

Global Renewable and Low-Carbon Gas Report

2021 edition

About IGU

The International Gas Union is the global voice of the gas industry. With more than 160 members in over 80 countries, covering 95% of the global gas market: from exploration and production of natural gas, low and zero carbon gas and technologies, to transit, pipelines, and LNG, and through distribution and use of gas, the IGU is the only international association covering the entire supply chain across all continents.

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Message from the President

Welcome to the inaugural edition of the International Gas Union's *World Renewable and Low-Carbon Gas Report*.

This is the first report in what is to become a new series. We made the choice to launch this report to demonstrate our support and appetite for the accelerated growth of the global renewable and low-carbon gas sector. Developing effective growth strategies, requires an understanding of the baseline, and that is what we aim to establish with this series. It will track the industry's progress, as it grows and develops over time.

Renewable gas and low-carbon hydrogen are two vital elements in an achievable energy transition. They will be critical for the global energy system to achieve the required levels of decarbonisation, fast enough to avoid irreversible climate change.

The clear message is that scale of projected supply is going to be more and more challenging to attain, without a rapid and significant increase in production. The current level of planned and installed production capacity for renewable and low-carbon gases appears negligible compared to the stated plans, and that must be changed.

As such, this report is a call to action on all fronts – policy, industry, and the financial community. We all need to play our part if there really will be a practicable gaseous energy revolution.

The IGU aspires for this report to develop into authoritative source of information on global renewable and low-carbon hydrogen gas, as our other flagship reports are on natural gas. We will tap into the IGU's wide-reaching global network and one of the most extensive gas industry knowledge bases in the world to make that possible. Over a thousand professionals participate in IGU's Committees and Task Forces. They produce insightful reports and design the Technical Program of one of the biggest global energy events, the World Gas Conference with the next edition in Daegu, Korea, in May of 2022.

I also take the opportunity to call on all IGU members and partners with renewable gas and low-carbon hydrogen projects to participate in the next year's edition of this survey. For more information, you can reach out to the IGU report study group leader or IGU Public Affairs.

I hope this report will be informative and inspire action in the global energy community to accelerate the production scale-up of the key renewable and low-carbon gas technologies.

Joe. M. Kang
President, IGU

Message from the Oxford Institute for Energy Studies

The Oxford Institute for Energy Studies (OIES), together with its partners in this project from the Sustainable Gas Institute, Imperial College, London and the Bureau of Economic Geology, University of Texas, Austin, has been delighted to work with the International Gas Union on the production of this renewable gas database report. While we recognise that this first edition has only be based on limited data, it has already produced some valuable insights, and we expect this to grow further as the data coverage increases in future editions.

We felt it particularly valuable to look at both biomethane and hydrogen in one report, as we see them playing complementary roles in decarbonisation of the global energy system and both are very relevant to the natural gas industry.

We look forward to continuing the co-operation with the International Gas Union over the coming years.

Martin Lambert

Senior Research Fellow, Oxford Institute for Energy Studies

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Executive Summary

As we release this first edition of the Global Renewable and Low-Carbon Gas Report, the world is about to find out what the path from Glasgow toward the desired success of Paris may look like. Representatives from over 100 countries are about to meet to negotiate a global consensus on climate change mitigation actions, and while the details are not yet known – the fact that a raising of global ambitions is required is undeniable.

Over the recent years, the momentum of supportive policy commitments toward reaching the goals of 2015 Paris Agreements has been growing – including, in no small part, plans and strategies to develop low-or-zero carbon hydrogen and renewable gas.

While natural gas, which currently provides around 25% of global primary energy supply, is the lowest carbon fossil fuel, there is growing recognition of the importance of low-carbon gases, as key decarbonisation actors. These include biogas, produced by anaerobic digestion and typically used for combined heat and power near the point of production; biomethane (also known as renewable natural gas) from upgrading biogas, and low-carbon hydrogen. A key question, however, is whether these low-carbon gaseous fuels can be developed fast enough and at a reasonable cost. Against that background, the International Gas Union, with support from the Oxford Institute for Energy Studies and its partners from Imperial College London and University of Texas, Austin, started launched this global renewable gas database project to track development of low-carbon and renewable gas supply around the world. As more projects are developed, and scope and coverage of the databases increases in parallel, this will provide the ability to track the extent to which actual project developments are consistent with ambitious goals which have been set.

For this first edition of the report, while it is recognised that the database currently has some gaps, it has been possible to benchmark data, particularly for some of the key countries, to provide confidence in the assessment of the current status.

These are the key conclusions of that assessment:

- Total global production of both biogas and biomethane is around 400 TWh¹, or around only **1% of total global natural gas production**. Over half of this production is concentrated in a few countries in Europe, with a further 25% in China.
- An estimate of sustainable biogas potential suggests that this could rise to around 20 times that level (so around **20% of global natural gas demand**) but our database does not indicate that there is sufficient momentum of projects under development for this potential to be realised in the near term.
- The production level for low-carbon hydrogen is similarly low, with only around **0.5% of current hydrogen production being from low-carbon sources**, that is only about 0.03% of global natural gas production. Despite significant focus on the role of hydrogen in the transition around the world, there has been only a very small increase in low-carbon hydrogen output in the last 5 years.
- A stronger policy focus on increasing production of low-carbon hydrogen is a positive force to grow the pipeline of hydrogen projects, which we expect to be reflected in future editions of this report.

¹ For consistency, we have tried to normalise units to TWh, since energy content is the important metric and volumetric measures can be confusing across different gases with different energy density. For readers familiar with bcm, 1 bcm of natural gas is approximately 10.4 TWh

- Green hydrogen is significantly more expensive than any other form of renewable gas, but costs are expected to fall, as the costs of both renewable electricity and electrolysers decrease over time. It is intended that as this database develops, more consistent analysis of actual trends in scale up of production and reduction in costs would be possible.
- While there is much stronger interest among policy makers in low-carbon hydrogen than biomethane, the current levels of production and the relative costs of biomethane and hydrogen suggest that it is **important to raise biomethane up the policy agenda.**
- Given the scale of the decarbonisation challenge, and the need for as many workable solutions as possible to ease the path to decarbonisation, **all forms of renewable gas should be pursued as quickly as possible.** This will require strong and clear policy support from governments globally, robust entrepreneurial initiative from the incumbent industry players and disruptors alike, and importantly – bankability and access to project finance.

This first edition of the IGU Global Renewable and Low-Carbon Gas Report is intended to set a baseline and to promote interest among policymakers, industry stakeholders, and other relevant players in all forms of renewable and low-carbon gas. The key ambition we set out for this series is to track progress of renewable and low-carbon gases from their current early days and small beginnings today to becoming important fuels in the future decarbonised energy system.



Introduction

The pace of the Energy Transition has been accelerating, particularly since the conclusion of the landmark Paris Agreement at COP 21 in December 2015. As this report is being released, a major review point is taking place in Glasgow, at the COP 26 meeting. Building on the Paris Agreement's ambition to limit global warming to well below 2°C, a total of 137 countries², including many major economies, made "Net Zero" emissions pledges, aiming that their economies should be carbon-neutral by a specific date, typically 2050, although by 2060 in the case of China. Key countries and regions to have made Net Zero commitments include the European Union (and individual member states), United Kingdom, Japan, South Korea, United States and Canada*. To take these and other national commitments under the COP process from pledge to reality, requires exceptional and rapid change in the entire global energy system, including the gas industry. The natural gas supply will need to progressively decarbonise by applying low, zero, and negative carbon technologies – such as carbon capture, hydrogen, and renewable gas. It also goes without saying that the natural gas value chain must operate as efficiently as possible, across every segment and on all continents – methane emissions should continue to be minimised and eliminated; end-use appliances must perform at the highest possible efficiency; reduced consumption through conservation and new technologies should be pursued.

Against that background there has been rapidly growing interest in renewable forms of gas, notably biomethane (also known as renewable natural gas – RNG – in North America) together with low-carbon hydrogen and its derivatives, like ammonia. A key outstanding question is whether these renewable and low/zero carbon forms of gas can be developed fast enough, and at a reasonable cost, consistent with decarbonisation requirements of the Paris Agreement. The International Gas Union is therefore undertaking to develop a global database to track the baseline and current status of biomethane and low/zero carbon hydrogen gas production projects, thereby gauging the state of this new growing market. This will enable a realistic assessment of the current level of production, the likely near-term additions in supply from projects under development, and the required steps to achieve the scale of production required to meet decarbonisation goals. It is envisaged that over time, this report will encapsulate a truly global state of play in zero and low-carbon gas.

In this first edition of IGU's global renewable gas database, the data that we were able to gather across IGU's global network has shown some gaps³. For many countries collecting such data can be challenging, and, in some cases, there are simply very few renewable gas plants to report on; however, it is expected that the scope of coverage of the database will expand over time in future editions of this report, as our global network becomes increasingly familiar with the data gathering process⁴.

² <https://www.visualcapitalist.com/race-to-net-zero-carbon-neutral-goals-by-country/>

³ There are several explanations for shortage on data, with one being rooted in the nascent nature of the industry, and therefore scarcity in some places or dispersed nature of repositories in others, but there is also a need for higher transparency.

⁴ Here we will also build on our experience in developing the well-established IGU Global Wholesale Natural Gas Pricing report, which also started from a similar state with patchy data, and now covers 98% of the global gas consumption.

* In the time of editing this report, the Kingdom of Saudi Arabia also announced its pledge to reach net-zero by 2060.

Types of Renewable Gases

More details are given in the Appendix, but the following are brief explanations of types of renewable gases covered by this report:

Biogas (or “Raw Biogas”): A mixture of gases, predominantly methane and carbon dioxide produced by anaerobic digestion of biomass (typically agricultural waste, manure, sewage, municipal waste). This process makes use of the methane that would have otherwise been released into the atmosphere; hence, having a direct GHG offsetting value.

Biomethane (or Renewable Natural Gas): Raw Biogas from anaerobic digestion which has been upgraded to remove CO₂ and other impurities such that it is of a comparable quality to natural gas – thus it can be used as a direct supplement/substitute for natural gas in the existing infrastructure and equipment. Biomethane can also be manufactured from woody biomass in a thermal gasification process although this is much less common than production via anaerobic digestion.

Blue Hydrogen (or hydrogen from natural gas with carbon capture and storage): Hydrogen produced from natural gas with the addition of carbon capture and storage to remove emissions from the production process.

Green Hydrogen (or renewable hydrogen): Hydrogen produced via electrolysis (splitting water into hydrogen and oxygen) using renewable electricity.

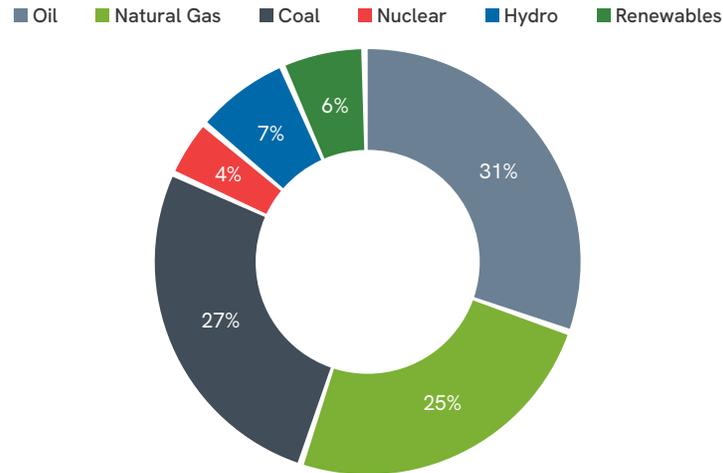
Low-Carbon Hydrogen: The term used in this report as a collective term for blue and green hydrogen. The actual carbon footprint of a particular low-carbon hydrogen supply depends on specific factors like the percentage of CO₂ captured and the carbon footprint of the electricity used for electrolysis.

Report Scope

The scope of the database and this report covers biomethane and low-carbon hydrogen projects which are *operational, under construction* or at various stages of development (as defined in the Appendix). This edition is the first step in our endeavour to develop a realistic assessment of the baseline current and expected production levels of both biomethane and low-carbon hydrogen, as well as these fuels’ production cost trends. This work is intended to help industry and governments to formulate their strategies around the global low-carbon gas market development.

This first edition of the report sets the scene, providing detail on the background and context (section 2), on the methodology for data collection and analysis (section 3), analysis of the data, initial conclusions, and focus sections for those countries where the most data has been received (Section 4). More details on the methodology are provided in the Appendix.

FIGURE 1: SHARE OF PRIMARY ENERGY BY FUEL



Source: analysis of data from BP Statistical Review 2021

As shown in Figure 1, natural gas provided around 25% of total global primary energy in 2020 (138 EJ out of a total of 557 EJ)⁵. Apart from short-term declines in 2009 and 2020, natural gas production has been growing steadily and is well spread across all regions of the world (Figure 2). Total global gas demand in 2020 was 3,850 bcm, equivalent to around 40,000 TWh.

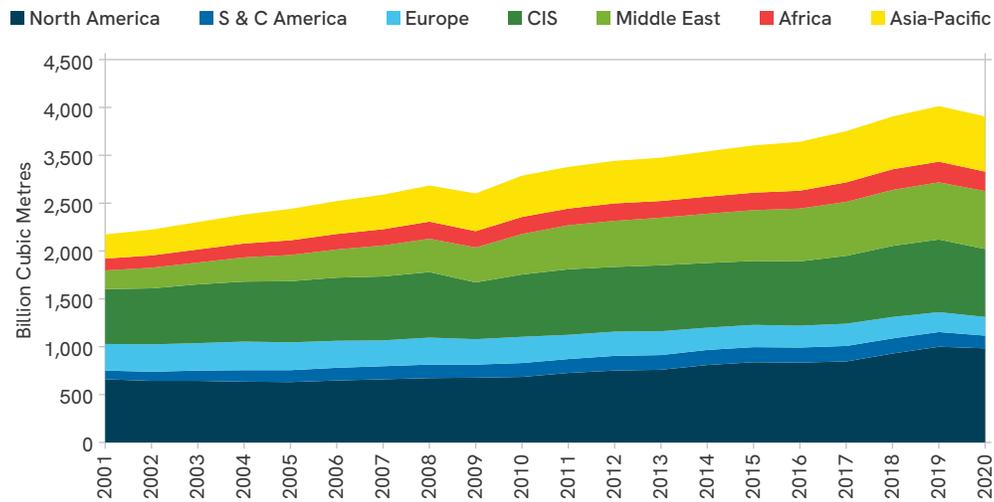
By contrast, total global production of biogas and biomethane (in 2018) is estimated around 35 Mtoe (400 TWh, 40 bcm of natural gas equivalent)⁶ so just 1% of the size of total natural gas production. A little over half of that production (18.5 Mtoe/215 TWh) is concentrated in a few countries in Europe, with a further 25% (7.5 Mtoe/87 TWh) in China. Of the total biogas production in Europe, only around 10% (24 TWh) is upgraded to biomethane, suitable for injection into the natural gas grid. (The rest is consumed in small volumes near the point of production – often in rural communities for combined heat and power production.)⁷

⁵ BP Statistical Review (2021): <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>

⁶ IEA Outlook for biogas and biomethane (2020): <https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth>

⁷ European Biogas Association (2021) <https://www.europeanbiogas.eu/eba-annual-report-2020/>

FIGURE 2: NATURAL GAS PRODUCTION BY REGION 2001-2020



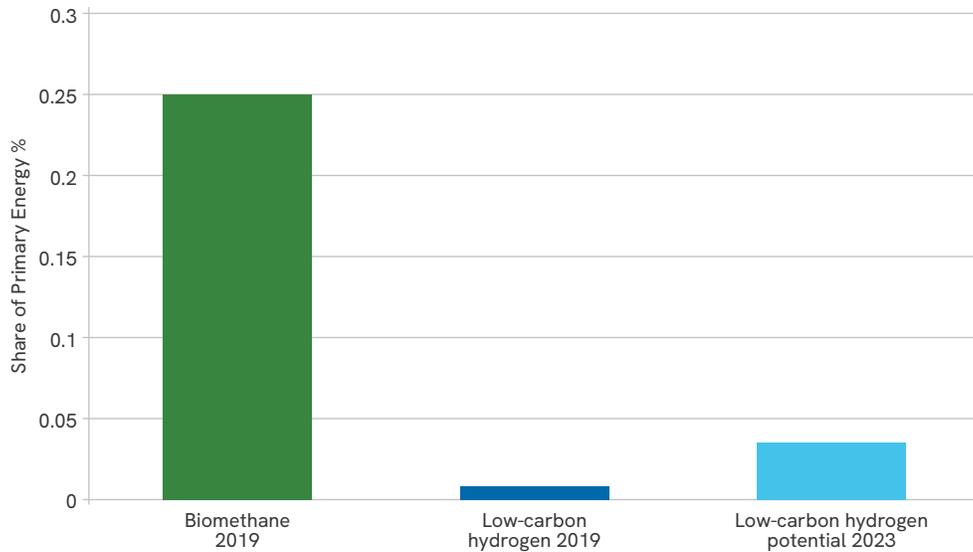
Source: BP Statistical Review 2021

While current biogas and biomethane production is only around 35 Mtoe, total sustainable production potential is estimated to be over 20 times that level at 730 Mtoe (8,500 TWh).⁸ At this potential level, if all biogas were upgraded to grid quality⁹, biomethane could provide around 20% of today's natural gas demand, providing a significant decarbonisation benefit reducing global emissions by around 1.5 Gt CO₂e. However, that also requires a very rapid build-up of biomethane production capacity. It is important to stress that this production level is considered sustainable, largely from waste streams, including forest residues used for gasification, so does not result in additional land use change, competition with food production or other negative environmental impacts.

