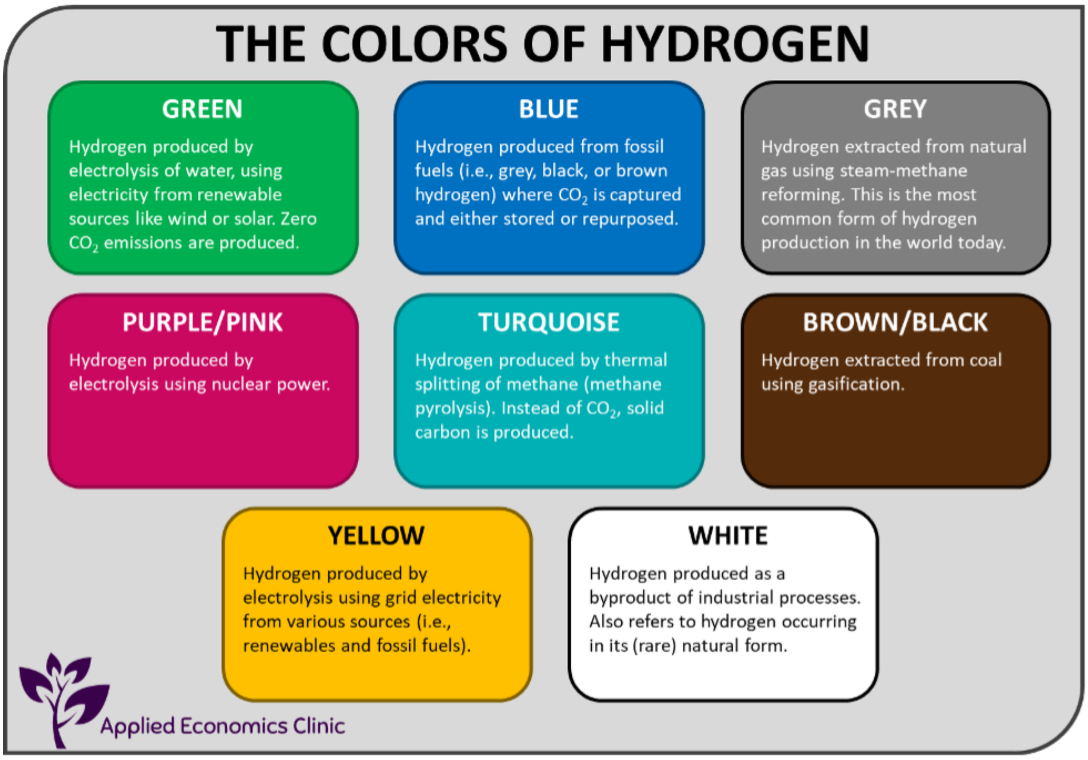


Figure 20: Colors of hydrogen[91]

Why is Green Hydrogen Considered the Most Sustainable Option?

Green hydrogen stands as the pinnacle of hydrogen innovation because it seamlessly integrates into the renewable energy ecosystem. By leveraging solar, wind, and hydroelectric power, green hydrogen ensures energy security while eliminating carbon emissions. As renewable energy capacity expands, green hydrogen is expected to become more affordable, reinforcing its status as the preferred hydrogen source for industrial, transportation, and energy storage applications. Furthermore,

[90] https://wearenium.com/news/entry/white-hydrogen-has-the-solution-to-climate-change-been-buried-deep-in-earth-all-along?utm_source=chatgpt.com.
[91] The "Colors" of Hydrogen — Applied Economics Clinic

compared to hydrogen derived from fossil fuels or natural reservoirs, green hydrogen is entirely generated from water, ensuring minimal environmental disruption.

What Technological Advancements Make Green Hydrogen the Future of Energy?

- *Electrolyser Efficiency Improvements* – Innovations in proton exchange membrane (PEM) and solid oxide electrolyzers are significantly reducing electricity consumption, making green hydrogen more cost-effective.
- *Integration with Smart Grids* – Green hydrogen production can dynamically respond to electricity supply and demand, stabilizing energy grids and *maximising the use of surplus renewable power.*
- *Scalability with Offshore and Onshore Renewables* – The ability to co-locate green hydrogen production with wind and solar farms ensures year-round, uninterrupted supply.
- *Advances in Storage and Transportation* – Emerging liquid organic hydrogen carriers (LOHC) and ammonia-based transport solutions make long-distance green hydrogen trade viable.[92]

Why is White Hydrogen Less Predictable as a Long-Term Energy Source?

