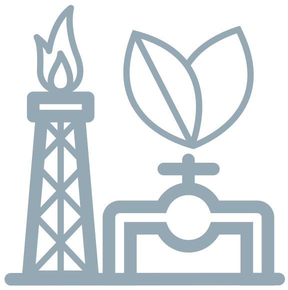
ROLE OF GREEN GASES IN THE ENERGY TRANSITION OF V4 COUNTRIES



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ROLE OF GREEN GASES IN THE ENERGY TRANSITION OF V4 COUNTRIES

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List of abbreviations

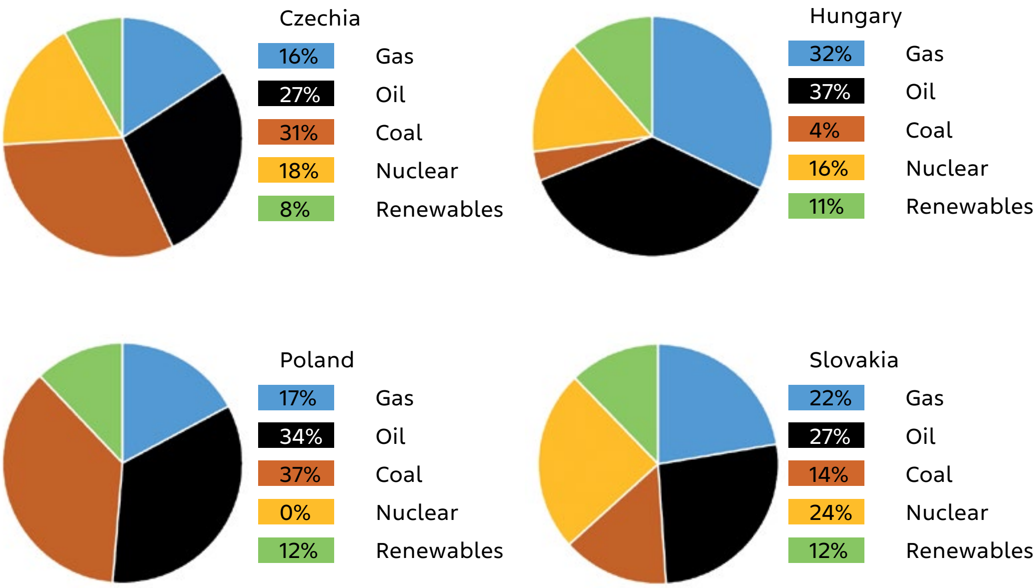
ATR	Auto-thermal reforming
BGP	Biogas plant
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization and storage
CDHS	Central district heating systems
CHP	Combined heat and power
GHG	Greenhouse gases
HP	Heat pump
LNG	Liquefied natural gas
RES	Renewable energy sources
SMR	Steam methane reforming
WTP	Wastewater treatment plant

INTRODUCTION

During the recent energy crisis, which began in 2021[1], European countries faced significant increases in the prices of imported fossil fuels, which subsequently affected electricity prices. The increased energy prices were then reflected both in the state of national economies as well as in individual household budgets. For national economies, the result was extremely high inflation; for households, many fell into energy poverty.[2]

Even today, the energy market remains fragile. A large portion of the energy needs in the V4 countries continues to be met by imported natural gas and oil, often sourced from unstable regions.

Figure 1. Primary energy consumption by source in the V4, 2023



Source: own chart based on Energy Institute

Fluctuations in the prices of imported fossil fuels, further amplified by the existing or planned carbon pricing within the European Emissions Trading System (ETS), create an unstable investment environment and make economic planning difficult at virtually all levels, including the creation of strategic and conceptual documents.

Billions of euros are spent annually on the purchase of these fuels, which drains domestic economies and directly impacts the foreign trade balance. Since the beginning of Russia's full-scale invasion of Ukraine, the V4 countries have spent many times more on the purchase of Russian oil and natural gas than they have provided in aid to the attacked Ukraine.[3]

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1 International Energy Agency: Global Energy Crisis, https://www.iea.org/topics/global-energy-crisis

2 European Economic and Social Committee: Impact of the energy crisis on the European economy, may 2023, https://www.eesc.europa.eu/en/news-media/press-summaries/impact-energy-crisis-european-economy

3 See for example Russia Fossil Tracker project: https://www.russiafossiltracker.com/

At the same time the emission footprint of imported liquefied natural gas (LNG), for example, may be even higher than that of coal-fired power.[4] Despite this, fossil gas is seen in some countries as one of the main replacements for existing coal sources. This shift would likely increase demand for this commodity for electricity and district heating production, thereby deepening our import dependence.

In the area of electricity generation, among other things, one major challenge is the current lack of seasonal storage capacity for intermittent renewable energy sources (RES). This issue is temporarily addressed by using gas-fired power plants, which serve to generate electricity at peak times and when the wind is not blowing and the sun is not shining.

Reducing the consumption of imported fuels in the areas of transport and industry comes up against the slow pace of electrification, limited alternative options, or the overall conservatism of these sectors in their implementation.

One possible solution to the above-mentioned problems with imported fossil fuels is the increased use of low-carbon or green gases produced locally or within other EU countries.

In terms of European directives, these green gases are represented by biogas, biomethane and low-carbon hydrogen and its derivatives.[5] Together, these gases could help reduce dependence on imports from unstable regions, reduce emissions intensity and ultimately support the European economy's transition to carbon neutrality.[6]

4 Robert W. Howarth: The greenhouse gas footprint of liquefied natural gas (LNG) exported from the United States, published in Society of Chemical Industry: Energy Science & Engineering, Volume 12, Issue 11, November 2024 https://scijournals.onlinelibrary.wiley.com/doi/10.1002/ese3.1934

5 Directive (EU) 2024/1788 of the European Parliament and of the Council of 13 June 2024 on common rules for the internal markets for renewable gas, natural gas and hydrogen, amending Directive (EU) 2023/1791 and repealing Directive 2009/73/EC, https://eur-lex.europa.eu/eli/dir/2024/1788/oj

6 European Union Agency for the Cooperation of Energy Regulators: Low-carbon gases—How can hydrogen support the European Green Deal, https://www.acer.europa.eu/gas/decarbonisation-of-gas/low-carbon-gases

WHAT ARE THE GREEN GASES?

Biogas and biomethane

Biogas is produced by the biological decomposition of organic material in the absence of oxygen during the so-called anaerobic digestion. This multi-stage process takes place thanks to the activity of microorganisms that decompose organic substances such as plant biomass, food residues, biodegradable municipal waste and the like.

From a chemical point of view, biogas consists mainly of methane (CH_4) with a volume of approximately 50–75%, carbon dioxide (CO_2) with a volume of 25–50% and in smaller quantities of other components such as water vapor, sulfur dioxide (H_2S), nitrogen, ammonia and others.

In the natural environment, biogas is produced, for example, in the digestive tracts of ruminants or in wetlands. In agriculture, it is released during rice cultivation or the storage of livestock manure. Landfills or anaerobic wastewater treatment plants (WTP) are also significant sources of biogas.