⁸ IEA Outlook for biogas and biomethane (2020)

⁹ As detailed further in the Appendix, biogas is a mixture of CO₂, methane and other impurities, and can be upgraded to a high percentage of methane suitable for injection into the natural gas grid.

FIGURE 3: SHARES OF PRIMARY ENERGY OF RENEWABLE GASES



Source: Author's analysis

For hydrogen, current total demand for pure hydrogen is estimated to be 70 million tonnes per year (around 2,500 TWh energy content), mostly for oil refining, petrochemicals, and ammonia production. Most of this hydrogen has typically been produced from reforming natural gas, in a manufacturing process which typically emits around 10 tonnes CO₂ per tonne of hydrogen. The interest in low-carbon hydrogen has been growing, as it offers significant benefits as a potential future energy carrier. As detailed in the Appendix the principal technologies for producing low-carbon hydrogen are; (a) reforming of natural gas combined with carbon capture and storage (so-called blue hydrogen), and (b) splitting water into hydrogen and oxygen using electrolysis with renewable electricity (so-called green hydrogen).¹⁰

In 2019, total low-carbon hydrogen production was estimated at 0.36 million tonnes per year (around 13 TWh energy content) around 0.5% of total pure hydrogen demand, and nearly all produced from natural gas using carbon capture and storage) an increase of only 0.13 million tonnes per year since 2013. This low level of production is forecast, based on announced projects to nearly quadruple to 1.46 million tonnes by 2023.¹¹

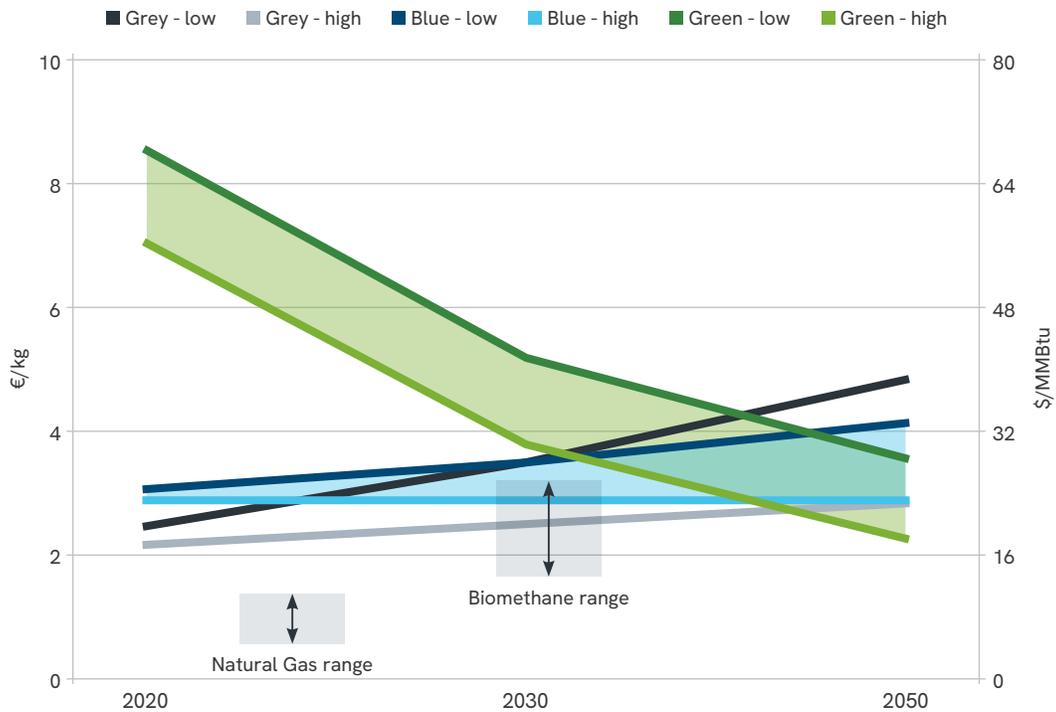
With a quarter of the world's energy demand today met by gaseous fuels, at present predominantly natural gas, it is clear that the gaseous component of the world's energy system is foundational, and for any realistic rapid energy transition to occur, the gas network must continue to play a critical role. It is also clear that current production of renewable/low-and-zero-carbon gases (biogas, biomethane and low-carbon hydrogen) is very small in that context. This underlines the scale of the challenge in ramping up production significantly in the coming years. It is also noteworthy from Figure 1 that total non-hydro renewables contribution to primary energy is only 6%, so the scale up challenge also applies to all forms of renewable energy and not just renewable gases. This background is one of the key drivers for establishing the global renewable gas database, which forms the basis of this report. Over the coming years it will be important to form a realistic assessment of the scale-up rate of renewable gas production to ensure that sufficient action is being taken by industry, governments, and all relevant stakeholders for actual production to be available to meet required targets.

¹⁰ Hydrogen pyrolysis is another potential technology, but it is currently at quite early stage of development.

¹¹ <https://www.iea.org/reports/hydrogen>

In addition to scale-up of low-carbon gas production volumes, a related challenge is to drive down the costs of these fuels. Figure 4 shows an estimate of costs of “blue” and “green” hydrogen and a comparison with typical costs of biomethane and wholesale natural gas prices. There are necessarily broad ranges around such estimates, as costs will vary depending on specific circumstances, but several important observations can be made.

FIGURE 4: RENEWABLE GAS PRODUCTION COST COMPARISON



Source: OIES analysis based on Zero Emission Platform data

- All forms of renewable gases are more expensive than their fossil-derived counterparts, so there will be a strong reliance on government policy to create a business case for significant investments in renewable gases.
- Ultimately the costs will be borne either by energy consumers, or taxpayers, so there will need to be sufficient community acceptance to make such government policy politically acceptable.
- Carbon capture and storage adds a relatively small premium to the cost of grey hydrogen and if, as expected, carbon prices increase over time, blue hydrogen can become more economic than grey hydrogen.
- Green hydrogen is significantly more expensive than any other form of renewable gas, but costs are expected to fall, as the costs of both renewable electricity and electrolyzers decreases over time. While the graph shows the cost of green hydrogen approaching the cost of blue hydrogen during the 2030s, whether that actually happens will depend on whether production ramps up sufficiently to enable the economies of scale – from a baseline that is currently quite far from that.

It is intended that as this database develops, more consistent analysis of actual trends in scale up of production and reduction in costs will be possible.

2. Methodology

Data collection was carried out via a survey template distributed to the IGU network in each country/region. Data was requested as one record for each production facility/project. The survey requested data on plants or projects with a capacity >1MW, since the primary focus is on production at scale, which will be significant in the overall energy system. Small pilot/demonstration projects are therefore out of scope. The key data requested were related to the status of each plant (for example whether operational, under construction or at an earlier stage of development, the expected start-up date, and annual production volume. In addition, the survey sought to gather anonymised cost information (in subsequent iterations of the survey we expect that the quality of such data will increase).

In this first edition of the survey, data has been received covering 21 countries, across five continents, and around half of these allowed for robust analysis and conclusions. These countries are reported in Section 4. Where possible, we have also cross-checked the information against other available public sources, including data from the International Energy Agency, the European Biogas Association, as well as independent research by the project team. For those countries where a focus section has been included, we are reasonably confident that the data provides a realistic picture of the renewable gas production situation in that country.

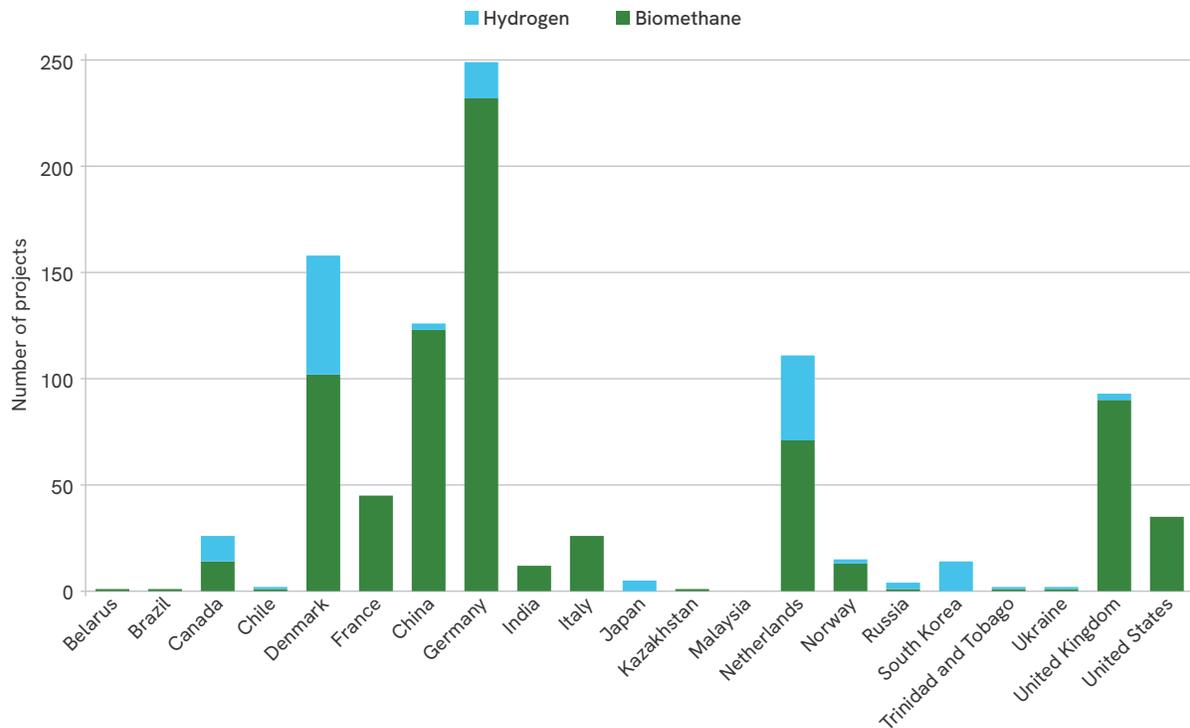


3. Analysis and conclusions

Summary Results

The charts below summarise data received, supplemented by data from the analysis team as appropriate. It can be seen that the number of biomethane plants and projects currently far exceeds the number of low-carbon hydrogen projects. This is consistent with the total production of biomethane being higher than the production of low-carbon hydrogen as noted in Section 1. The map shows the geographically extensive coverage of data received, providing a sound basis for further refinement in future editions of the report. Key country analysis is included in Section 4 below.

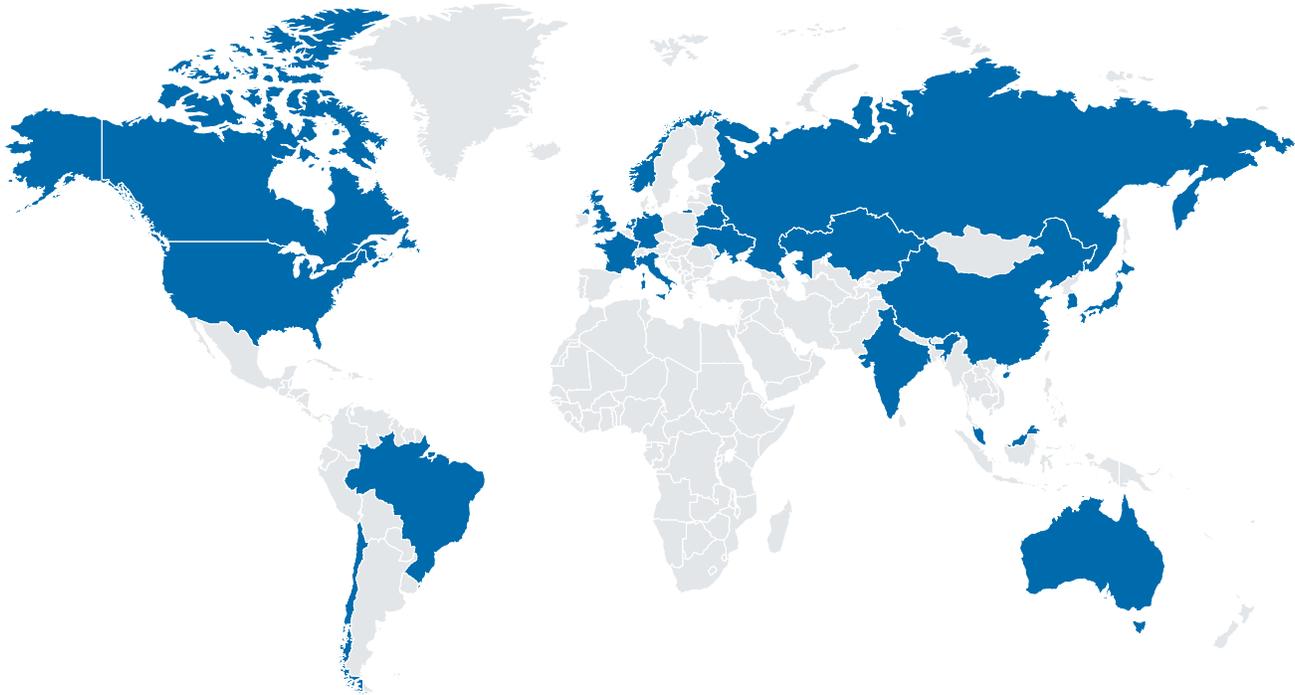
FIGURE 5: NUMBER OF HYDROGEN AND BIOMETHANE PLANTS REPORTED IN DATABASE



Across the countries covered in the focus sections, there are some key observations:

- Biogas and biomethane currently have a greater number of plants and higher production volumes than low-carbon hydrogen. China and Europe are the major producers of biomethane.
- In Europe (e.g. in Denmark and Germany) an increasing amount of biogas is being upgraded to biomethane. Denmark is noteworthy for its ambition to achieve 100% biomethane in its gas grid by 2040.
- Only limited quantities of raw biogas are upgraded to biomethane. In this first edition of the survey we had only requested data regarding biomethane injected into the grid, but some countries (e.g. Malaysia with no biomethane injection) reported raw biogas anyway. In future editions of the report, we will also request data for raw biogas to assess the potential for this to be upgraded to biomethane.

FIGURE 6: MAP OF GLOBAL COVERAGE OF IGU RENEWABLE GAS DATABASE



Key Initial Learnings

Biogas and Biomethane

Based on the survey data gathered and additional research, in the main markets of China, Europe and North America, most biogas is produced by anaerobic digestion and typically used for generating electricity or for combined heat and power generation close to the point of production. As such, it provides a useful source of dispatchable renewable energy, but it only has a relatively indirect link to the mainstream natural gas business. In all markets, only a small proportion of biogas is upgraded to grid quality biomethane where it has a more direct link to the natural gas business. The scale of biogas and biomethane production added together is only around 1% of global natural gas production. An estimate of sustainable biogas potential suggests that this could rise to around 20 times that level (so around 20% of global natural gas demand) but our database does not indicate that there is sufficient momentum of projects under development for this potential to be realised.