White hydrogen, despite being a naturally occurring resource, faces major uncertainties:

- *Limited Geographical Availability* – White hydrogen is only found in specific geological formations, making its global deployment inconsistent.

- *Uncertain Extraction Viability* – Unlike green hydrogen, which is backed by well-established electrolysis technology, white hydrogen extraction is still in its experimental phases, with no guarantee of widespread feasibility.

- *High Exploration and Drilling Costs* – Identifying and extracting white hydrogen requires significant investment, much like fossil fuel drilling operations, making it an uncertain economic bet.

- *Potential Methane and CO_2 Co-Emissions* – Some white hydrogen deposits are found alongside hydrocarbon reserves, meaning that extracting hydrogen from these sources could result in unintended emissions.[93]
- *Infrastructure Readiness* – White hydrogen produced offshore will need to be transported via pipelines, hundreds of kilometres from the cost. However, building such a pipeline will come at significant cost.

What Environmental Advantages Does Green Hydrogen Offer to make it the best solution?

- *Predictable and Controlled Production* – Green hydrogen is manufactured in a controlled manner, avoiding the risks associated with underground hydrogen extraction, such as geological disturbances and gas leakages.
- *Zero Emissions from Production* – Unlike white hydrogen, which may require invasive extraction techniques, green hydrogen is generated using electrolysis, leaving no environmental footprint.

[92] https://www.iea.org/reports/the-future-of-hydrogen
[93] https://about.bnef.com/

- *No Risk of Groundwater Contamination* – Extracting white hydrogen could disturb underground ecosystems, potentially affecting groundwater quality, while green hydrogen is safely produced above ground.

Can White Hydrogen and Green Hydrogen Coexist?

Yes, both white and green hydrogen can serve complementary roles in the global hydrogen economy. White hydrogen presents an opportunity for naturally sourced hydrogen, particularly in regions where underground reservoirs are accessible. However, green hydrogen remains the most predictable and sustainable long-term solution, as it aligns directly with global climate targets. Together, they can expand hydrogen accessibility and adoption, each serving distinct roles based on geography, infrastructure, and policy priorities.[94]

What is the Environmental Impact of White Hydrogen?

During extraction white hydrogen, there is high potential leakage of greenhouse gases such as methane, ozone and water vapor, resulting in indirect global warming in particular, methane is 25 to 30 times more harmful than CO_2 when released into the atmosphere and could significantly increase to global warming[95]. Whereas compared to industrial hydrogen production, white hydrogen extraction has a lower carbon footprint. However, concerns exist over potential groundwater contamination and induced seismic activity.[96]

[94] https://hydrogencouncil.com/en/
[95] https://www.un.org/en/climatechange/science/causes-effects-climate-change#:~:text=Fossil%20fuels%20%E2%80%93%20coal%2C%20oil%20and,they%20trap%20the%20sun's%20heat
[96] https://www.woodmac.com/news/the-edge/unlocking-the-potential-white-hydrogen/?utm_source=chatgpt.com

Part B – Cost, Market Potential, and Economic Viability

Section 9: Cost Comparison of Hydrogen Types

How Does White Hydrogen Compare in Cost to Green and Blue Hydrogen?

- *White Hydrogen* – Cost estimates are still developing but could be lower than green hydrogen. As of March 15,20205, Canada-based producer Hydroma extracts white hydrogen at an estimated cost of $0.5 per kg[97&98].
- *Green Hydrogen*– $3–6 per kg due to high electricity and electrolyser costs but is expected to become more affordable due to:

Government Incentives and policy – Many countries are introducing subsidies and tax benefits for green hydrogen projects.
Emerging technologies – discovery of cheaper electrolysers
Declining renewable energy costs – wind and solar are becoming cheaper, thus, reducing the input costs for green hydrogen plants.