On an industrial scale, biogas is produced in biogas plants (BGP). These essentially imitate natural processes, where conditions suitable for activity of the relevant microorganisms are maintained in closed reactors (fermentors). According to the inputs to this process, we distinguish the following types of BGP:

Agricultural BGP—biogas is produced here from inputs of agricultural primary production. This mainly concerns plant biomass and farm fertilizers. Plant biomass can come from purposefully grown energy crops, or it can be residual biomass from plants primarily grown for other purposes, leftover food from farm animals, etc.

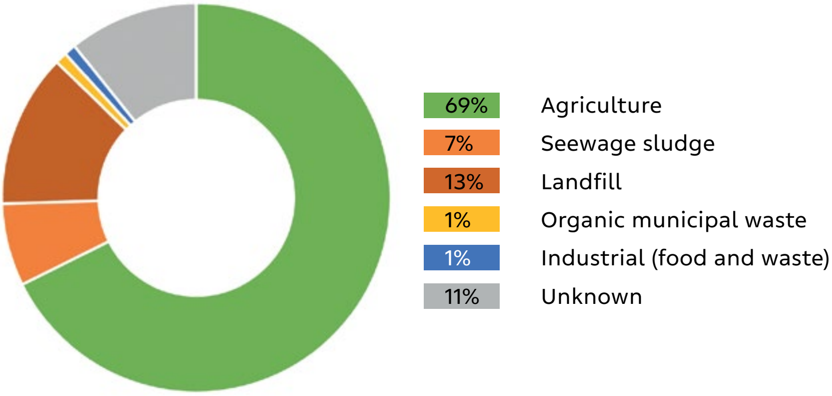
Waste BGP—municipal biowaste, gastro waste, etc. are used as input. Compared to agricultural BGP, the operation of waste BGP is more demanding. The input material must, among other things, undergo thorough inspection, be free of undesirable impurities and undergo a process of so-called hygienization—a process where bacterial contamination is eliminated by heating to a specific temperature.

Industrial BGP—biogas is partially or completely produced here from high-risk inputs such as slaughterhouse waste, sludge from various operations (especially WTP), etc. Similar to waste BGP, higher demands are placed on the technology used and compliance with hygiene regulations to mitigate the risks associated with the nature of the input materials.

In addition to the above methods, biogas can also be collected from WTP digesters or captured as it is generated during landfilling. In the second case, it is an uncontrolled and discontinuous process, where the amount of biogas generated decreases over time along with the decrease in microbial activity.

At the end of the anaerobic digestion process, a stabilized digestate is produced, which can be used as agricultural fertilizer under certain conditions, and above all, biogas itself. Due to its high methane content, it is used for energy purposes. In order for its subsequent combustion to proceed without problems, it is first necessary to remove sulphide and other undesirable impurities from it.

Figure 2. Biogas production in EU by source, 2022



Source: own chart based on European Biogas Association

Biogas is usually burned in combined heat and power (CHP) units based on piston engines, located in the BGP area. The heat from the operation of the CHP units is supplied to end consumers in the form of hot water using pre-insulated pipes. If the distance between the BGP and end consumers is too great (which can easily happen in the case of agricultural BGP) a different layout can also be used. In order to minimize heat transfer losses the biogas itself can be transported via dedicated pipes and then burned within decentralized CHP units located at the point of consumption.

Biomethane can be produced in various ways. The first of them is biogas treatment, which involves removing unwanted impurities and reducing the CO_2 content. In this context, we speak of the so-called biogas upgrading. The result of the process is gas with a methane concentration of 90% or more, making it effectively interchangeable with fossil natural gas.

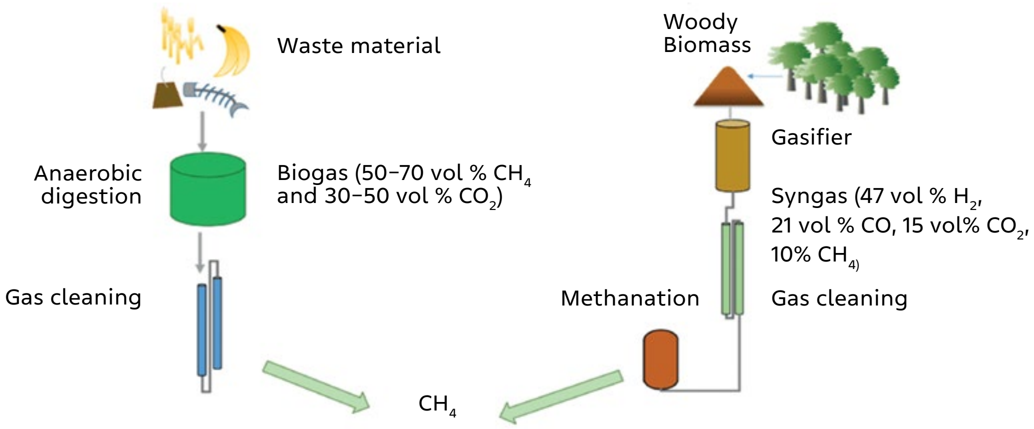
Another possible method is the so-called thermal gasification, a multi-stage process that begins with the gasification of biomass. In this case, the input material is mainly plant biomass, such as wood chips, straw, wood waste, forestry residues, landscape care wood, prunings or municipal solid waste. This material is then heated to a high temperature in an environment with limited access to oxygen. The output of this phase is the so-called syngas, consisting of hydrogen (H_2), carbon monoxide (CO) and other components. This is followed by catalytic methanization and treatment of the resulting gas, similar to the production of biomethane from biogas.

Globally, the vast majority of biomethane is produced by the first of the above-mentioned methods, i.e. by upgrading biogas, typically from agricultural biogas plants.

The biggest advantage of biomethane is its compatibility with the existing gas infrastructure. Biomethane produced by any method can be injected into the natural gas distribution network. It can also be stored in existing gas reservoirs long-term and used without significant restrictions wherever fossil gas is currently used.

Biomethane can be used for electricity and heat generation, for heating buildings and for industrial purposes. A key benefit is its high combustion temperature, exceeding 1900°C (compared to up to 1000°C for biomass combustion). This allows decarbonization in hard-to-abate sectors such as glass production, which takes place at a temperature of around 1200°C, cement production, which takes place at a temperature of around 1500°C, or steel production, which takes place at a temperature of around 1600°C.

Figure 3. Schematic representation of the basic methods of biomethane production



Source: Pääkkönen, A. et al., The Potential of Biomethane in Replacing Fossil Fuels in Heavy Transport—A Case Study on Finland, Sustainability 2019

Biomethane can also be used in the field of transport where other alternatives are unsuitable or unavailable for various reasons. Additionally, modifying existing power units to use biomethane is easier than converting them to electric or hydrogen propulsion.

Biomethane can also serve as a renewable alternative for producing chemicals like methanol and ammonia.

The production emissions of biogas and biomethane depend on the technology used and other factors, including the quality of maintenance and inspection of the given facility. It is important to note that biogas and biomethane are greenhouse gases themselves due to their high methane content. The estimated global warming potential of methane is approximately 30 times higher in a 100-year time horizon compared to the same volume of CO_2. Even relatively small leaks during the production process can have a large impact on the overall emission footprint. On the other hand, e.g. when using landfill gas or capturing biogas during WTP operation, one can talk about preventing methane emissions that would otherwise escape into the atmosphere.