Hydrogen

The production level for low-carbon hydrogen is only around 0.5% of current hydrogen production, which is about 0.03% of global natural gas production, with only a very small increase in low-carbon hydrogen output in the last five years. The stronger policy focus on increasing production of low-carbon hydrogen, is a positive force to create a stronger pipeline of hydrogen projects, which we expect to be reflected in future editions of this report.

Infrastructure

In terms of infrastructure, biomethane also has the advantage that it can be blended seamlessly with natural gas in existing gas networks, without requiring any changes to end use appliances.¹² It has also been demonstrated (for example in the Netherlands) that natural gas pipelines can be converted to carry 100% hydrogen, but this requires significant investment, around ¼ of the cost of building new hydrogen pipelines. Equipment and appliances at the point of use would also need to be hydrogen-ready.

While there is much stronger interest among policy makers in low-carbon hydrogen than biomethane, the current levels of production and the relative costs of biomethane and hydrogen do not yet provide confidence that low-carbon hydrogen will grow rapidly. Given the scale of the decarbonisation challenge, and the need for as many workable solutions as possible to ease the path to decarbonisation, all forms of renewable gas should be pursued as quickly as possible. This will require strong and clear policy support from governments globally.



¹² There can be minor quality differences between natural gas and biomethane which may require adjustments to metering systems but these can be resolved relatively easily.

4. Country Focus Section

For each country where sufficiently consistent data was available, we have included a focus section below.

Summary observations from the focus country analysis:

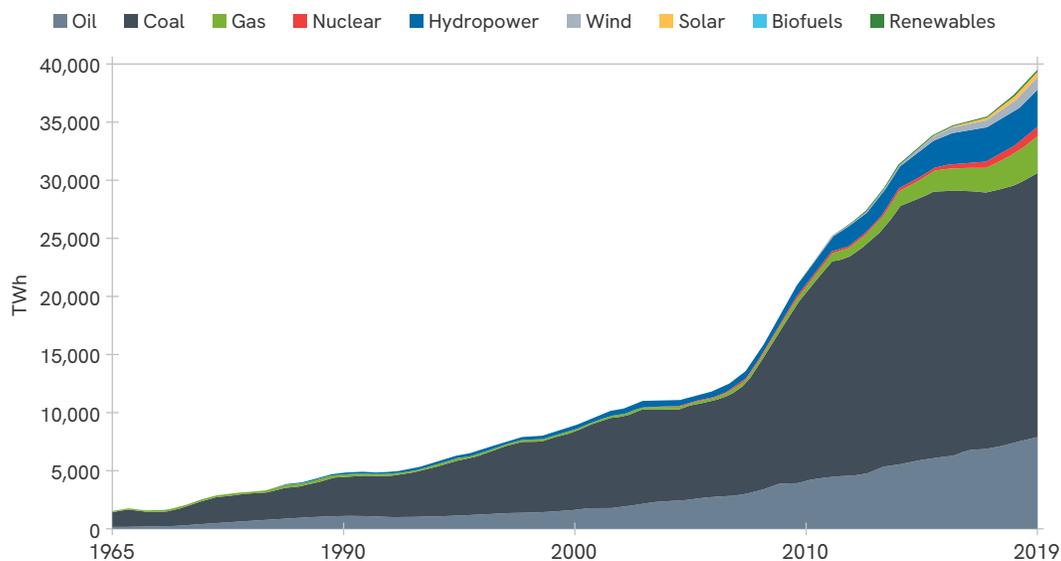
- Biogas and biomethane currently have a greater number of plants and higher production volumes than low-carbon hydrogen. China and Europe are the major producers of biomethane.
- In Europe (e.g. in Denmark and Germany) an increasing amount of biogas is being upgraded to biomethane. Denmark is noteworthy for its ambition to achieve 100% biomethane in its gas grid by 2040.
- Only limited quantities of raw biogas are upgraded to biomethane. In this first edition of the survey we had only requested data regarding biomethane injected into the grid, but some countries (e.g Malaysia with no biomethane injection) reported raw biogas anyway. In future editions of the report, we will also request data for raw biogas to assess the potential for this to be upgraded to biomethane.

4.1 China

Key Decarbonisation and Renewable Gas Targets

On 12 December 2020, China updated NDC targets at the 2020 Climate Ambition Summit. As the world's most populous economy and the largest emitter of greenhouse gases, China will aim to have CO₂ emissions peak before 2030 (previous NDC said peak around 2030)¹³ and strive for carbon neutrality before 2060. As the largest coal consumer in the world (Figure 7), fuel switching including hydrogen and renewable natural gas can be a very important pathway for carbon emissions reduction and sustainable development.

FIGURE 7: ENERGY CONSUMPTION BY SOURCE IN CHINA



Source: BP Statistical Review of World Energy

¹³ <https://www.iea.org/policies/12987-carbon-neutrality-target-before-2060?country=People%27s%20Republic%20of%20China>

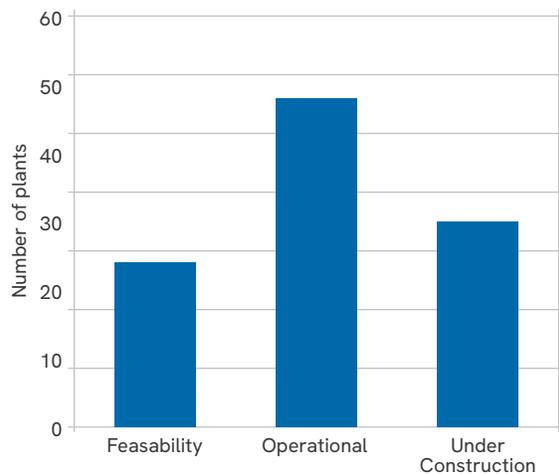
Analysis of survey data

Biomethane

The IGU survey shows that there are 102 large-scale biomethane plants, which are distributed in various provinces of China: 48 operational, 30 projects under construction, and 24 at the feasibility stage (Figure 8). More than half of the 48 projects that went into production received government construction incentives. These projects all use *biomass* (typically, agricultural waste, animal waste, industrial waste water) as a source, and *anaerobic digestion* as production technology. The earliest project start time reflected in the survey was 2011, and the latest came online, as recently as 2020, with more planned in the coming years.

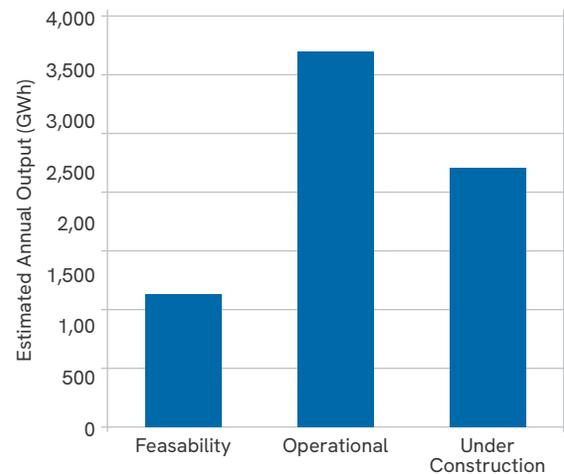
Based on the data we obtained, the 48 operational plants are expected to produce 3,650 GWh biomethane every year, and the total expected production from plants in the database is 7,458 GWh (around 7 bcm natural gas equivalent). The actual total production number could differ, because some of the projects at the feasibility stage do not have an estimated volume for output. However, whether these expected volumes can be realised will depend on the strength of China's policy support and the maturity of the projects' business models.

FIGURE 8: NUMBER OF BIOMETHANE PLANTS IN CHINA BY STATUS



Source: Author's analysis

FIGURE 9: ESTIMATED OUTPUT OF BIOMETHANE PLANTS IN CHINA BY STATUS

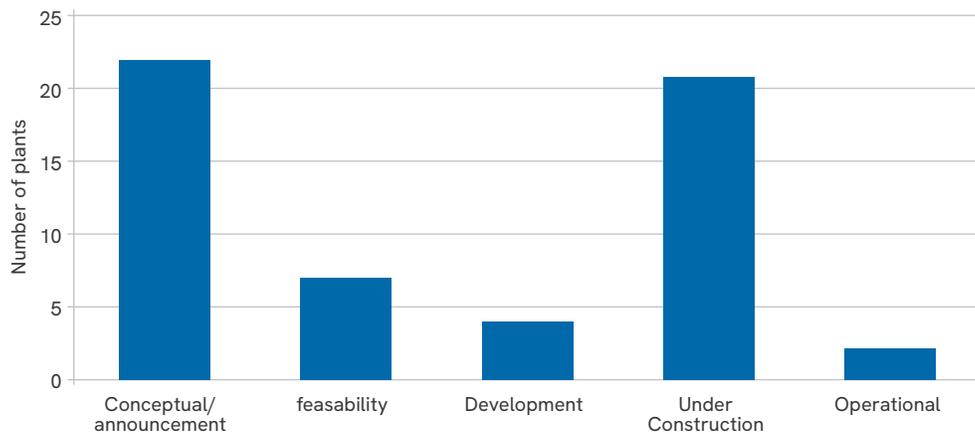


Source: Author's analysis

Hydrogen

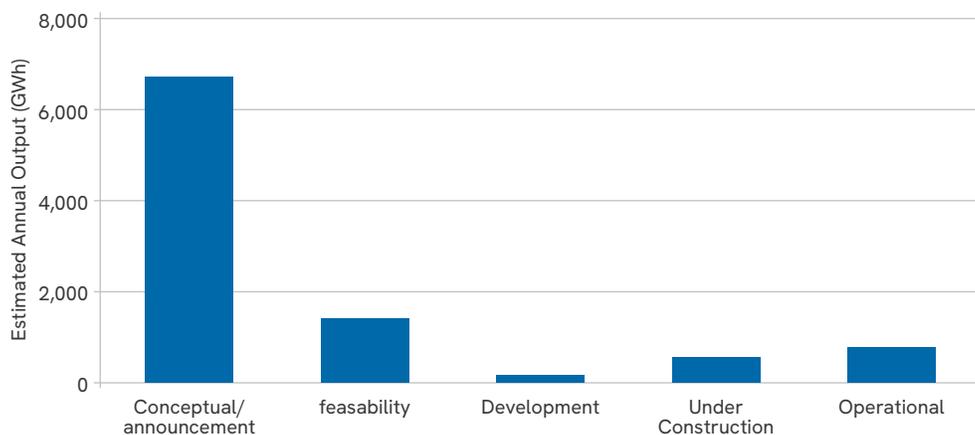
In the context of China’s goal to achieve carbon peak and carbon neutrality, China is encouraging the development of green hydrogen – i.e production using electrolysis with wind or solar power. In contrast to biomethane, the survey counts a total of 56 low-carbon hydrogen plants in China, of which only two are operational (Figure 10). However, there are 21 plants under construction, and 22 new projects announced with significant government investment. Many of the projects under construction will start operating at the beginning 2022 or 2023. Although the survey data on investment are not complete, it suggests a total of 150 billion CNY (around 23 billion USD) investments. The annual output chart (Figure 11) is only an estimate, calculated based on data received, and as such may not present the actual potential production. If all projects, including those at the very early conceptual stage, came to fruition, total hydrogen production would be around 10 TWh or 1 bcm natural gas equivalent. Compared to China’s ambitious goal for hydrogen, these projects may not represent the full picture, but they help us better understand the progress and plan China has been making toward its target.

FIGURE 10: NUMBER OF HYDROGEN PROJECTS IN CHINA BY STATUS



Source: Author’s analysis

FIGURE 11: ESTIMATED OUTPUT OF HYDROGEN PLANTS IN CHINA BY STATUS



Source: Author’s analysis

Evolution of Policy in China

China has been a pioneer in biogas, with the industry's roots going back to the 19th century. The State has been investing heavily in biogas since 2001, with about 23 million biogas digesters built between 2001 and 2010. At the same time, many medium- and large-scale biogas plants were constructed.

In 2015, China began to transform and upgrade rural biogas, and the central government invested mainly to support the construction of large-scale biogas projects and biomethane pilot projects. Ministry of Agriculture (MOA) and the National Development and Reform Commission (NDRC) published its 2015 Working Plan of "Upgrading and Transforming Rural Biogas Project," that targets building large-scale biogas projects (with daily production of above 500 m³), and to implement biomethane demonstration projects (where the methane content exceeds 95%; 1 m³ biogas can usually be upgraded to 0.6 m³ biomethane). The central government funded 25 biomethane demonstration projects for the first time in 2015, which was followed by the approval of 22 and 18 more biomethane projects in 2016 and 2017, respectively^{14 15}. According to the Statistics of the Ministry of Agriculture and Rural Affairs of China, more than 7,700 large-scale biogas and biomethane projects have been built in China, with an annual output of more than 1.3 billion cubic meters, supplying gas to nearly 500,000 households. Among them, there are more than 20 large-scale bio-gas projects with an annual gas output of more than 300 million cubic meters. MOA expects the number of BNG projects to increase to 197, and biogas production to increase to 20.7 Gm³ by 2025⁸.

When it comes to hydrogen, China is also the largest hydrogen producer globally with 25 million tons/year of producing capacity, according to the China Hydrogen Alliance. In 2018, the annual production of hydrogen was 21 million tons, when converted to energy content using heat value, that is around 2.7% of China's energy system. Based on their forecast, by 2030 the revenue of the country's hydrogen energy industry will reach 1 trillion yuan (\$152.6 Billion in 2021 equivalent), and demand for hydrogen will reach 35 million tons, accounting for at least 5% of China's energy system (Figure 2).

China has been increasing investments in hydrogen, especially low-carbon hydrogen energy with central and local government policy guidance to explore the hydrogen industry which has been linked in the country's 14th Five-Year Plan 2021-25 as one of the six future industries along with rechargeable batteries¹⁶. China's 14th Five Year Plan labels hydrogen a "frontier" area that the country pledges to advance. Even though a national strategy for hydrogen development has yet to be developed, 16 provinces and cities have launched their own five-year plans that specifically feature hydrogen. For example, Beijing includes accelerated planning and construction of hydrogen refuelling stations. Jiangsu Province's plan includes development of hydrogen fuel cell vehicles and hydrogen fuelling infrastructure¹⁷.

¹⁴ <https://www.mdpi.com/2071-1050/12/4/1490>

¹⁵ <https://www.mdpi.com/2071-1050/12/4/1490>

¹⁶ <https://www.globaltimes.cn/page/202104/1220923.shtml>

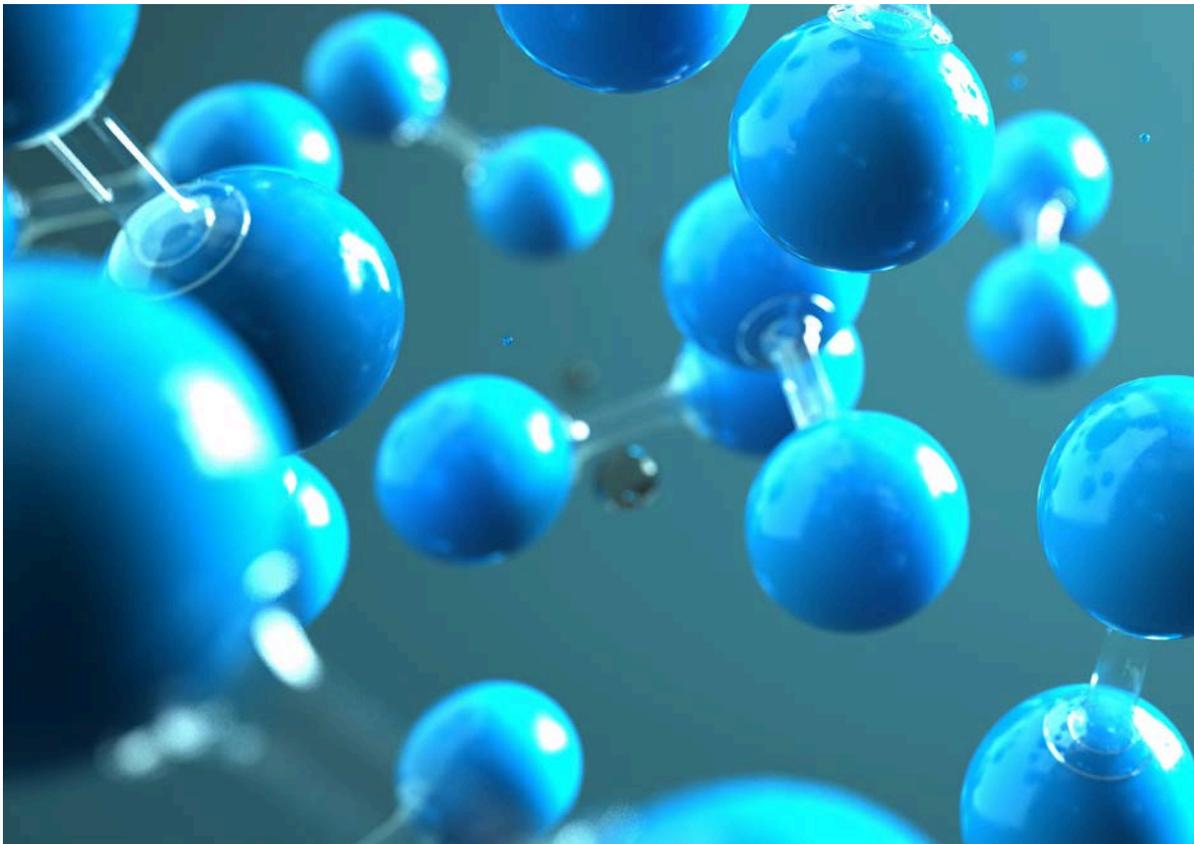
¹⁷ <https://asia.nikkei.com/Spotlight/Caixin/China-s-hydrogen-roadmap-4-things-to-know>

Conclusion - China

Although China has been utilising biogas for a long time, China's biomethane industry relies heavily on policy and most of the projects have been relying on government support. Biogas-to-biomethane plants are continually being built and the production of biomethane is expected to grow in the future. Economic analysis by an IGU analyst in China highlights several challenges that must be overcome for biomethane to grow to its full potential, namely:

- Feedstock supply (agricultural waste, animal waste, etc.) is a major challenge, by availability and price fluctuations.
- Biomethane can be too expensive to be connected to the city gas grid because most plants are situated in rural areas far away from major demand centers.
- Overall, at present biomethane projects are not economic in China having to rely on a government subsidy to survive. This holds both for plants in operation, which without clear incentives are struggling to run profitably, as well as for projects that are under construction that are likely to be halted for economic reasons.