- *Blue Hydrogen*– $2–3 per kg with carbon capture technology, however, emissions are still quite high, especially, fugitive methane, while 3 to 5 kilograms of CO_2 are emitted per blue kilogram of hydrogen produced[99&100] .
- *Grey Hydrogen* – $1–2 per kg but with high CO_2 emissions.[101]

[97] https://www.mining.com/cost-advantage-of-natural-hydrogen-sparks-energy-companies-interest-report/
[98] https://montel.energy/blog/what-is-white-hydrogen#:~:text=White%20hydrogen%20is%20almost%20pure,a%20viable%20source%20of%20energy.
[99] https://climate.mit.edu/ask-mit/how-clean-green-hydrogen#:~:text=Around%2012%20kilograms%20of%20CO,e%20per%20kilogram%20of%20hydrogen.&text=That's%20compared%2C%20again%2C%20to%20potentially,1%20kilogram%20for%20green%20hydrogen.
[100] https://scijournals.onlinelibrary.wiley.com/doi/10.1002/ese3.956#:~:text=Far%20from%20being%20low%20carbon,to%20justify%20on%20climate%20grounds.
[101] https://about.bnef.com/

Part C – White Hydrogen in Namibia, SADC, and Africa

Section 10: White Hydrogen in Namibia

What is the Status of White Hydrogen Exploration in Namibia?

Namibia has started geological surveys to assess natural hydrogen deposits, particularly in the Damara Belt. These studies aim to determine white hydrogen's feasibility as an energy source.[102]

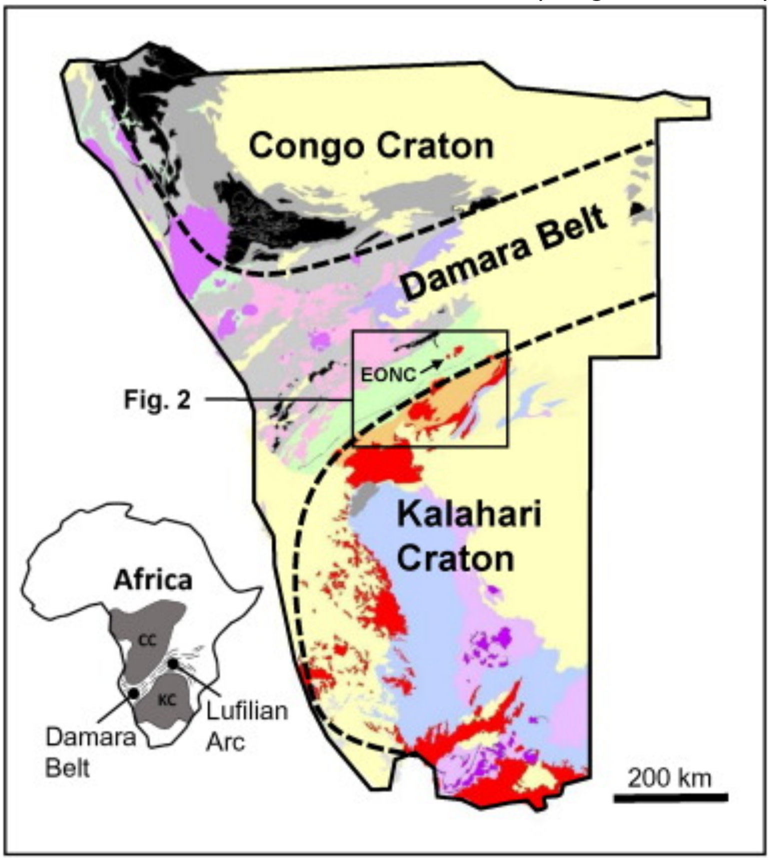


Figure 21: Potential concentration sites for white hydrogen in Namibia[103]

How Does White Hydrogen Impact Namibia's Energy Strategy?

- *Complements Green Hydrogen* – Offers a potentially lower-cost alternative.
- *Economic Growth* – Creates investment and job opportunities.
- *Export Potential* – Could be supplied to international markets.[104]

[102] https://www.namibian.com.na/white-hydrogen-study-in-namibia

[103] Shear-zone hosted copper mineralisation of the Omitiomire deposit — Structural controls of fluid flow and mineralisation during subduction accretion in the Pan-African Damara Belt of Namibia - ScienceDirect

[104] https://www.hydrogeninsight.com/

Section 11: Regional Developments in SADC and Africa

How is White Hydrogen Being Explored in the SADC Region?

Countries such as South Africa and Angola are conducting feasibility studies on white hydrogen potential, integrating it with existing energy policies.[105]

[105] https://www.leap-re.eu/hyafrica