Compared to fossil gas, the advantage is that the production of biogas and biomethane takes place in a controlled environment, unlike in-situ extraction of natural gas, where it is relatively difficult to prevent leaks into the atmosphere.

Combustion emissions from biomethane are nearly identical to those from fossil gas.[7] However, biomethane is a local resource, meaning emissions associated with long-distance transport—such as those for liquefied natural gas (LNG)—are significantly reduced.

7 Holta N., Ruelas A.: Understanding biogas: how to cut Scope 1 emissions with biomethane, October 2024, https://www.ecohz.com/blog/understanding-biogas-cut-scope-1-emissions

Hydrogen and its colors

Hydrogen is the lightest gaseous element, occurring primarily in the form of so-called elemental hydrogen (H_2). In connection with its occurrence and production, we speak of the so-called colors of hydrogen. These do not represent the real color (hydrogen itself is a colorless gas) but help to distinguish the individual methods of its production.

Figure 4. Colors of hydrogen

Renewable origin	Green hydrogen	RES electricity or biological origin
	Yellow hydrogen	Solar electricity
Nuclear origin	Pink/red/purple hydrogen	Nuclear electricity or heat
Fossil origin	Blue hydrogen	Fossil gas + CCS
	Turquoise hydrogen	Fossil gas + CCS
	Gray hydrogen	Fossil gas (no CCS)
	Black/brown hydrogen	Coal
Naturally occurring	White/gold hydrogen	

Source: own chart

Green hydrogen is produced primarily by water electrolysis, in which water (H_2O) is decomposed into hydrogen (H_2) and oxygen (O_2) using electricity originating exclusively from RES, such as solar or wind power plants. The by-products are the aforementioned oxygen and waste heat. No other greenhouse gases are produced during the production of green hydrogen itself.

In addition to electrolysis, green hydrogen can also be produced by biological methods such as photobiological production using photosynthetic microorganisms, dark anaerobic fermentation using anaerobic bacteria, photofermentation combining both previous methods, or microbial electrolysis using electrogenic bacteria. Unlike water electrolysis, biological methods for producing green hydrogen are characterized by very low efficiency and specific production conditions, which is why they are not yet used in practice.

Yellow hydrogen is produced by electrolysis, but only using electricity from solar or photovoltaic power plants. Sometimes this designation is also used for production using electricity of mixed origin from RES and non-renewable energy resources.

Pink, red or purple hydrogen is produced using nuclear energy. Pink hydrogen is produced using electrolysis, just like green or yellow hydrogen, with the only difference being that the electricity comes from nuclear power plants. Red hydrogen is produced through the high-temperature catalytic splitting of water using nuclear thermal power as an energy source. Purple hydrogen is produced using nuclear electricity and heat via combined chemo-thermal electrolysis splitting of water. Of the methods described, only pink hydrogen is currently produced, and in completely negligible quantities.

Blue hydrogen is produced from fossil gas, mainly using steam methane reforming (SMR). In this process, methane (CH_4) contained in fossil gas reacts with water vapor (H_2O) at high temperature, producing hydrogen (H_2) and carbon dioxide (CO_2). In this case, it is expected that the resulting CO_2 will be captured and stored (carbon capture and storage—CCS) or further utilized (carbon capture, utilization, and storage—CCUS). In addition to SMR, a technique known as auto-thermal reforming (ATR) combines the steam reforming reaction and fuel oxidation into a single unit. ATR should enable more efficient capture of the resulting CO_2.

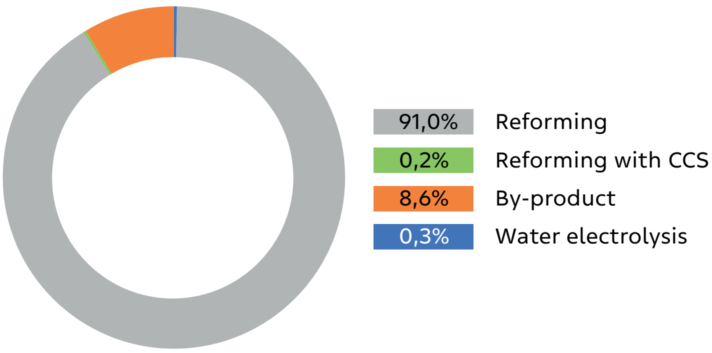
Turquoise hydrogen is also obtained from fossil gas, but by thermal splitting of methane using methane pyrolysis at very high temperatures. The resulting carbon is to be separated in the form of so-called carbon black in solid form. This material is currently used in industry, for example, to produce lithium-ion batteries. However, the production of turquoise hydrogen is still in the experimental phase.

Gray hydrogen, like blue hydrogen, is produced from fossil gas using SMR or ATR, but with the difference that the resulting CO_2 is released into the atmosphere. Currently, this is by far the most common method of producing hydrogen.

Black and brown hydrogen are produced from coal. Black hydrogen originates from bituminous coal, and brown hydrogen from lignite. The coal gasification technique is mainly used for production. The resulting CO_2 and toxic CO are released into the atmosphere. Considering the availability of coal, this is a relatively cheap but very polluting method of production.

White or golden hydrogen is a naturally occurring hydrogen. It is assumed that most white hydrogen is formed by a process called serpentinization, which consists of the reaction of water with ultrabasic rocks (a term for a group of igneous rocks). In Europe, the occurrence of white hydrogen has so far been noted in Albania and France, where its extraction is to begin by the end of this decade. Nowadays, white hydrogen is only mined in small quantities in Mali, Africa.[8]

Figure 5. Hydrogen production capacity by production process in Europe, 2022



Source: own chart based on European Hydrogen Observatory

The above overview presents commonly used designations, which can sometimes be interpreted in different ways (see, for example, yellow hydrogen), and have no normative or legal basis. The concept of hydrogen colors also does not take into account, for example, the production of hydrogen as a by-product within existing industrial processes.

8 Maiga O. et al.: Characterization of the spontaneously recharging natural hydrogen reservoirs of Bourakebougou in Mali, July 2023, https://www.nature.com/articles/s41598-023-38977-y

From the perspective of the European Gas Directive[9], low-emission hydrogen can be considered not only hydrogen of renewable or nuclear origin, but also fossil hydrogen, if its production meets the condition of reducing greenhouse gas (GHG) emissions by at least 70% compared to the reference level.[10] Thus, blue or turquoise hydrogen can also meet this condition under certain circumstances.

At present, most hydrogen is produced from fossil gas by reforming (mainly SMR, less so ATR). This preference is due to the relatively low production costs and the fact that SMR is a well-established technology. Only a very small part of the CO_2 emissions generated are captured by CCS. Similarly, hydrogen production via electrolysis currently accounts for a very small proportion.

Today, hydrogen is used for chemical industry purposes rather than as an energy carrier. It is used in the refining of oil, particularly in desulfurization process, in the production of methanol, which is used as a solvent or as a raw material for the production of other organic substances, or in the production of ammonia, which is used for the production of nitrogen fertilizers.

Due to its low density, hydrogen takes up a significant volume, making storage challenging. For instance, hydrogen stored at a pressure of 20, MPA and a temperature of 20°C takes up approximately five times more volume than fossil gas with the same energy content, stored under the same conditions.