There is a significant pipeline of green hydrogen production projects in China and a large amount of downstream hydrogen investment has contributed to the planning and implementation of many projects. However, uncertainty remains regarding the rate of progress of the many early stage projects and the number and scale of actual green hydrogen production will largely rely on policy development, technology breakthrough and reduction of production costs.

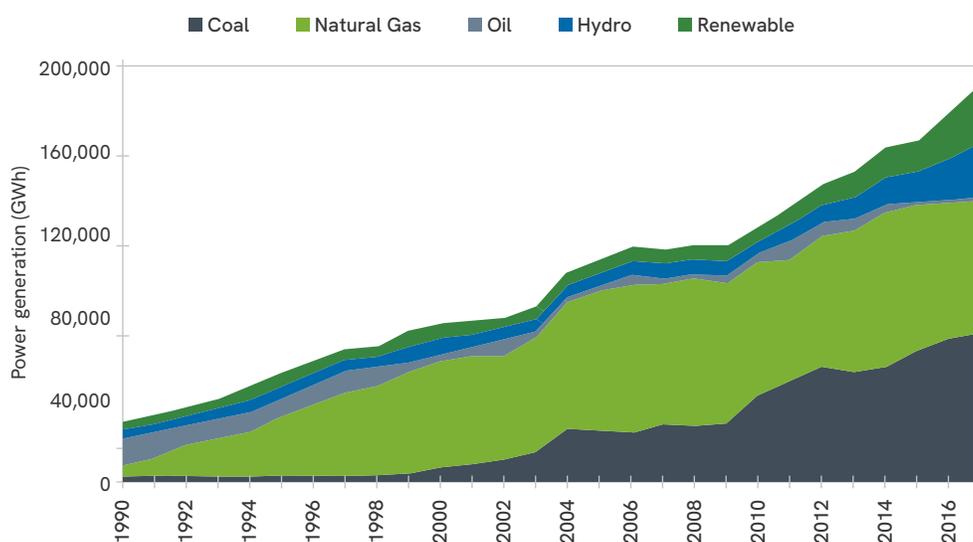


4.2 Malaysia

Key Decarbonisation and Renewable Gas Targets

Malaysia's NDC includes a target of reducing its greenhouse gas (GHG) emissions intensity of GDP by 35% by 2030 relative to 2005, and by up to 45% conditionally to international support¹⁸. While the share of renewable generation in Malaysia's electricity system (Figure 12), has been increasing since 2010, so has the use of coal representing today around 30% of total power generation. The Ministry of Energy, Green Technology and Water (KeTTHA), Malaysia set a target of near to 18 GW of installed renewable energy capacity by 2035, to increase the share of renewables to 40 % of the national power generation mix¹⁹. Sources that qualify as renewable energy include: biogas, biomass, municipal solid waste (MSW), small hydro and solar photovoltaic.

FIGURE 12: POWER GENERATION BY SOURCE IN MALAYSIA



Source: UN energy statistics

The biogas industry in Malaysia is currently being driven primarily by palm oil mills and biogas capture from landfills. The Palm Oil Mill Effluent (POME) is high in organic carbon loading and also releases methane into the atmosphere during decomposition. With the palm oil industry growing year on year, capturing methane from these waste materials presents a unique opportunity in high production countries like Malaysia, Indonesia, and Thailand. As of the end of 2018, Malaysia had 451 palm oil mills operating. The mills generate 68 million m³ of POME as a result. If all this effluent were digested anaerobically, it can generate over 500 MW of electricity for the mills (calculated)⁹.

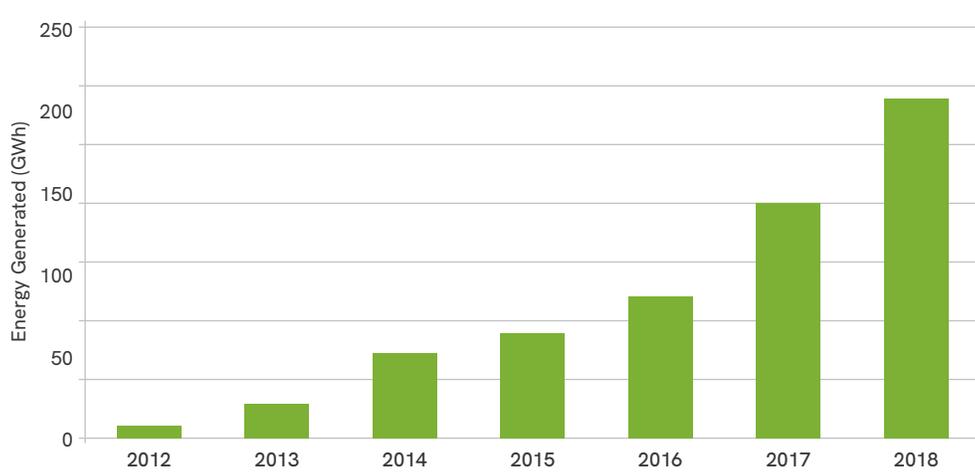
In 2019, Malaysia had ~68 MW of installed biogas capacity under a feed-in-tariff scheme with an additional 73 MW approved and waiting commencement. According to World Biogas Association (2019)²⁰, the biogas industry in Malaysia has grown by 400% since 2014 (Figure 13). A total capacity of 410 MW from biogas is targeted by 2028.

¹⁸ <https://www.iea.org/policies/11766-nationally-determined-contribution-ndc-to-the-paris-agreement-malaysia?country=Malaysia&qs=Malays>

¹⁹ Optimal Biomethane Injection into Natural Gas Grid – Biogas from Palm Oil Mill Effluent (POME) in Malaysia

²⁰ http://www.worldbiogasassociation.org/wp-content/uploads/2019/03/WBA-malaysia-4ppa4_v1.pdf

FIGURE 13: BIOGAS PRODUCTION IN MALAYSIA



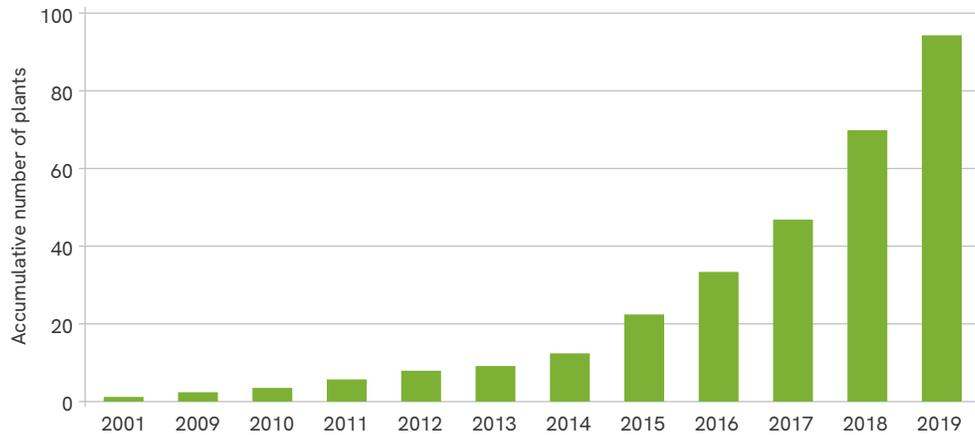
Source: World Biogas Association

Analysis of survey data

The survey covered 85 biogas projects, which became operational mainly between 2015 and 2019 (Figure 14). The earliest projects date back to 2001, and all the plants are operational, with capacity varying from 0.064 to 4.06 MW, but no biomethane upgrading capacity. Similar to the cumulative number of plants, the cumulative capacity of these plants has been growing rapidly since 2015 (Figure 15). The total capacity of biogas plants was 159.65 MW in 2019. This number is close to what was provided in Statista²¹. Compared to the 2028 target of 410 MW, the capacity needs to be tripled.

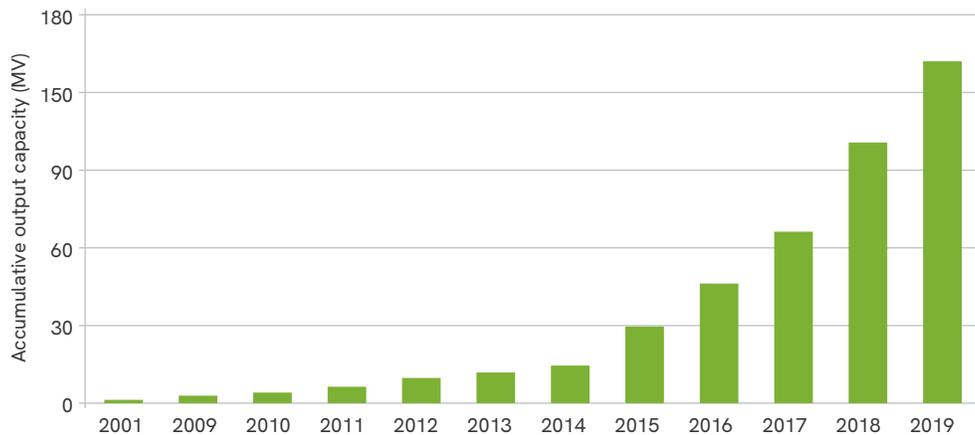
²¹ <https://www.statista.com/statistics/1019463/malaysia-biogas-energy-capacity/>

FIGURE 14: CUMULATIVE GROWTH IN NUMBER OF BIOGAS PLANTS IN MALAYSIA



Source: Author's analysis

FIGURE 15: CUMULATIVE GROWTH IN CAPACITY OF BIOGAS PLANTS IN MALAYSIA



Source: Author's analysis

Conclusion - Malaysia

Biogas plant numbers and capacity are expected to grow for the next decade to meet the national target. Malaysia is the second largest producer and exporter of palm oil in the world, so Palm Oil Mill Effluent (POME) brings a unique opportunity for Malaysia biogas development. A large amount of livestock manure, agricultural residues, food waste and sewage also provide an opportunity for biogas growth in Malaysia. However, there are also challenges – as most palm oil mills are in remote areas, they are not always connected to the grid or are not connected to the high-voltage transmission grid. This leads to either inability to make use of the FIT incentives, or higher upfront expenditure to build infrastructure. This is being addressed by the government, but infrastructure upgrades are long term projects. Insufficient funds for feed in tariff and high opportunity cost are also barriers for the government to overcome. Therefore, the government is working on a variety of programs and reforms to achieve the ambitious target.

4.3 Netherlands

Key Decarbonisation and Renewable Gas Targets

The first government support for production of biogas in the Netherlands started in the late 1990s. Initially, the focus had been on production of biogas combined with direct consumption, mostly in smaller CHP (combined heat and power) units, thus circumventing the need for expensive biogas upgrading to grid grade quality and fitting with the Dutch energy policy landscape of strong support for CHP. Later, in the 2000s the industry's focus shifted towards the production of grid quality biomethane.

In May 2019, the Government of the Netherlands passed the Climate Act with a target to reduce greenhouse gas emissions by 49% by 2030, compared to 1990 levels and by 95% by 2050. This was closely followed by the National Climate Agreement in June 2019, setting out more detailed plans for each sector. Achieving the 49% reduction by 2030 will be challenging – since 2019 total emissions were 184 million tonnes CO₂e, only a 17% reduction from 1990 levels.²³

The Netherlands does not have firm targets for biomethane production, but in 2017 the biomethane industry formulated an ambition in the “Roadmap Green Gas” for 1.2 bcm (12 TWh) biomethane production by 2020 and 3.7 bcm (37 TWh) by 2030.²⁴ Later, in the Climate Agreement²⁵ an ambition was formulated of 70 PJ or 2 bcm. By contrast, total natural gas consumption in the Netherlands is around 330 TWh²⁶ or 34 bcm.

For hydrogen, both the Climate Agreement as well as the Netherlands National Energy and Climate Plan target an installed electrolyser capacity of 3-4 GW in 2030. This capacity should run on renewable electricity, and consequently requires at least a similar amount of additional renewable electricity production capacity to be realised by that time. The document also mentions blue hydrogen (i.e. produced from natural gas with CO₂ capture), but gives no specific numbers for this option.

Analysis of survey data

Biomethane

The survey included 44 operational biomethane plants. Unfortunately, the data on annual production was not complete, but where necessary we estimated production based on stated capacity (assuming 6000 operating hours per year). This gives an estimated annual production of 2.2 TWh. To validate this data, we compared with the statistical report of the European Biogas Association which states a total of 51 biomethane plants in 2019 producing 1.5 TWh (an increase of 0.5 TWh from 2018), and data from Statistics Netherlands gives a number of 1.8 TWh. Thus, it is reasonable to assume a total production around 2 TWh. In any case, however, these estimates are still far short of the 12 TWh target for 2020 set in the “Roadmap Green Gas” in 2017 (see above). In addition, the database includes a further seven plants under construction, with a total estimated output of 0.7 TWh, and 16 plants at the “Detailed Engineering” stage with a total estimated output of 1.2 TWh, bringing the expected near-term production potential to around 4 TWh (or 0.4 bcm.) Figure 16 shows a breakdown of number of plants and output by stage of development.

²² <https://www.klimaataakkoord.nl/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands>

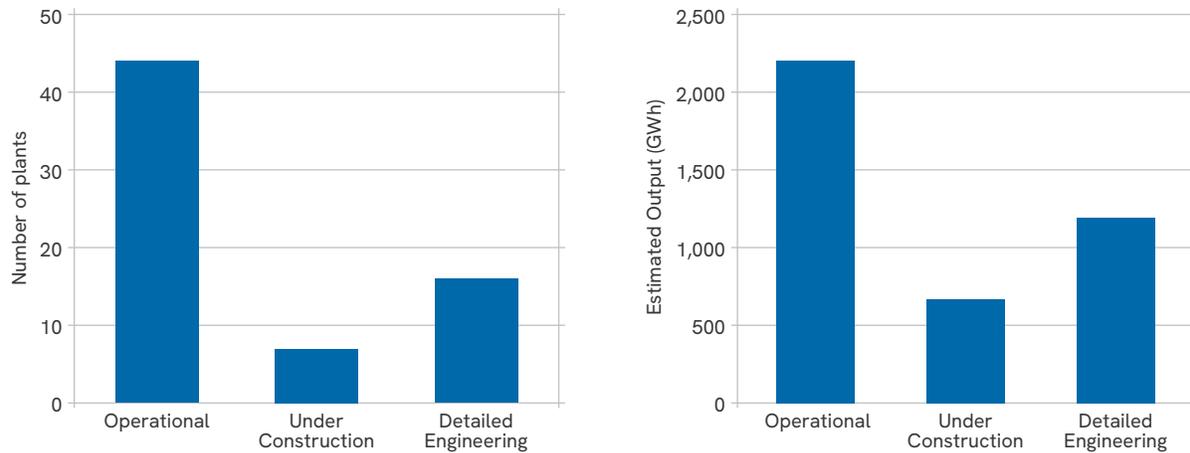
²³ Netherlands Climate and Energy Outlook 2020: <https://www.pbl.nl/sites/default/files/downloads/pbl-2020-netherlands-climate-and-energy-outlook-2020-summary-4299.pdf>

²⁴ https://www.greengasinitiative.eu/upload/content/ggi-biomethane_report_062017_1.pdf

²⁵ Klimaataakkoord (2019) p. 38, see www.klimaataakkoord.nl

²⁶ Eurostat (2020)

FIGURE 16: NETHERLANDS BIOMETHANE PLANTS AND ESTIMATED OUTPUT BY STAGE OF DEVELOPMENT



Source: Author's analysis

Hydrogen

The Netherlands already has substantial production of hydrogen, almost exclusively for industrial feedstock use and from methane reforming. With an initial focus on electrification, it was not until the second half of last decade that the attention for the possibilities of green or low-carbon hydrogen arose.