The volume of hydrogen can be reduced either by storing it under higher pressure or by liquefying it. However, liquefaction poses additional challenges due to the extremely low temperature required. For example, while LNG is produced by cooling and condensing fossil gas at a temperature of approximately -160°C, hydrogen needs to be cooled down to -253°C (i.e. only 20°C from absolute zero) to liquefy, making it a very energy-intensive process. Liquefying one kilogram of hydrogen consumes roughly one-third of the energy contained in that hydrogen, compared to about one-tenth for fossil gas.

Some other specific properties also make handling hydrogen difficult. One of them is the so-called hydrogen embrittlement affecting various metals, especially steel. It occurs due to the diffusion of hydrogen into the material's crystal lattice, subsequently causing its brittleness, or loss of mechanical properties, which can lead to cracks.

This property complicates not only hydrogen storage but also its transportation. Existing gas pipelines can be used to transport hydrogen, but for this purpose, among other things, the pressure must be reduced so as to limit the penetration of hydrogen into the pipeline material. This in turn reduces the transport capacity. Alternatively, this problem can be resolved by applying a plastic coating to the inside of the pipeline or by using pipelines made of a different material.

Modifying existing gas pipelines for hydrogen transport is feasible and, while expensive, remains significantly more cost-effective than constructing new, dedicated hydrogen pipelines. The existing gas infrastructure can handle the transport of gas and hydrogen mixtures containing up to 20% hydrogen by volume without major modifications.

Another unpleasant property of hydrogen is its wide explosion limit. Hydrogen forms an explosive mixture with air at concentrations ranging from 4%

9 Directive (EU) 2024/1788 on common rules for the internal markets for renewable gas, natural gas and hydrogen, amending Directive (EU) 2023/1791 and repealing Directive 2009/73/EC

10 Eurogas position paper: Eurogas' guiding principles on low-carbon fuels, https://www.eurogas.org/resource/eurogas-guiding-principles-on-low-carbon-fuels/

to 77% by volume (compared to 4% to 15% for fossil gas). For this reason, strict safety precautions must be observed when handling this gas.

Last but not least, hydrogen itself acts as GHG. Its warming potential is 5 to 11 times greater than for the same amount of carbon dioxide. Therefore, it is necessary to monitor possible leaks in the hydrogen infrastructure to limit fugitive emissions.

Future uses of low-emission hydrogen include applications in transport, energy and decarbonisation of hard-to-abate sectors.

Electricity can be produced from hydrogen either in fuel cells or by combustion, for example in a gas turbine. No harmful emissions are released during the operation of fuel cells and the only by-product is pure water. The combustion of hydrogen produces not only water vapour but also nitrogen oxide emissions caused by the reaction with nitrogen contained in the air, which acts as an oxidiser during combustion. In addition to harmful emissions, another problem during combustion is the high combustion temperature of hydrogen, which is around 2100°C. This is at the very edge of the material possibilities of turbine blades, which is why the range of turbines capable of burning pure hydrogen is currently very limited.

On the other hand, hydrogen's high combustion temperature is an advantage in the decarbonization of glass, cement or steel production, similar to biomethane. In steel production, hydrogen not only provides the necessary temperature, but also serves as a reducing agent.

In the transportation sector, hydrogen can power road and rail vehicles and aircraft. Initially, hydrogen propulsion was seen as most suitable for heavy trucks and long-distance buses. Recently, however, it has been competing strongly with battery electric vehicles, whose performance continues to improve annually.

Similarly, in rail transport, it is important to consider hydrogen propulsion only on non-electrified routes longer than 100 km. Battery-powered trains are now able to serve shorter distances.

In the field of air transport, hydrogen, together with synthetic fuels, represents one of the few options for decarbonizing long-distance flights. Some manufacturers, such as Airbus[11], are considering using this fuel in liquefied form, despite the disadvantages that its use in aviation brings.

11 Airbus: ZEROe Towards the world's first hydrogen-powered commercial aircraft, https://www.airbus.com/en/innovation/energy-transition/hydrogen/zeroe

CZECHIA

Green gasses—state of affairs

Biogas and biomethane production

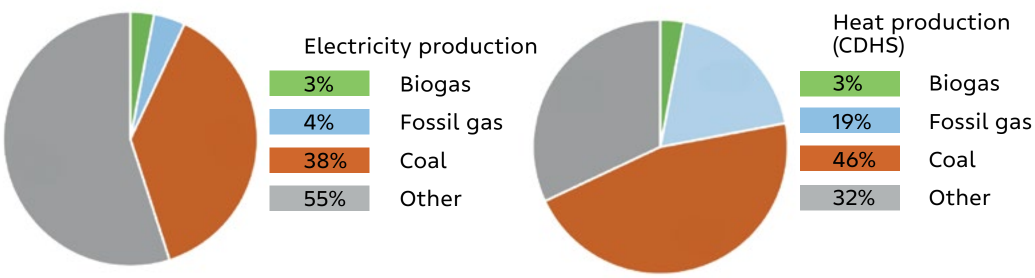
According to the Czech Biogas Association, 540 BGPs were in operation in the Czech Republic at the end of 2023. Most of these BGPs are used to produce electricity and heat, supplied within the framework of central district heating systems (CDHS). However, several installations produce raw biogas, which is then transported via pipeline to cogeneration units located at the point of consumption.

In terms of electricity production, the installed capacity of Czech BGPs is 380.5 MW. In 2023, they produced 2,590 GWh, of which 2,401 GWh were supplied to the grid, while the rest (approximately 7%) served to cover their own technological consumption.[12] Over the past 10 years, electricity production in BGPs has been approximately constant at around 2,500 MWh.

In 2023, the share of electricity produced by BGPs among all renewable sources was 23%. Their total share in electricity production was approximately 3%. For comparison, 4% of electricity was produced from imported fossil gas in the same year. If we talk about the share of consumption (the Czech Republic still has a relatively large share of electricity exports), then BGPs covered more than 4% of domestic consumption.

Additionally, BGPs supplied 4201 TJ of heat to the district heating system in 2023, which represented a 3% share of total heat production. By comparison, 19% of heat was produced from fossil gas.[13]

Figure 6. Share of biogas on electricity and heat (CDHS) production in Czechia, 2023



Source: own chart based on Energy Regulatory Office

12 Energetický regulační úřad: Roční zpráva o provozu elektrizační soustavy ČR pro rok 2023, https://eru.gov.cz/rocni-zprava-o-provozu-elektrizacni-soustavy-cr-pro-rok-2023

13 Energetický regulační úřad: Roční zpráva o provozu teplárenských soustav ČR za rok 2023, https://eru.gov.cz/sites/default/files/obsah/prilohy/eruteplo2023.pdf

Biomethane production in the Czech Republic began in 2019. From a technological standpoint, all biomethane in the Czech Republic is produced by treating biogas. As of early 2025, a total of 11 biogas stations were operating, supplying biomethane to the natural gas distribution network.

In 2024, 6 million m^3 of biomethane was produced in the Czech Republic. However, this production falls short of the available capacity, as some facilities are shut down part of the time. Due to inappropriately structured support mechanisms, they sometimes incur financial losses during operation.

Biomethane production is supported through investment and operational support. Investment support is provided through the Operational Programme Environment, which offers subsidies for the construction and modernization of biogas stations with biomethane production. For instance, in 2024, the Ministry of the Environment supported seven large biogas and biomethane production projects with a total subsidy of 33 million CZK. Another program is the National Environment Program, which offers subsidies for projects aimed at reducing greenhouse gas emissions, including biomethane production.

Operating support is based on biomethane purchase prices, determined by its production costs and environmental benefits, or through the so-called green bonus.[14] However, traders refuse to buy biomethane at a fixed annual price and are forcing producers to pay spot prices. This creates significant uncertainty in this business.

Hydrogen production

According to the European Hydrogen Observatory, the annual hydrogen production capacity in the Czech Republic is 130 kt. Of this, 120 kt is produced through reforming, while 10 kt is produced as a by-product. CCS is not used in hydrogen production. In 2022, actual hydrogen production reached 100 kt.[15]

The first–and so far only–green hydrogen production plant in the Czech Republic was launched in 2023 in the town of Napajedla. It uses electricity from a small hydroelectric power plant for production, with expected annual production of 8 t of green hydrogen.

A number of hydrogen projects are currently being prepared in the Czech Republic, most of which aim to produce green hydrogen for use in transportation.

The GreenGas program within the Modernization Fund is intended to finance green hydrogen production projects.[16] Hydrogen projects can also be financed through the Operational Program Technologies and Applications for Competitiveness or the National Recovery Plan.

14 The amount of the annual green biomethane bonus is calculated by subtracting the average natural gas price in the first half of the year from the reference price. The green bonus is therefore higher when the natural gas price is low and vice versa.

15 European Hydrogen Observatory: The European hydrogen market landscape, https://observatory.clean-hydrogen.europa.eu/sites/default/files/2023-11/Report%2001%20-%20November%202023%20-%20The%20European%20hydrogen%20market%20landscape.pdf

16 https://www.sfzp.cz/dotace-a-pujcky/modernizacni-fond/programy/

Table 1. List of hydrogen projects in Czechia.

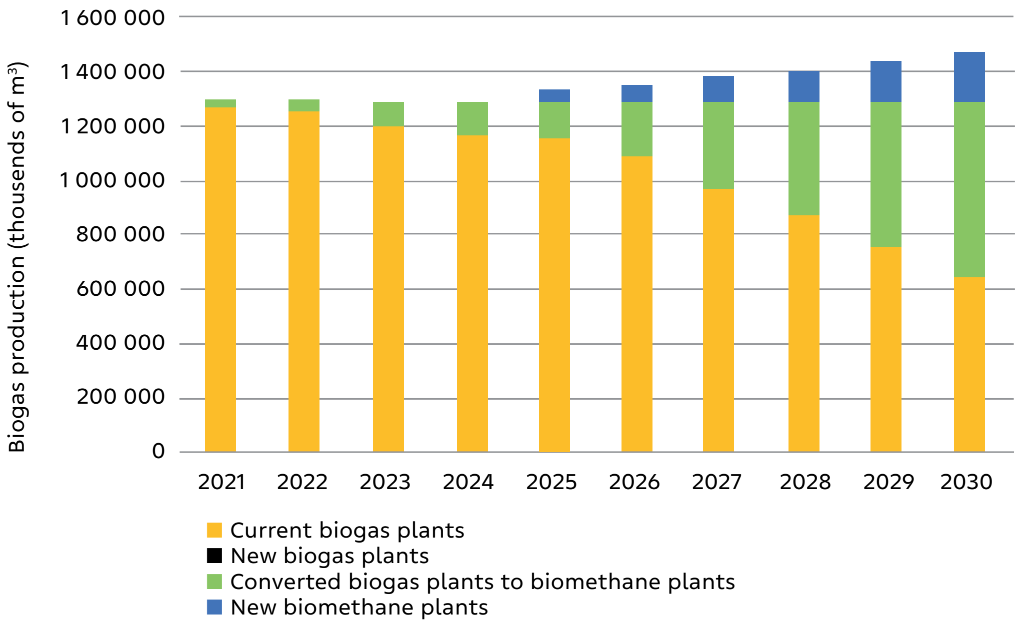
Year of planned start of operation	Location	Investor	Installed electro-lyzer capacity [MW]	Expected annual produc-tion [t/year]	Energy source	Installed energy source capacity [MW]	Expected use
2023	Napajedla	Solar Global	0,2	8	Hydro	0,6	Transportation
2024	Tábor	C-Energy	N/A	N/A	PV	8	Public transportation
2025	6 different locations	ČEZ	10	N/A	N/A	N/A	Public transportation
2026	Frýdek-Místek	Veolia Energie	2	270	PV + biomass	N/A	Public transportation
2026	Žatec	For H2 Energy	4	630	PV	4	Transportation
2027	Litvínov	Orlen	26	4500	PV	60	Industry + transportation
2030	various locations	Black Horse	N/A	23 000	N/A	N/A	Transportation
N/A	Brno	Teplárny Brno	N/A	N/A	PV	N/A	Public transportation

Source: own chart based on publicly available information from media

Future plans

The production of green gases is enshrined in fundamental strategic documents such as the National Climate and Energy Plan (NECP) or the Updated State Energy Concept. According to these documents, biogas and biomethane are regarded as important tools for decarbonization, primarily in the heating and transport sectors, while also emphasizing their role in the diversification of energy sources and strengthening energy security.

Figure 7. Expected biogas production divided into current, converted and new BGP



Source: Ministry of Industry and Trade

The draft Action Plan for the Support of the Development of Biomethane Utilization, which builds upon the NECP, aims to achieve the production of 500 million m^3 of biomethane per year by 2030 and increase the share of biomethane in transport to 10%.[17] To this end, the reconstruction of part of the existing BGP for the biomethane production is planned.

The analysis done by the Ministry of Industry and Trade found that out of the more than 500 existing BGPs, 270 are located within 2 km of a high-pressure gas pipeline. In these cases, the produced biomethane can be injected into the gas infrastructure without high additional costs.

The updated Hydrogen Strategy sets a goal to produce and possibly import at least 20 kt of renewable hydrogen by 2030 to replace fossil hydrogen in industry and transport, which represents approximately 20% of the current hydrogen production in the Czech Republic.[18]

The strategy includes the construction of 400 MW electrolyser capacity with utilization between 30 and 50%. The Hydrogen Strategy is further divided into three stages, based on the expected development of renewable hydrogen prices, see Figure 8.