The survey covers 38 low-carbon hydrogen projects, of which only two plants are operational (both small pilot plants). We do not yet have sufficiently reliable data to make estimates of future hydrogen production by year for the Netherlands, but there are several significant projects at the feasibility/detailed engineering stage. For example, the H-Vision project²⁷ aims to have a first (methane reforming with CCS) plant of 750 MW capacity operational by 2026, doubling to 1,500 MW before 2030. The HyNetherlands Project²⁸ is intending to have 100 MW electrolysis operational by 2025 with an expansion to GW scale at an unspecified future date. The largest project in our database is NorthH2²⁹ which claims to be Europe's most ambitious wind to hydrogen project, with the ambition to have a capacity of 1 GW of green hydrogen by 2027, 4 GW by 2030, with a possible expansion to 10 GW by 2040.

Conclusion

While the Netherlands does not have official targets for biomethane production, in 2019 the industry set a target to reach 2 bcm (20 TWh or around 6% of current natural gas consumption) by 2030. It is less than the originally formulated target of 37 TWh, possibly in response to missing the original intermediate target of 12 TWh by 2020 by a large margin, as the actual production in 2020 was only around 0.2 bcm or 2 TWh.

There is a more positive picture for hydrogen, where there are several projects under development, and if they are all delivered as currently planned, production could exceed the government target of 4 GW capacity by 2030. Assuming 4,000 annual running hours (which is feasible for offshore wind projects) this could result in hydrogen production around 16 TWh by 2030, which is a substantial amount when compared to Dutch hydrogen production from natural gas steam reforming of 21 TWh as reported for 2013³⁰.

²⁷ <https://www.h-vision.nl/en>

²⁸ <https://tractebel-engie.com/en/news/2021/hynetherlands-one-of-europe-s-largest-green-hydrogen-plants-to-accelerate-the-journey-to-carbon-neutrality>

²⁹ <https://www.north2.eu/en/>

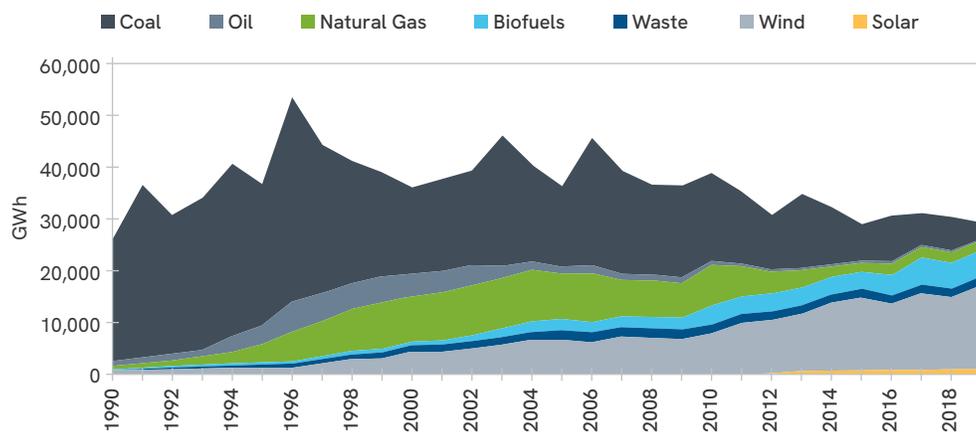
³⁰ Weeda, M., Productieroutes Duurzame Waterstof, ECN (2016).

4.4 Denmark

Key Decarbonisation and Renewable Gas Targets

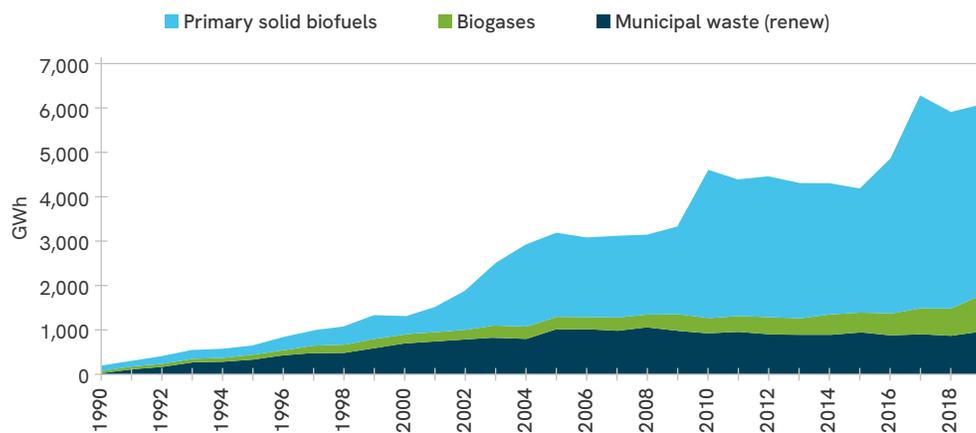
Denmark has the ambition to reduce its greenhouse gas emissions by 70% by 2030, relative to 1990 levels (aiming for net-zero emissions by 2050). The ambition to reduce greenhouse gas emissions by 70% by 2030 is higher than the EU's 55% target by 2030. To reach this target, new solutions will have to be developed in the power and gas sectors, in road transport, aviation and industry as well as in the agricultural sector. The Danish government has agreed to phase-out all coal-fired power by 2030³¹ and Denmark energy mix has experienced a decline in coal use and increase in alternative fuels including biofuels (Figure 17). Solid biofuels still dominate the biofuel mix (Figure 18). The share of biomethane in Danish consumption is expected to reach around 20 % in 2021³².

FIGURE 17: ELECTRICITY GENERATION BY SOURCE 1990-2019



Source: Denmark Energy Statistics

FIGURE 18: DENMARK ELECTRICITY GENERATION FROM BIOFUELS AND WASTE BY SOURCE 1990-2019



Source: Energinet

³¹ NECP (2019), <https://kefm.dk/media/7095/denmarks-national-energy-and-climate-plan.pdf>

³² <https://energinet.dk/Gas/Biogas>

Analysis of survey data

From the survey data, Denmark has 67 operational biomethane plants. Data obtained on annual production from 34 of these plants is 956 GWh out of a total of approximately 4417 GWh³³. The estimate of biomethane is far short of the target set for 2020. The database also includes one power-to-hydrogen plant with a 6 GWh production capacity from a 1.2 MW PEM electrolyser, and one power-to-methane plant with a 4 GWh production capacity from a 1 MW electrolyser. The estimate of hydrogen is also far short of the target set for 2030.

Conclusion

At a policy level, the difference between the actual production of hydrogen and biomethane and the targets set shows accelerative scale-up is required for renewable gases if Denmark is to fulfil its climate ambition.

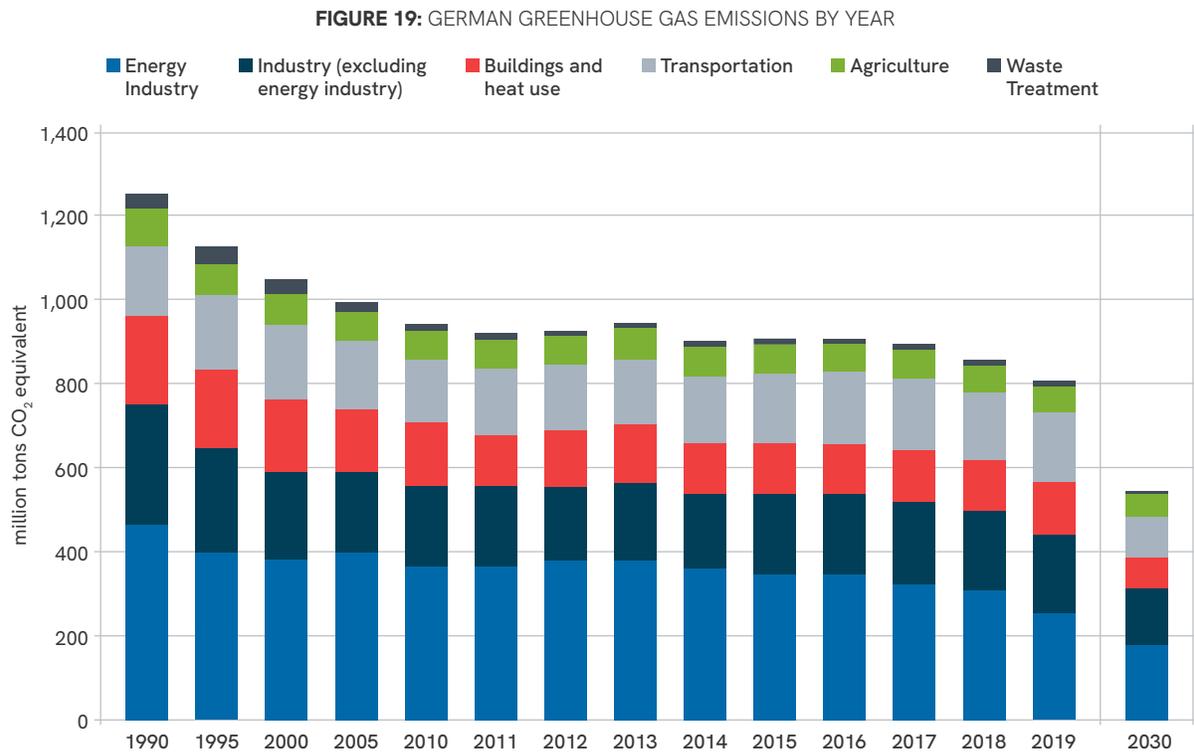


³³ Data from <https://online.energinet.dk/data/Pages/publicdata.aspx>

4.5 Germany

Key Decarbonisation and Renewable Gas Targets

Germany aims to be greenhouse gas emissions neutral by 2045 and hydrogen is seen as an important tool in reaching this goal. Germany has also set the preliminary targets of cutting emissions by at least 65% by 2030, compared to 1990 levels (Figure 3), and 88% by 2040³⁴.



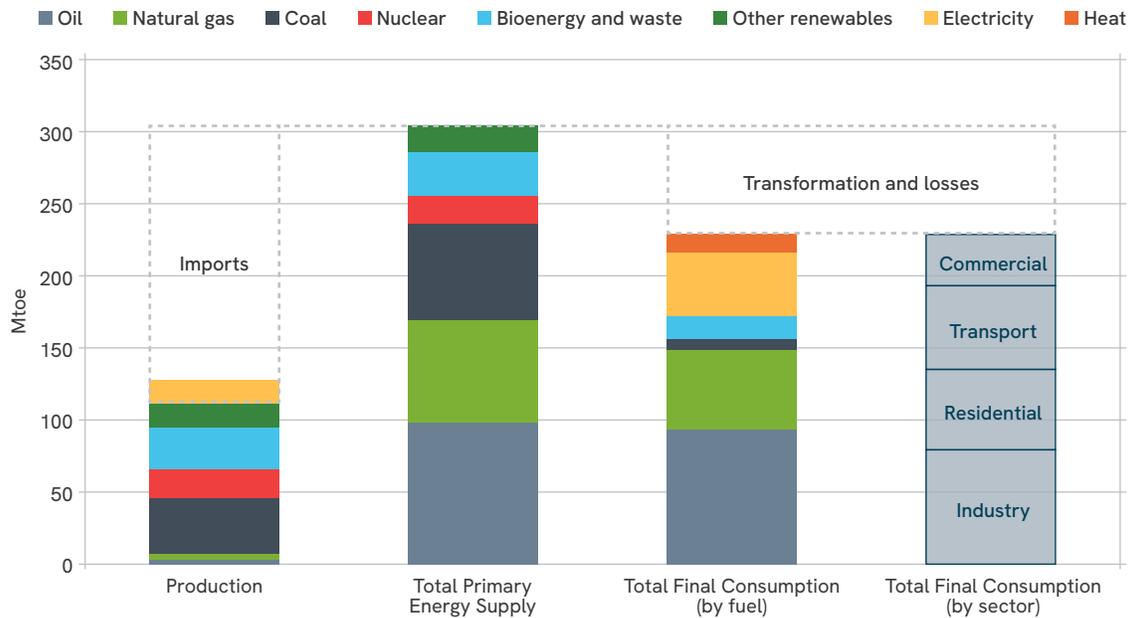
Source: German Environment Agency

Germany supports the use of green hydrogen. The Federal Government sees a hydrogen demand of about 90 to 110 TWh until 2030. Hydrogen production plants with a total capacity of up to 5 GW are expected to be built in Germany by 2030 to produce up to 14 TWh green hydrogen³⁵. Based on the existing fuel mix for Germany's energy system (Figure 4), accelerating uptake of hydrogen and other renewable gases is required.

³⁴ <https://www.cleanenergywire.org/factsheets/germanys-greenhouse-gas-emissions-and-climate-targets>

³⁵ Germany National Hydrogen Strategy (2020) https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6

FIGURE 20: GERMAN ENERGY SYSTEM BY FUEL AND SECTOR 2018



Source: IEA

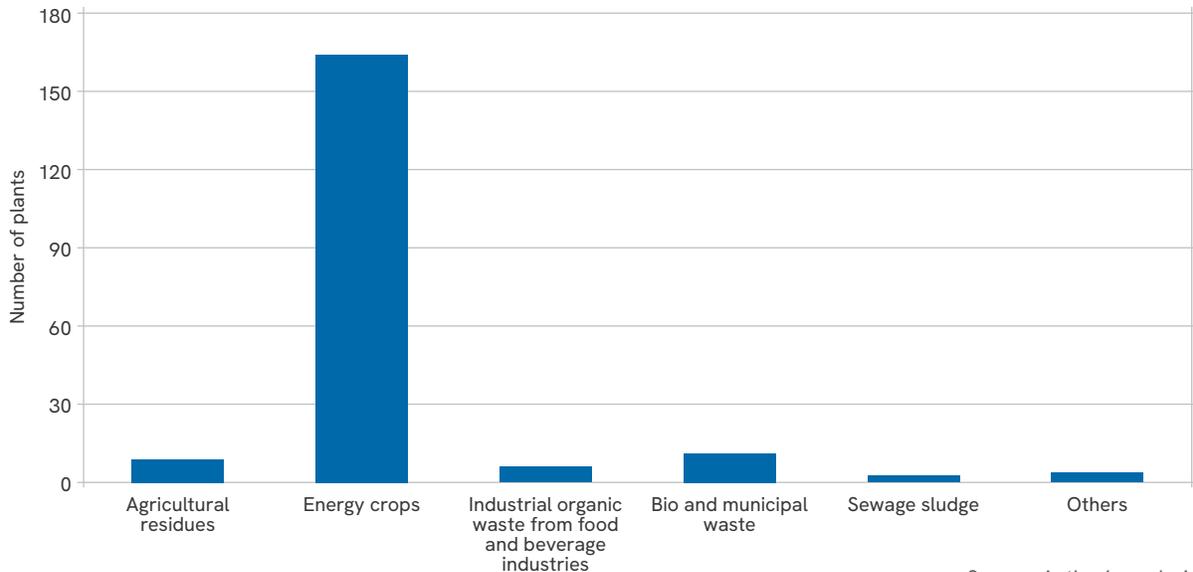
Germany is also one of the global leaders in biomethane production (as biomethane sales grew nearly 5.5% between 2019 and 2020 to 10,269 gigawatt-hours (GWh)³⁶) even though there is no firm policy target for biomethane production. The opportunities for biomethane are increasing as Germany looks towards decarbonising the heat and transport sectors. Biomethane is considered a medium- to longer-term option for transport and heat due to high production costs at present.