Figure 8. Stages of the Czech Hydrogen Strategy

	Hydrogen Production	**Hydrogen Transport**	**Hydrogen Usage**
1. Local Islands (€8/kg H_2)	Local RES, organic waste, low-carbon electricity	Preferably used at the production site or transport by road/railroad up to 150 km	Mobility, chemical industry, RES compensation, blending
2. Global Bridges (€2,7–4/kg H_2)	RES in other countries (Czech and foreign producers)	Hydrogen pipelines, local hydrogen distribution networks	Mobility, chemical industry, specific elektricity & heat production
3. New Technologies (€2/kg H_2)	Combined production of electricity, heat and hydrogen from geothermal or nuclear	Hydrogen pipelines, local hydrogen distribution networks	Mobility, all industries, production of heat and electricity

2025 2030 2035 2040 2045 2050

Source: Ministry of Industry and Trade

The first Czech hydrogen valley is being prepared in the Moravian-Silesian Region. The project is being prepared by the Moravian-Silesian Hydrogen Cluster, which has 34 members. In addition to green hydrogen, the project also includes other low-emission hydrogen colors.[19]

17 Hospodářská komora České republiky: Akční plán podpory rozvoje a využívání biometanu, https://www.komora.cz/pravni-predpis/9-25-akcni-plan-podpory-rozvoje-vyuzivani-biometanut15-1-2024/

18 Ministerstvo průmyslu a obchodu: Vodíková strategie, aktualizace 2024, https://mpo.gov.cz/assets/cz/prumysl/strategicke-projekty/2024/7/Vodikova-strategie-CR-aktualizace-2024.pdf

19 Moravskoslezský vodíkový klastr: https://www.ms-vk.cz/

HUNGARY

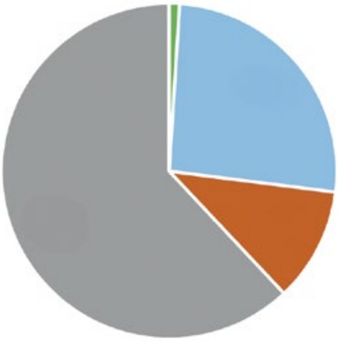
Green gasses—state of affairs

Biogas and biomethane production

In 2020, there were 76 BGPs in operation in Hungary, with an installed capacity of 37 MW. According to the Bioenergy Europe report, these plants generated 326 GWh of electricity and 126 TJ of derived heat.[20]

Their total share in electricity consumption was approximately 0.7%. For comparison, over 19% of electricity was produced from fossil gas in the same year.

Figure 9. Share of biogas on electricity consumption in Hungary, 2020



Source: own chart based on Eurostat and Countryeconomy data

According to the European Commission, two biomethane stations are currently operating in Hungary. The total biogas and biomethane production is 0.9 bcm, which corresponds to 0.9% of natural gas supply.[21] These biogases are mainly used to produce electricity, either in electricity-only or CHP plants (66%). In final energy consumption (17%), the main consumers are industry (13%) and commercial and public services (4%).

Hydrogen production

According to the European Hydrogen Observatory, Hungary's annual hydrogen production capacity is 250 kt. Of this, 230 kt is produced through reforming, while 20 kt is produced as a by-product. CCS is not used in hydrogen production. In 2022, actual hydrogen production reached 190 kt.[22]

20 Bioenergy Europe: Statistical Report 2022, https://www.europeanbiogas.eu/wp-content/uploads/2022/07/SR22_Biogas_Fullversion.pdf

21 European Commission: BIOMETHANE FICHE—Hungary (2021), https://energy.ec.europa.eu/system/files/2023-09/Biomethane_fiche_HU_web.pdf

22 European Hydrogen Observatory: The European hydrogen market landscape, https://observatory.clean-hydrogen.europa.eu/sites/default/files/2023-11/Report%2001%20-%20November%202023%20-%20The%20European%20hydrogen%20market%20landscape.pdf

Green hydrogen production is carried out in Százhalombatta, where MOL Group launched operations in 2024. This facility has an installed capacity of 10 MW and an annual capacity of 1,600 t,[23] making it the largest green hydrogen production plant in Central and Eastern Europe. The hydrogen produced is used for refining oil at a nearby refinery.

Future plans

Hungary has ambitious plans for the development of biomethane and green hydrogen, as outlined in several strategic documents. Hungary's National Energy and Climate Strategy (NECP) estimates that biogas and biomethane could realistically replace around 3% of the Hungarian natural gas consumption by 2030, which would mean the current production to approximately triple. The strategy also highlights the importance of green hydrogen for the decarbonisation of industry and transport, supporting its production from renewable energy sources.[24]

The Biogas Action Plan calls for the modernization of existing biogas stations and their transformation into biomethane stations. As a primary goal the biomethane should be injected into the gas network and used in transport. As a secondary goal, biogas should be used in electricity and heat production locally.

The strategic plans of the government that were presented at the end of 2024 envisage an increase of the biomethane production from 5.4 mcm in 2022 to 184 mcm by 2030.

Table 2: Main Goal and Timeline of the Hungarian biogas and biomethan strategy, 2024

Million m3	**2022**	**2026**	**2028**	**2030**
Biogas production	203	240	300	600
Self-consumption (fermenter heating)	34	40	50	100
Biogas used for biomethane production	10	40	90	340
Biomethane produced from this	5.4	22	49	184
Biogas-based electricity and onsite heat consumption	159	160	160	160

Source: Horváth V: Biogas Forum Budapest, December 2024

To reach this goal 25 new facilities should come online each with a 1,000 m^3/h average capacity. The planning of these facilities is rather centralized, and supported by integrators to cover the necessary feedstock and to ensure that

23 Molgroup: MOL started production in the largest capacity green hydrogen plant of the region, https://molgroup.info/en/media-centre/press-releases/mol-started-production-in-the-largest-capacity-green-hydrogen-plant-of-the-region

24 European Commision: Final updated NECP 2021–2030 (submitted in 2024), https://commission.europa.eu/publications/hungary-final-updated-necp-2021-2030-submitted-2024

green waste is utilized and agricultural GHG emissions are reduced in a professional manner. Up to 100 biogas plants are planned in locations where 100,000–500,000 tons of feedstock is available and grid injection is feasible.

Revenue will increasingly come from **guarantees of origin** and **sustainability certifications** that are to be set up soon.

The government provides investment support in the magnitude of 40 billion HUF. All enterprises can apply for the non-refundable funds with a max support intensity of 65%. Eligible activities are:

- Equipment for feedstock preparation and handling.
- Storage facilities (raw materials and end products).
- Fermenters, hygienizers, and sterilizers.
- Gas quality improvement equipment.
- Grid connection infrastructure (gas & electricity).
- Equipment for digestate application (only essential components).

The project completion deadline is 31 December 2028. Project grant range is 500 million–5 billion HUF.

There is an additional 8 million HUF earmarked for infrastructure to end users, biomethan purification equipment and equipment for local biomethan conversion into heat and electricity.

FGSZ, the Hungarian TSO, already launched a non-binding interest call for biomethan connections in October 2024. Altogether 17 stakeholders submitted requests for 48 production facilities and 3 consumption places with a total estimated 255 mcm/yr production by 2030. Most of them are in the conceptual phase. The typical size of planned facilities is in the range of 1000–1500 m^3/h capacity. According to the current regulation connection shall be financed by the biomethan facility but the technical plans need TSO/DSO approval. These costs might be co-financed up to 45% by grants.

On the regulatory side there are non-financial market development measures foreseen, most importantly a Guarantees of Origin System will be implemented. There are plans for simplification of biogas plant permitting processes and efficient utilization of by-products: standardized digestate products and easier placement of digestate liquid. It is promised to introduce a simplification of natural gas grid connection processes.

The GO system in Hungary

From April 1, 2024, the energy quantity of renewable gas can only be verified to the user by the seller through a Guarantee of Origin (GO). The Guarantee of Origin (GO) is an electronic document that verifies, based on objective, transparent, and non-discriminatory criteria, that a certain quantity of gas produced by a given production unit qualifies as renewable gas. GO trading is independent of the physical gas flow in the network. This means GOs can be sold separately from the actual gas quantity. Pending legislation (Bill T/9720) proposes that from April 1, 2025, GOs may also be issued for low-carbon gases.

Renewable gases (biomethan, biogas and green hydrogen) can apply for GO in the following cases:

- Injection into the natural gas transmission or distribution system
- Transport by tanker truck

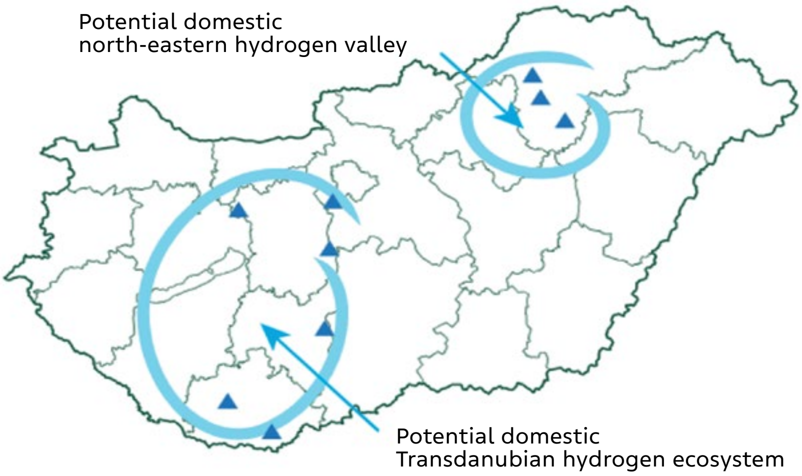
- On-site consumption
- Auxiliary consumption: If used directly in gas production, conversion, or storage (losses included).
- Withdrawal from storage
- Conversion: The upgrading of biogas into biomethane is considered conversion.

However, mixing hydrogen with natural gas is NOT considered conversion.

The GO system is operated by the regulator MEKH, and has a registration fee. In the near future MEKH plans to join the AIB EECS system (European Energy Certificate System). This will enable international trade of the certificates.

Hungary's National Hydrogen Strategy aims to have 240 MW of green and low-carbon hydrogen production capacity by 2030. This would enable the production of 16 kt of green and other carbon-free hydrogen per year and 20 kt of low-carbon hydrogen.[25]

Figure 10. Potential hydrogen valleys of Hungary



Source: Hungary's National Hydrogen Strategy

Hungary also plans to establish two new hydrogen valleys by 2030:

Hydrogen ecosystem of the Transdanubia: in addition to already existing large hydrogen users, there are several sectors that may potentially become new hydrogen users: iron and steel works (Dunaújváros) and cement production facilities (Beremend, Királyegyháza). The Paks nuclear power plant may supply a significant amount of carbon-free electricity to support the hydrogen value chain.

North-eastern hydrogen valley: This industrial region, which includes Miskolc, Tiszaújváros, and Kazincbarcika, has a well-developed chemical and petrochemical industry with significant existing hydrogen demand. It is seen as an area with high potential for hydrogen use due to its concentrated industrial activities.

25 HUNGARY'S NATIONAL HYDROGEN STRATEGY, https://cdn.kormany.hu/uploads/document/a/a2/a2b/a2b2b7ed5179b17694659b8f050ba9648e75a0bf.pdf

POLAND

Green gasses—state of affairs

Biogas and biomethane production

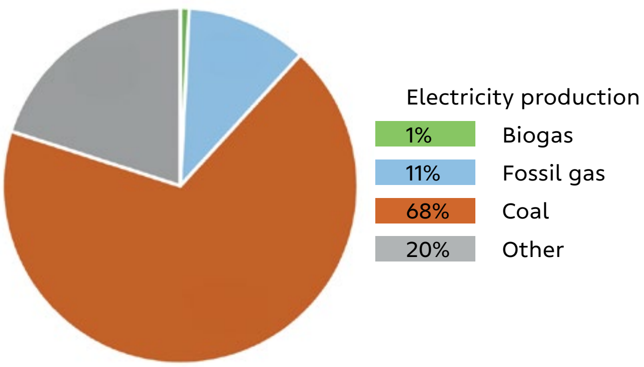
By the end of 2023, there were 218 agricultural BGPs and 148 municipal BGPs in Poland. According to the Bioenergy Europe report, Polish BGPs generated 1,233 GWh of electricity and 921 TJ of derived heat in 2020.[26]

Their total share of biogas in electricity consumption was approximately 0.7%. For comparison, 10% of electricity was produced from fossil gas in the same year.

According to Eurostat, the total biogas production in 2021 was 0.4 bcm, which corresponded to 1.8% of natural gas supply. Biogas is mainly used to produce electricity, either in electricity-only or CHP plants (73%), whereas final energy consumption (27%) has commercial and public services (19%) as the main consumer.[27]

Based on the available data, there is currently no commercial production of biomethane in Poland.

Figure 11. Share of biogas on electricity consumption in Poland, 2020



Source: own chart based on Eurostat and Countryeconomy data

Hydrogen production

According to the European Hydrogen Observatory, Poland's annual hydrogen production capacity is 1100 kt. Of this, 1080 kt is produced through reforming, while 20 kt is produced as a by-product. CCS is not used in hydrogen production. In 2022, actual hydrogen production reached 780 kt.[28]

26 Bioenergy Europe: Statistical Report 2022, https://www.europeanbiogas.eu/wp-content/uploads/2022/07/SR22_Biogas_Fullversion.pdf

27 European Commission: BIOMETHANE FICHE—Poland (2021), https://energy.ec.europa.eu/system/files/2023-09/Biomethane_fiche_PL_web.pdf

28 European Hydrogen Observatory: The European hydrogen market landscape, https://observatory.clean-hydrogen.europa.eu/sites/default/files/2023-11/Report%2001%20-%20November%202023%20-%20The%20European%20hydrogen%20market%20landscape.pdf

There are several smaller green hydrogen production projects in Poland. The first hydrogen hub was launched by Orlen in 2022 in Trzebinia, southern Poland, supplying hydrogen fuel for Kraków's public transport buses.[29]

Green hydrogen is also being produced to store electricity from the Gaj Oławski 5 AHE pilot hybrid power plant, which combines wind power and agrovoltaics. The installed capacity for this project is 5 MW.[30]

Future plans

The Polish hydrogen strategy envisions 2 GW of installed capacity for low-carbon hydrogen production facilities by 2030, along with the creation of five hydrogen valleys.[31]

By 2030, Poland plans to invest PLN 11 billion in hydrogen technologies, with PLN 9 billion allocated to facilities for the production of low-emission and zero-emission hydrogen. The planned offshore wind farms are expected to be a key source of electricity for green hydrogen production.[32]

The European Commission has already approved public aid of €143 million for Polenergia's H2Silesia project. This project involves the construction of a 105 MW green hydrogen production facility for heavy industry and transport in Upper Silesia. The planned plant will be able to produce approximately 13 000 tonnes of hydrogen per year.