Analysis of survey data

Biomethane

From the survey data, there are 194 operational biomethane plants with a total production of 8.8 TWh. The total production aligns with data from the statistical report of the European Biogas Association and is around 10% of total raw biogas production. A diverse range of substrates are used for biogas production: energy crops (Figure 21) (in 164 plants, producing 84% of the biomethane), agricultural residues (in 8 plants, producing 4% of the biomethane), industrial organic waste from food and beverage industries (in 6 plants, producing 3% of the biomethane), bio and municipal waste in 11 plants producing 6% of the biomethane), sewage sludge (in two plants producing 1% of the biomethane). The substrates used were unknown in three plants. The high proportion of energy crops has raised concerns regarding the sustainability of biogas production in Germany and led to a change in legislation to focus future developments on biowaste substrates.

FIGURE 21: GERMANY BIOMETHANE PLANTS BY SOURCE OF FEEDSTOCK

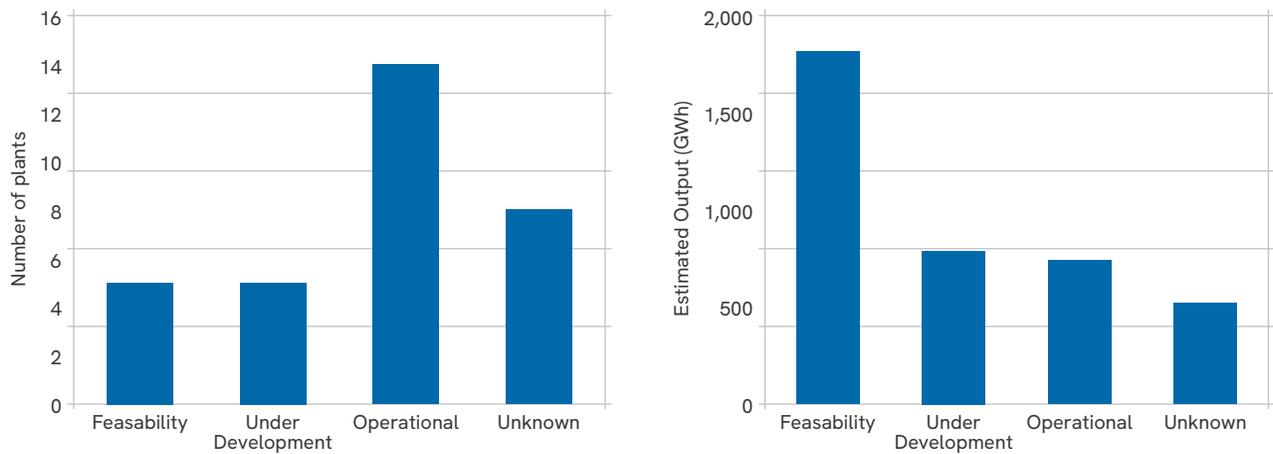


Source: Author's analysis

Hydrogen

The database lists 32 hydrogen plants located in several parts of Germany. Based on the projects listed (from feasibility to operational), the estimated hydrogen production capacity is 3.9 TWh. (Figure 22). Production of green hydrogen dominates the 32 plants with Proton Exchange Membrane electrolysis and Alkaline electrolysis being the dominant technologies. Only 14 plants are operational with a total production capacity of 0.74 TWh. The status and production capacity of eight plants were unknown in the database.

FIGURE 22: GERMANY HYDROGEN PLANTS BY STAGE OF DEVELOPMENT



Source: Author's analysis

Conclusion

Germany has an ambitious target to reduce GHG emissions by at least 65% by 2030.

In the early 2010s, Germany led Europe in developing biogas production, although policy incentives were scaled back following a concern regarding the large quantity of energy crops being used for biogas production. Germany upgrades about 10% of raw biogas production to produce around 10 TWh per year of biomethane. Further expansion of biomethane in Germany is feasible, but does not appear to be a significant policy focus at present.

Production of green hydrogen does have a strong policy focus in Germany. Existing hydrogen production capacity, should all the projects in the database come to fruition, is 3.9 TWh. If further projects are developed rapidly and given the strong policy drive, meeting the target of 5 GW by 2030 (producing up to 14 TWh) may be possible.

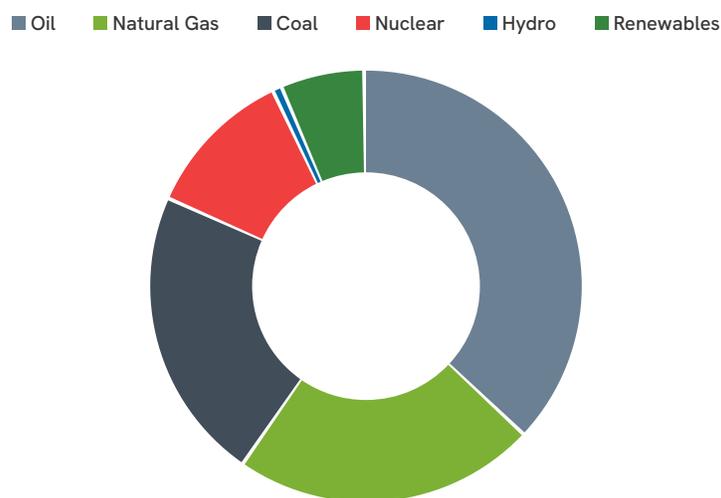


4.6 South Korea

Key Decarbonisation and Renewable Gas Targets

In October 2020, South Korea’s President, Moon Jae-in, announced that the country would aim to reach carbon neutrality by 2050. In December 2020, the government adopted a “carbon-neutral strategy”. Korea’s Paris Agreement NDC target for 2030 is to reduce GHG emissions by 24.4% compared to 2017 levels;³⁷ however in May 2021, the President announced that a more ambitious target would be announced at the COP26 conference in Glasgow in November 2021.

FIGURE 23: SOUTH KOREA PRIMARY ENERGY SUPPLY



As shown in Figure 23 natural gas contributes around 25% to South Korea’s Primary Energy Supply, and its total fossil fuel share in primary energy is 82.5% (oil 37%, coal 21.8%). Nuclear provides 11% and renewables only 6.4%.³⁸ South Korea already produces around 2 million tonnes of hydrogen per year – mainly manufactured (without carbon capture) for own use in petrochemical complexes in Ulsan, Daesan and Yeosu.³⁹

Hydrogen plays a key role in Korea’s carbon-neutrality strategy, which intends to “expand use of clean power and hydrogen across all sectors”. Biomethane is not mentioned in the strategy, although there are commitments to recover methane from landfill waste and wastewater/sewage treatment facilities. In 2019, Korea published its Hydrogen Economy Roadmap and the National Roadmap of Hydrogen Technology.⁴⁰ The focus of these documents was on fuel cell vehicles (6.2 million FCEVs by 2040) and fuel cell power generation (15GW by 2040, plus 2.1 GW of fuel cell applications in buildings). The carbon neutral strategy also refers to use of hydrogen in low-carbon steel-making. The strategy does not set explicit targets for levels of low-carbon hydrogen production, and indeed in the 2019 roadmap it was contemplated that much of the hydrogen production would come from existing grey hydrogen facilities in refineries and petrochemical plants. Over the longer term, the climate-neutral strategy contemplates both green hydrogen (electrolysis using renewable power generation) and blue hydrogen (using natural gas with CCUS) as low-carbon forms of hydrogen production.

³⁷ [https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/690693/EPRS_BRI\(2021\)690693_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/690693/EPRS_BRI(2021)690693_EN.pdf)

³⁸ Korea Energy Economics Institute (Feb 2021): <http://www.keei.re.kr/keei/download/MES2105.pdf#page=22>

³⁹ <http://www.drd.wa.gov.au/Publications/Documents/Hydrogen%20Energy%20of%20KOREA.pdf>

⁴⁰ Carbon Neutral Strategy of Republic of Korea: https://unfccc.int/sites/default/files/resource/LTS1_RKorea.pdf

Analysis of survey data

Perhaps consistent with the lack of focus on biomethane in the policy documents referred to above, the database does not contain any biomethane projects.

For hydrogen, the database captured 15 projects of which 11 are under construction and 4 are at conceptual stage. Total production from these projects totals 35,000 tonnes per year. Many of these projects, however, are not yet low-carbon hydrogen projects, although the addition of carbon capture and storage could be contemplated at a later stage.⁴¹

Conclusion

Biomethane is not currently a significant consideration in South Korea although hydrogen is seen as playing an important role in its energy future. Hydrogen plans have focussed mainly on the transport and power generation sectors with relatively little focus on scaling up low-carbon hydrogen production. Indeed, nearly all hydrogen production and the projects listed in the database continue to relate to grey (CO₂ emitting) hydrogen. It is expected that a greater focus on low-carbon hydrogen would emerge in future, to support the ambitious decarbonisation targets.



⁴¹ <https://www.greencarcongress.com/2021/03/20210305-sk2.html>

4.7 United States

Key Decarbonisation and Renewable Gas Targets

In April 2021 President Biden pledged a new target of a 50-52% GHG emissions reduction from 2005 levels by 2030 for the United States. The new nationally determined contribution (NDC) more than doubles the country's prior commitment under the 2015 Paris Climate agreement.

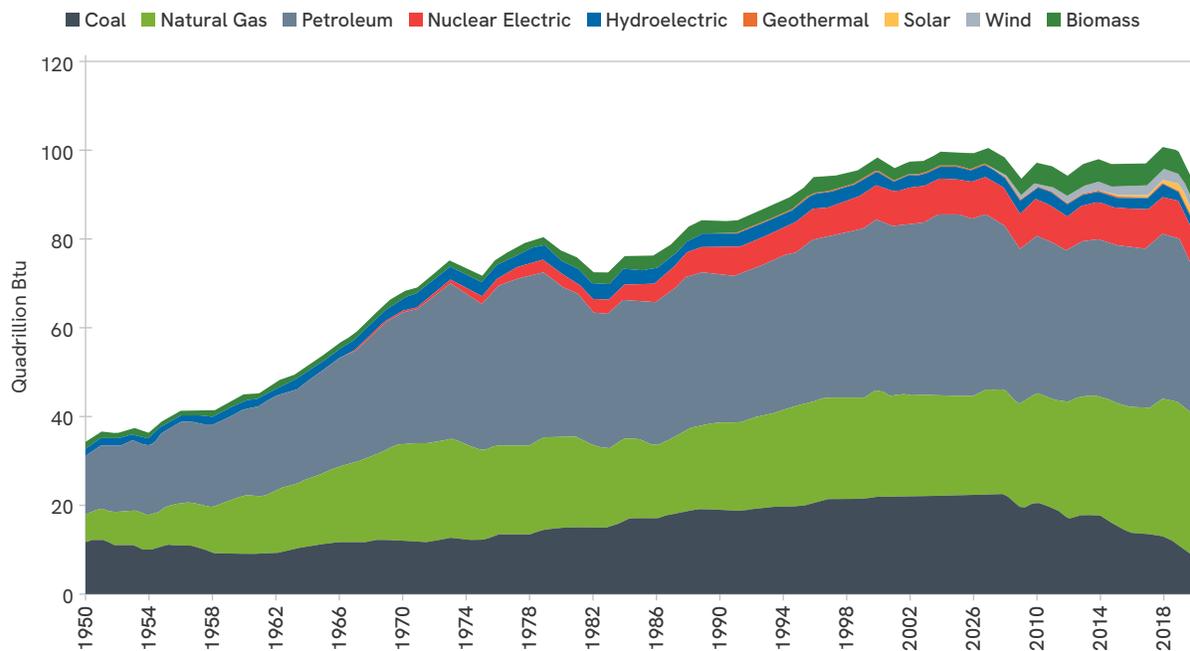
Compared to the slow development and lack of strong Federal actions on climate change, U.S. states have become an important testing ground for climate policies with a wide range of policies, to reduce greenhouse gas emission, develop clean energy resources and promote alternative fuels. Currently, 24 states and the District of Columbia have established economy-wide greenhouse gas emission targets⁴².

While state level actions and policies have proven to be effective, an assortment of state-level policies will not be enough to fully decarbonise the electricity sector and to meet the Biden administration's goals in the timeframe required to address climate change.

Roughly half of all growth in U.S. renewable electricity (RE) generation and capacity since 2000 is associated with state RPS requirements, though that percentage has declined in recent years, representing 23% of all U.S. RE capacity additions in 2019 the exception of the Northeast and Mid-Atlantic.⁴³

In 2020, U.S. energy consumption by major source (Figure 24) shows 33% of natural gas, and around 4.8% of biomass, of which biogas is less than 20% (so around 1% of total energy consumption).

FIGURE 24: US PRIMARY ENERGY CONSUMPTION 1950-2020

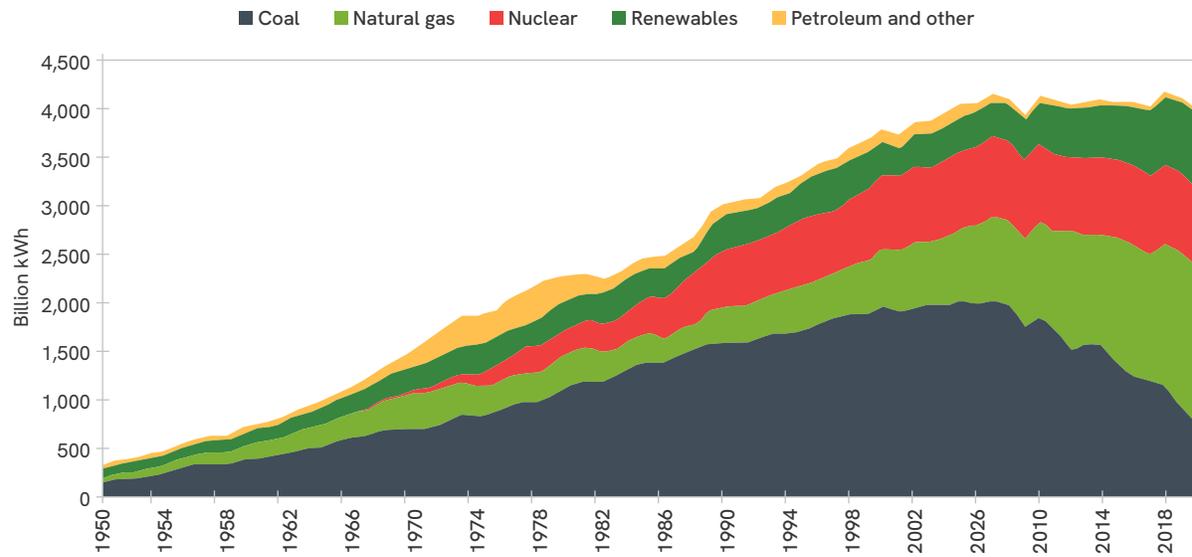


Source: US Energy Information Administration Jan 2021

⁴² Center for Climate and Energy Solutions (C2ES) – U.S. State Greenhouse Gas Emission Targets (March 2021)

⁴³ Berkeley Lab: U.S. Renewables Portfolio Standards 2021 Status Update: Early Release

FIGURE 25: US ELECTRICITY GENERATION 1950-2020



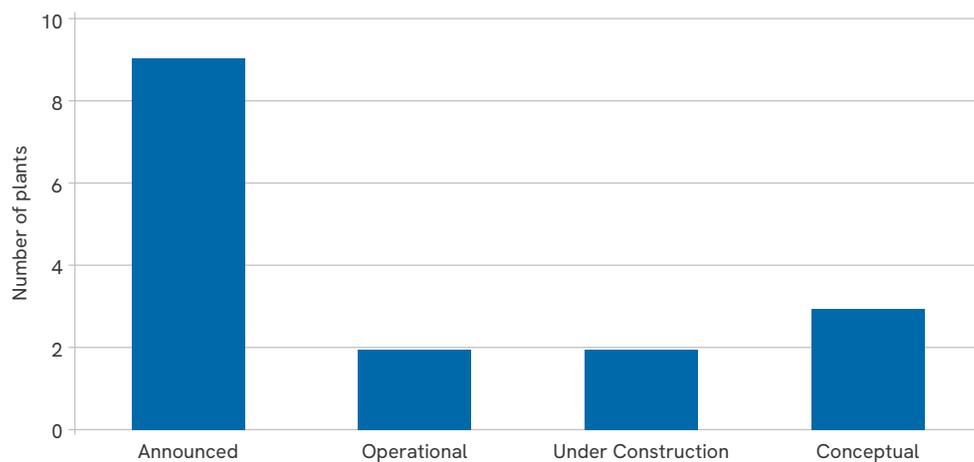
Source: US Energy Information Administration Jan 2021

Analysis of survey data

Hydrogen

From the survey data⁴⁴, there are 15 projects of hydrogen generation in the US, of which only three projects are either operational or under construction. Of the remaining projects, three projects are under proof-of-concept stage with innovative technology and nine projects have identified a technology provider and value chain sponsorship.

FIGURE 26: US HYDROGEN PROJECTS BY STAGE OF DEVELOPMENT



Source: Author's analysis

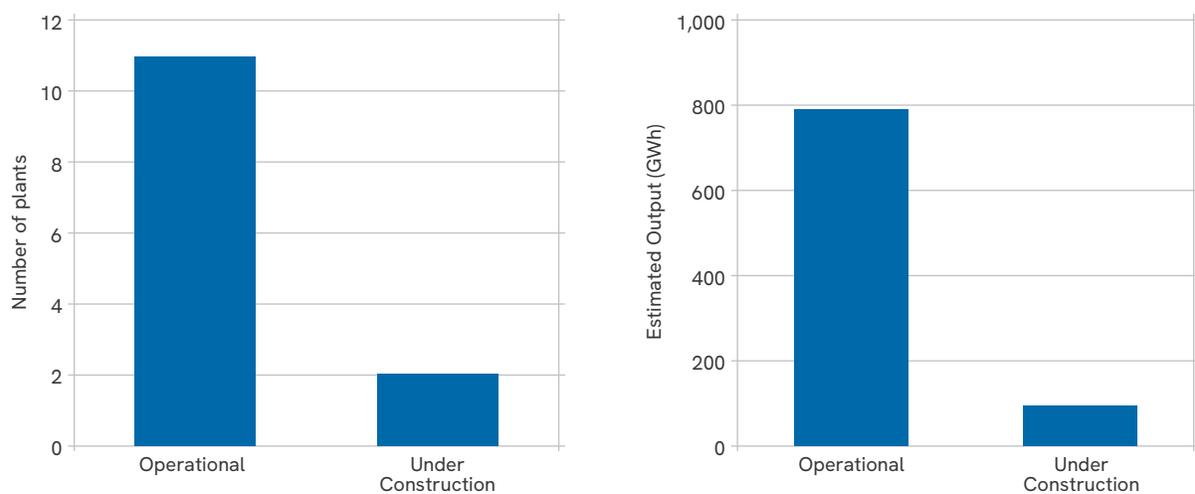
⁴⁴ IGU data survey did not include United States or Canada data; the research team has collected the data independently for this report.

Since many projects are only at a pilot stage, and not built for at-scale use, it is difficult in some circumstances to confirm the capacity and output. There are limited data points to provide a reliable overview of total hydrogen production capacities at this point. The six projects out of the 16 with announced energy output totalled 15,400 GWh. The relatively large energy output total depends on two projects that are both under development: the Bakken Energy project in North Dakota, which aims to convert a coal-gasification syngas plant to a 310,000 metric tons capacity (over 7,000 GWh) blue hydrogen plant that could potentially produce about 30% of the total current hydrogen production of the United States, once it is online after 2025, and the Intermountain Power Project (IPP) in Delta, Utah that has an expected nameplate capacity 840 MW. Besides these two large projects, other projects are relatively small in energy output, from 8-GWh to 260-GWh per year.

Biomethane

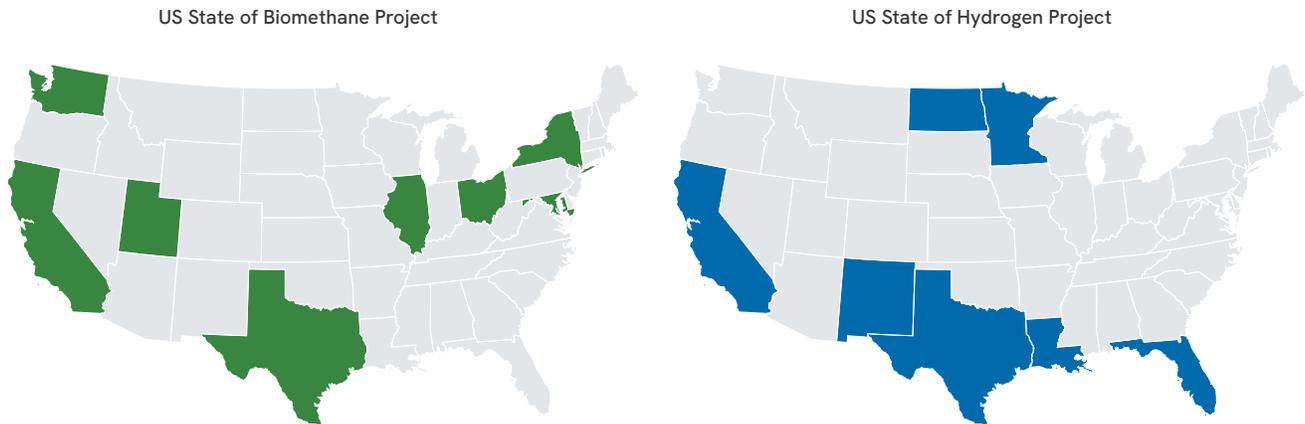
In the survey data, there 13 projects reported to generate biomethane as outputs from a total of 586 biogas projects in the United States, with a total energy output of 890 GWh per year, located in seven states. Another conclusion from the survey data is that there are only a handful of states that are active in both renewable gases, including California, Utah, and Texas.

FIGURE 27: US BIOMETHANE PROJECTS BY STAGE OF DEVELOPMENT



Source: Author's analysis

FIGURE 28: US RENEWABLE GAS PROJECTS BY STATE



Policy

Greenhouse Gas Emissions: Currently, 24 states and the District of Columbia have established economy wide greenhouse gas emission targets⁴⁵. Besides state level targets, 13 U.S. states have adopted market-based approaches to reduce greenhouse gas emissions. 11 Northeast states have jointly capped power sector emissions through the Regional Greenhouse Gas Initiative (RGGI) beginning in 2009. California has an economy-wide cap-and-trade system administered by the California Air Resources Board (CARB) and Washington state enacted a cap-and-invest program that will go into effect in 2023.

Portfolio Standard: 29 states and the District of Columbia have adopted Renewable Portfolio Standards (RPS), which require a certain percentage of a utility's electricity to come from renewable energy sources. And seven states have adopted a clean energy standard (CES), which requires electric utilities to deliver a certain amount of electricity from renewable or clean energy sources.

Climate action plans: 32 states have released a climate action plan or are in the process of revising or developing one. This includes 23 states that have released plans, 8 states that are updating their plans, and 1 state that is developing a plan.

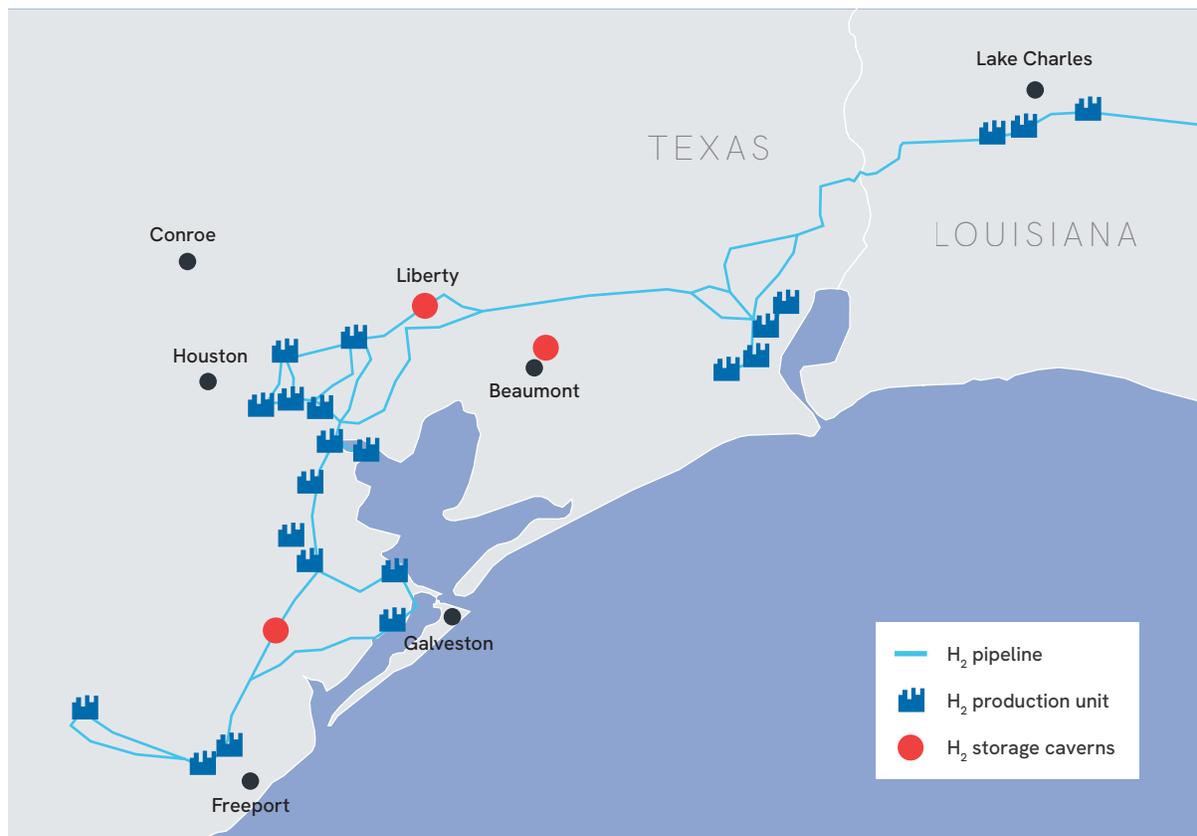
⁴⁵ Center for Climate and Energy Solutions (C2ES) – U.S. State Greenhouse Gas Emission Targets (March 2021)

Conclusion – United States

With one of the largest natural gas markets in the world, there could be great potential for renewable gases (hydrogen and RNG) in the United States, while there are currently relatively few projects compared to some other countries in Europe. With the current administration returning to the Paris Agreement, and a new government-funded hydrogen program, it is plausible one could observe an accelerated pace in project development in hydrogen production in the next couple of years.

Large scale hydrogen projects are starting to be realised in the United States, many with proper storage capacity and downstream distribution channels coupled with the generation plan. The United States has one of the most connected fossil fuels networks (oil, gas and NGL) in the world, including pipelines and underground storage. There is an emerging trend of considering new ways to leverage and retrofit the existing fossil fuel network to scale up the hydrogen economy in the United States especially in regions with a long energy tradition. Texas has been active in pushing for hydrogen as part of its decarbonization plan, leveraging its unique advantage, producing about one third of U.S. total hydrogen gas currently per year, and there are plans to expand a network of hydrogen production plants and pipelines with at scale geological storage in Texas Gulf Coast (Figure 29). It remains to be seen the extent to which these bold ambitions will be realised, which we will monitor in future editions of this report.

FIGURE 29: EXISTING HYDROGEN INFRASTRUCTURE IN US GULF COAST REGION



Sources: H2Tools, USDOT-PHMSA, Air Liquide, Air Products, Praxair

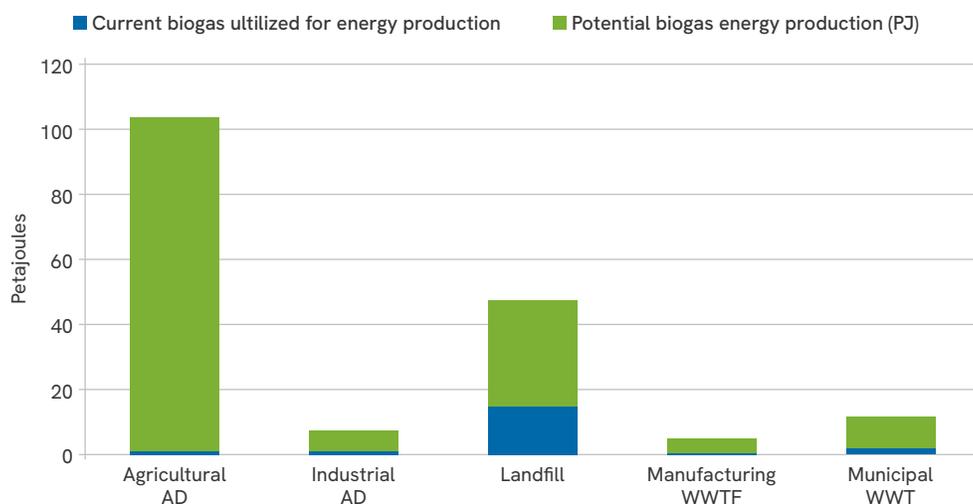
4.8 Canada

Key Decarbonisation and Renewable Gas Targets

In 2016, Canada released the Pan-Canadian Framework on Clean Growth and Climate Change – jointly developed by the federal, provincial, and territorial governments - which is designed to help Canada reach its 2030 GHG emissions goal of 511 metric ton CO₂ equivalent, a 30% reduction below 2005 levels, under the 2015 Paris Agreement. In December 2020, the Government of Canada released its strengthened federal climate plan, A Healthy Environment and a Healthy Economy, which builds on the efforts that are already underway to cut more pollution, create more jobs, support a healthier economy and environment and exceed Canada’s 2030 Paris Agreement emission reduction target.

Canadian biogas had a decade of rapid growth from 2011 to 2020, with an almost 50% jump in operating biogas projects across the country, according to the Canadian 2020 Biogas Market Report. Canada now has 279 biogas projects from coast to coast that are capturing methane from agricultural and community waste and turning it into 196 MW of clean electricity and 6 million GJ (1.7 TWh) of renewable natural gas.

FIGURE 30: CANADA BIOGAS USE AND POTENTIAL



Source: Canada Biogas Market Report

In Canada, three current provincial models highlight different approaches that demonstrate the trade-offs presented by RNG, in Ontario, British Columbia and Quebec. It is reasonable to expect that the federal government will continue to develop some credit creation opportunities for low-carbon gaseous fuels like renewable natural gas, although the most recent attempt by the federal government only included liquid form of renewable fuels.

Provincial hydrogen announcements have included the following:

British Columbia – Hydrogen development was promoted in the 2018 CleanBC plan and the 2019 Hydrogen Study, with an emphasis on transportation fuels including fuel cells and zero-emissions vehicles.

Alberta – A general hydrogen strategy was included in the 2020 Natural Gas Vision and Strategy, with a focus on producing hydrogen using natural gas and carbon capture, utilisation and storage (CCUS) and exporting hydrogen.

Ontario – In November 2020, the Ontario government published the Ontario Low-Carbon Hydrogen Strategy – Discussion Paper. This discussion paper emphasizes producing hydrogen through electrolysis, using hydrogen for electricity storage and blending hydrogen with natural gas to make Ontario’s natural gas cleaner.

Québec – Québec’s public electric utility, Hydro-Québec, published its Strategic Plan 2020-2024 in December 2019. The plan emphasises supporting the development of hydrogen through research and development and using hydroelectricity to produce hydrogen through electrolysis.

On December 16, 2020, Canada’s federal government released its Hydrogen Strategy for Canada (the Strategy). The Strategy sets an ambitious framework to cement hydrogen as a key part of Canada’s path to net-zero carbon emissions by 2050 and make Canada a global leader in hydrogen technologies.

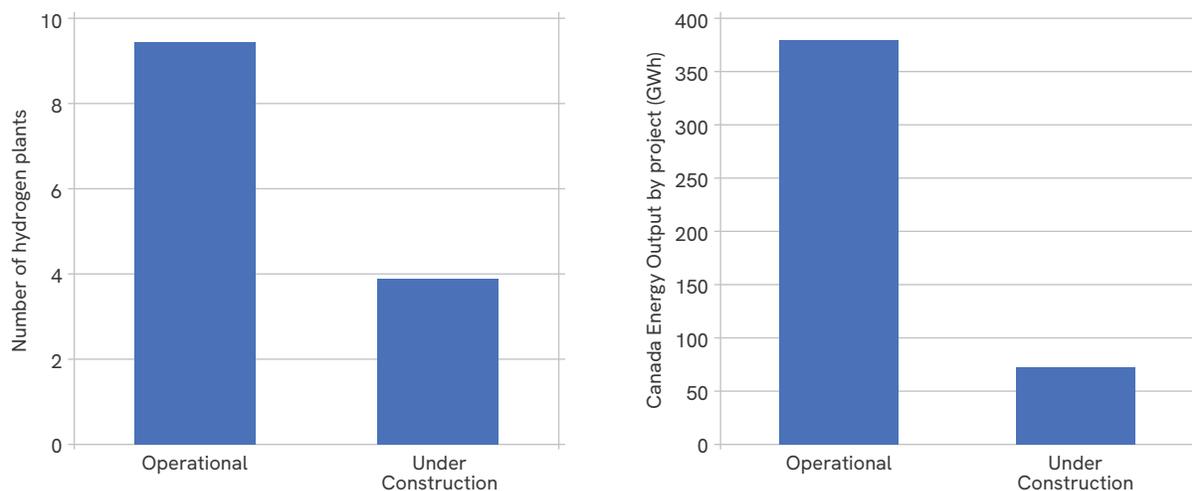
Analysis of survey data

Hydrogen

From the survey data, there are 12 projects of hydrogen generation in Canada from IGU data inputs, and four are currently operational. If all projects are realised, production could grow to a total of 372 GWh energy output per year (Figure 31).

It is worth noting that Shell announced a large-scale carbon capture and sequestration initiative at its Scotford refinery complex near Edmonton, AB. It is one of the largest recent efforts to integrate hydrogen production with CCS. This also highlights one crucial piece of the puzzle of scaling up low-carbon hydrogen production, which can be used at refineries, ammonia plants and other carbon-generating processes. Having the adequate CCS capacities is a necessary requirement for blue hydrogen.

FIGURE 31: CANADA HYDROGEN PROJECTS BY STAGE OF DEVELOPMENT

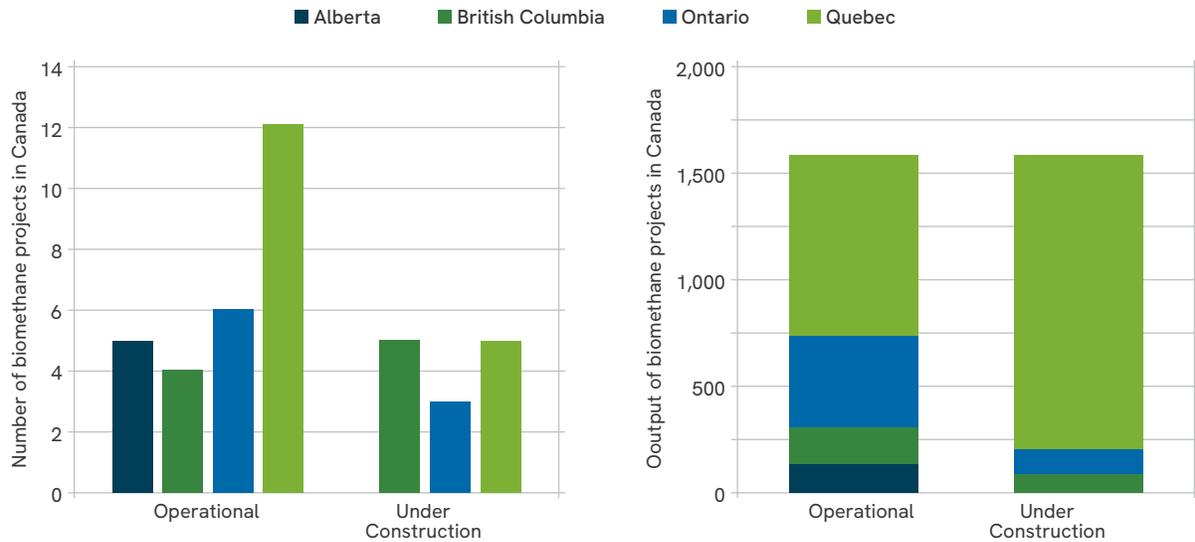


Source: Author’s analysis

Biomethane

As of 2021, there are 14 projects operating from IGU data survey, with a total of 1,478 GWh energy output per year (Figure 32). In addition to the information provided by Canada Biogas Association, there are also 26 projects currently under development, with total output close to 1,580 GWh per year.

FIGURE 32: BIOMETHANE PROJECTS IN CANADA BY STATE



Source: Canada Biogas Association

Conclusion – Canada

Canadian biogas had a decade of rapid growth from 2011 to 2020, with an almost 50% jump in operating biogas projects across the country, but future growth appears more uncertain. The primary barrier for further development of the renewable gas sector is currently weak and as-yet-undefined policy.

Canadian low-carbon hydrogen production is currently small, but with several projects in the pipeline it has the potential to grow in the coming years. This will depend on suitable policy incentives which we will continue to monitor in future editions of this report.

4.9 Brazil

Key Decarbonisation and Renewable Gas Targets

In December 2020, Brazil updated its Nationally Determined Contribution (NDC) under the Paris Agreement, where it committed to reducing emissions relative to 2005 levels: by 37% by 2025, 43% by 2030, and by 95% by 2050. Brazil will also target zero net emissions by 2060. More than 80% of its electricity is renewable – mostly hydro (60%), as well as wind, solar, and biomass. Brazil accounts for less than 3% of global carbon emissions, and the carbon credit market has a positive impact on reducing deforestation in that country.

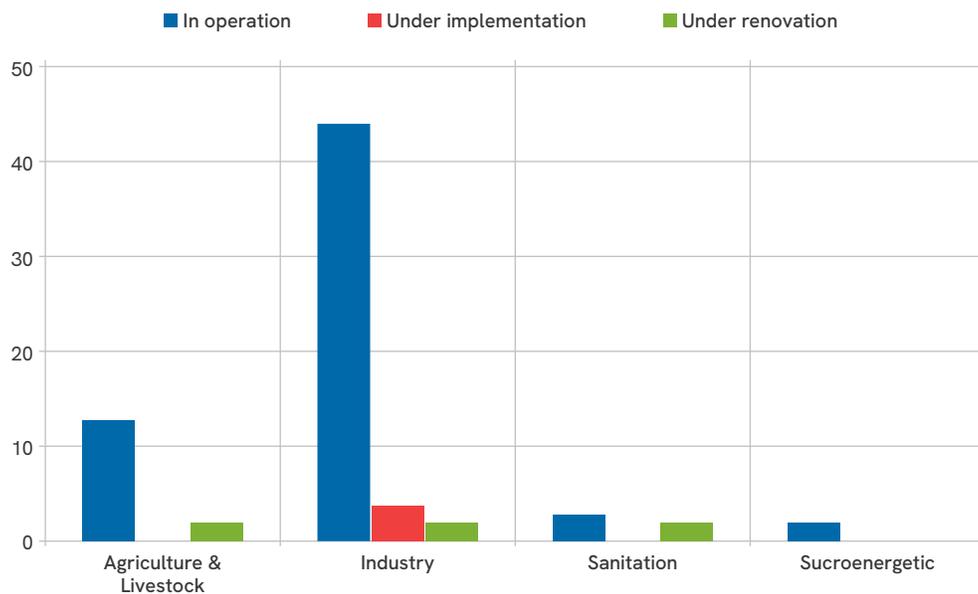
Brazil has the largest potential for biogas in the world. There are more than 520 biogas plants (although less than 10% produce biomethane) in Brazil with capacity to produce 2,200 m³/day of gas for electric or heat generation, or upgrading to biomethane. Based on the biogas and biomethane market research from Netherlands Enterprise Agency (based on 2019 data), the production potential can supply 36% of the Brazilian electrical demand, or replace 70% of the diesel demand. Abiogás (the Brazilian Biogas Association) aims to increase national production to 30,000 m³/day of biogas and biomethane by 2030 and envisages investment of 7 billion US dollars to reach the target.

Analysis of survey data

Biomethane

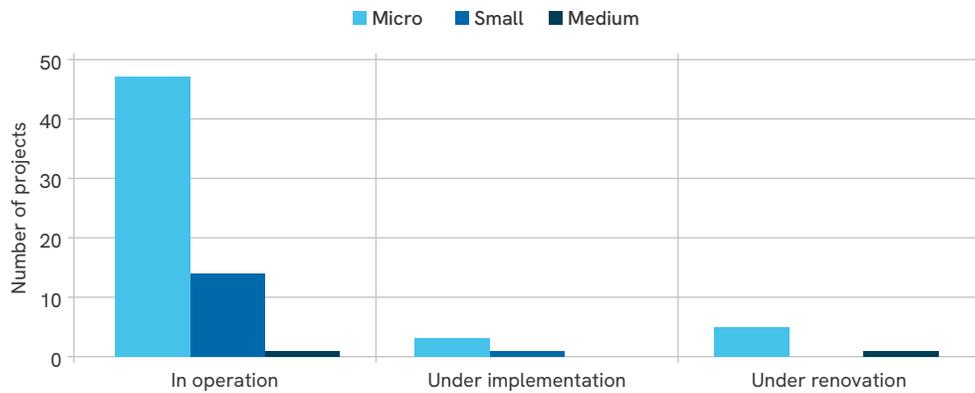
From the survey data, there are 62 biogas to biomethane plants stated as becoming operational between 2003 and 2019, of which 44 plants are in the category of industry, 13 of them are from agriculture and livestock. Most of the operational plants are in the micro or small size and geographically located in the south-eastern states of Brazil.

FIGURE 33: BRAZIL BIOMETHANE PROJECT BY STATUS



Source: Author's analysis

FIGURE 34: BRAZIL BIOMETHANE PROJECT BY SIZE AND STATUS



Source: Author's analysis

FIGURE 35: LOCATION OF BRAZIL BIOMETHANE PROJECTS BY STATUS



Source: Author's analysis

The total estimated annual biomethane production based on the listed plants in the database is 215,466,319 Nm³/yr (0.2 bcm or 2 TWh). Almost 60% production is from industry, more than 30% production from sanitation. The sugar industry accounts for 7% and agriculture, and livestock accounts for 2%.

The database does not currently hold any data on hydrogen projects, but given the recent policy announcements (see below), this may be expected to change in future.

Policy

On May 17, 2021, the Brazilian National Energy Policy Council (CNPE) established guidelines for public research, development, and innovation funds to allocate resources in priority areas that include hydrogen. Many pilot projects have been launched, amongst them one of the largest green hydrogen projects has been announced by the Government of the State of Ceará (to be located in the Brazilian port of Pecém), in partnership with Australian Eneqix Energy.

The investment of the green hydrogen hub is estimated at around US\$5.4 billion and it intends to transform solar and wind power into more than 600 million kilograms of green H₂ annually. It has the ambition to be the world's biggest green hydrogen plant, since Ceará State has an ideal location in the northeast of Brazil, facing the markets of Europe and North America.

Conclusion - Brazil

Although Brazil has a large potential for biogas production, the official target for biomethane and biogas production of 30,000 m³/d by 2030 seems to be an ambitious plan, compared to 2,200 m³/d current production. It's almost 15 times more than the current production and asks for over 3,000 m³/d incremental capacity for each year from now on to 2030. Moreover, most of the plants are small or micro size. To reach the goal, the key strategies for Brazil would be scaling up and seeking for sufficient investment to build up the capacity.

According to our analysis, 26% of 2,200 m³/d is from biomethane at the current level; at the target of 2030 with the same proportion of biomethane, the potential production of biomethane should be 8,000 m³/d. This would require significant investment in new biomethane plants.

There are several medium size biomethane projects under development which, if delivered as currently planned, could approach the government target by 2030. Faced with frequent droughts, the amount of available hydropower has become relatively unpredictable in Brazil. The Brazilian government is eagerly seeking alternatives to reach the target and backup the hydropower. Extending the production of hydrogen, biogas and biomethane is one of those alternatives with the goal of lower carbon emissions by 2030 and net-zero emissions by 2060.

5. Appendix

5.1 Types of Renewable Gases:

Biogas (or “Raw Biogas”): A mixture of gases, predominantly methane and carbon dioxide produced by anaerobic digestion of biomass (typically agricultural waste, manure, sewage, municipal waste). Proportions of methane and carbon dioxide vary depending on feedstock and production process, but a comparison of the properties of biogas and natural gas is provided in Table 1

TABLE 1: PROPERTIES OF BIOGAS AND NATURAL GAS

Substance	Biogas from anaerobic fermentation	Natural Gas
Methane	50-85%	83-98%
Carbon dioxide	15-50%	0-1.4%
Nitrogen	0-1%	0.6-2.7%
Oxygen	0.01-1%	-
Hydrogen	traces	-
Hydrogen sulphide	Up to 4,000 ppmv	-
Ammonia	traces	-
Ethane	-	Up to 11%
Propane	-	Up to 3%
Siloxane	0-5 mg/m ³	-
Wobbe Index	4.6-9.1	11.3-15.4

Biomethane (or Renewable Natural Gas): Raw Biogas from anaerobic digestion which has been upgraded to remove CO₂ and other impurities such that it is of a comparable quality to natural gas. Such upgraded biomethane is then typically injected into the natural gas grid. Biomethane can also be manufactured from woody biomass in a thermal gasification process although this is much less common than production via anaerobic digestion.

Grey Hydrogen (or hydrogen from natural gas, with emissions of carbon dioxide): Hydrogen produced from natural gas through methane reforming. Most hydrogen today is produced via steam methane reforming of natural gas, which emits around 10 tonnes of CO₂ per tonne of hydrogen. (Some hydrogen, particularly in China, is produced from coal or lignite and is sometimes called black or brown hydrogen). All of these types of hydrogen do not qualify as low-carbon.

Blue Hydrogen (or hydrogen from natural gas with carbon capture and storage): Hydrogen produced from natural gas with the addition of carbon capture and storage. While Steam Methane Reforming is commonly used for grey hydrogen production, the alternative AutoThermal Reforming is preferred for blue hydrogen as it typically results in a higher concentration of CO₂ in the flue gas more suitable for capture and storage.

Green Hydrogen (or renewable hydrogen): Hydrogen produced via electrolysis using renewable electricity. (In some cases, particularly initially, an electrolyser may run on grid-based electricity which is likely to also contain a component of fossil fuel generation, but we assume that in the long run the intention will be that the electrolyser runs entirely on renewable electricity).

5.2 Details of Methodology

Scope of Survey

The IGU Global Renewable and Low-Carbon Gas database survey aims to collect data on production facilities for biomethane and hydrogen. The 2021 edition focused primarily on biomethane injected into the natural gas grid (either directly or after intermediate truck / rail transportation), and renewable or low-carbon hydrogen data.

The survey asked to include data on projects which are under development (in feasibility study or engineering stage) as well as under construction or in operation.

Because the survey is focussed on the production capacity scale-up, it only requested data for plants with capacity of 1 MW or greater

Technology Type Options Included in Survey

- Anaerobic digestion (to produce biogas)
- Biomass gasification to produce methane
- MP [Methane Pyrolysis]
- PMP [pulse methane pyrolysis electrolysis]
- SMR [Steam Methane Reforming] with CCS
- ATR [Autothermal reforming] with CCS
- Biogas reforming
- Bitumen gasification + CCS
- ALK [Alkaline electrolysis]
- PEM [Proton exchange membrane electrolysis]
- SOEC [Solid oxide electrolysis]
- HTSE [High-temperature steam electrolysis]
- Coal gasification+CCS[Hydrogen production from coal gasification (all types of coals and derivatives) coupled with CO₂ capture]
- Microbial fermentation
- Biogas pyrolysis
- AEM[Anion Exchange Membrane]
- Unknown PtX [power-to-X]
- Others (please fill in comments)

Production Source Options

- Wind
- Solar
- Nuclear
- Grid electricity
- Natural Gas
- Coal
- Oil
- Hydro
- Biomass

Status

Allowable options for this field are:

- Conceptual/Announced
- Feasibility Study
- Detailed Engineering
- Under Construction
- Operational
- Mothballed
- Other (please explain in comments)



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