29 Orlen: Green project in Trzebinia produces fuel from used oils, https://www.orlen.pl/en/about-the-company/media/press-releases/2023/October-2023/Green-project-in-Trzebinia-produces-fuel-from-used-oils

30 Teraz Środowisko: Pierwsza polska hybryda OZE z koncesją. Pokazujemy instalację z bliska, https://www.teraz-srodowisko.pl/aktualnosci/pierwsza-polska-hybryda-oze-z-koncesja-pokazujemy-instalacje-z-bliska-14766.html

31 Polish Hydrogen Strategy until 2030, https://www.gov.pl/attachment/06213bb3-64d3-4ca8-afbe-2e50dadfa2dc

32 Bussinessinfo.cz: Polsko rozvíjí infrastrukturu pro výrobu i přepravu zeleného vodíku, https://www.businessinfo.cz/clanky/polsko-rozviji-infrastrukturu-pro-vyrobu-i-prepravu-zeleneho-vodiku/

SLOVAKIA

Green gasses—state of affairs

Biogas and biomethane production

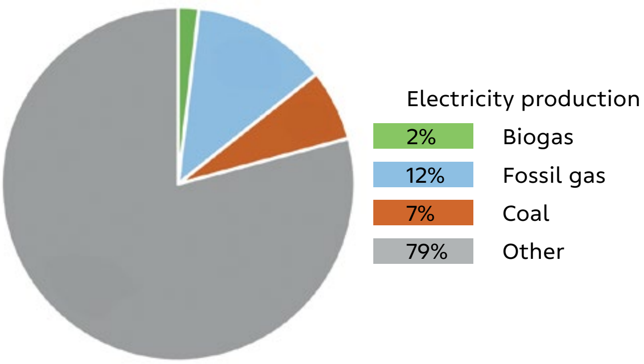
Currently, around 80 BGPs are in operation in Slovakia, with an installed capacity of 70 MW. This marks a decrease of approximately 30 BGPs compared to previous years.

According to the Bioenergy Europe report, Slovak BGPs generated 512 GWh of electricity and 712 TJ of derived heat in 2020.[33] Their total share in electricity consumption was more than 2%. For comparison, more than 12% of electricity was produced from fossil gas in the same year.

According to Eurostat, total biogas production in 2021 was 0.1 bcm, which corresponded to 2.9% of natural gas supply. Biogas is used to produce electricity, either in electricity-only plants or CHP plants (81%), followed by agriculture and forestry (14%) and commercial and public services (5%) in final energy consumption.[34]

Slovakia's first and, so far, only biomethane station was launched in 2022 in Jelšava.[35] Another biomethane station is expected to be completed by the end of 2025 near the municipality of Šarišské Jastrabie (Stará Ľubovňa district) for processing biomass and biowaste. The project has already received approval through the EIA process, as well as support from authorities and the public. The investor is Fobos SWM energy, with estimated costs of €18 million.[36]

Figure 12. Share of biogas on electricity consumption in Slovakia, 2020



Source: own chart based on Eurostat and Countryeconomy data

33 Bioenergy Europe: Statistical Report 2022, https://www.europeanbiogas.eu/wp-content/uploads/2022/07/SR22_Biogas_Fullversion.pdf

34 European Commission: BIOMETHANE FICHE—Slovakia (2021), https://energy.ec.europa.eu/system/files/2023-09/Biomethane_fiche_SK_web.pdf

35 Česká bioplynová asociace: První biometanová stanice na Slovensku, https://www.czba.cz/aktuality/prvni-biometanova-stanice-na-slovensku.html

36 ENVIROPORTÁL: Posudzovanie vplyvov na životné prostredie (EIA/SEA), Biometánová stanica 4,0 MW ENG, https://www.enviroportal.sk/eia/detail/biometanova-stanica-4-0-mw-eng

Hydrogen production

According to the European Hydrogen Observatory, Slovakia's annual hydrogen production capacity is 230 kt. Of this, 220 kt is produced through reforming, while 10 kt is produced as a by-product. CCS is not used in hydrogen production. In 2022, actual hydrogen production reached 110 kt.[37]

Green hydrogen is produced in small quantities as part of a pilot project launched in 2022 by the Slovak gas pipeline operator Eustream at the Veľké Kapušany compressor station.[38]

In 2022, the distribution company SPP-distribúcia launched a project called H2Pilot, a pilot initiative to distribute a mixture of natural gas and hydrogen to households in Slovakia. The project was carried out in the village of Blatná na Ostrove, where over 300 households temporarily received the gas-hydrogen mixture. One of the key outcomes of the project was the confirmation of the safe operation of all affected equipment with a mixture containing 10% hydrogen.[39]

Future plans

Slovakia is planning a series of activities to increase the production of biomethane and low-emission hydrogen. This includes the conversion of some biogas plants to biomethane production. Analysis shows that 33 BGPs are located less than 4 km from the high-pressure gas grid and can therefore be connected to this network with minimal challenges. Subsidies covering up to 75% of the related costs are available for such conversions. According to the NECP, it is expected that by 2030, 200 million m^3 of biomethane could be produced in this manner.

Slovak hydrogen strategy envisions the construction of 140–390 MW electrolyser capacity (410–1140 GWh/year) by 2030. The produced green hydrogen is expected to be used primarily in industry, buildings and transport, with significantly less allocated for electricity generation.[40]

Hydrogen is a focus not only at the national level but also at the regional level. Self-governing regions, such as Košice, consider hydrogen an important energy carrier for the future. The Košice region sees potential in cooperating with Ukraine on a hydrogen corridor and in utilizing hydrogen in the steel industry, as Košice is home to US Steel, the largest steel producer in Central Europe.[41]

37 European Hydrogen Observatory: The European hydrogen market landscape, https://observatory.clean-hydrogen.europa.eu/sites/default/files/2023-11/Report%2001%20-%20November%202023%20-%20The%20European%20hydrogen%20market%20landscape.pdf

38 ESG-investice.cz: Na Slovensku byla zahájena výroba vodíku z OZE, https://www.esg-investice.cz/na-slovensku-byla-zahajena-vyroba-vodiku-z-oze/

39 Teraz: Spoločnosť SPP-distribúcia už v roku 2022 zrealizovala projekt s názvom H2 Pilot – pilotnú distribúciu zmesi zemného plynu a vodíka domácnostiam na Slovensku, November 2024, https://www.teraz.sk/ekonomika/spp-distribucia-plynarenska-siet-je/836337-clanok.html

40 National Hydrogen Strategy, https://nvas.sk/NVS_EN.pdf

41 Halama M. et al.: Vodíková stratégia Košického kraja, 2021, https://web.vucke.sk/files/sk/kompetencie/regionalny-rozvoj/koncepcne-materialy/vodik_sk_21_11_14.pdf

AVAILABLE POTENTIAL AND RECOMMENDATIONS

If we base our conclusions on the study prepared by the European Biogas Association regarding the Feasibility of REPowerEU 2030 targets, production potentials in the Member States, and outlook to 2050, then by the year 2030 there is a potential for biomethane production in the V4 countries corresponding to 7 to 9% of current fossil gas consumption.[42]

Table 2. Potential of biomethane production in V4 countries

	Anaerobic digestion potential 2030 [bcm/year]	Thermal gasification potential 2030 [bcm/year]	Anaerobic digestion potential 2050 [bcm/year]	Thermal gasification potential 2050 [bcm/year]
Czechia	0,60	0,10	2,10	1,70
Hungary	1,00	0,05	3,15	0,85
Poland	3,05	0,20	8,85	3,80
Slovakia	0,25	0,05	0,65	0,60

Source: own chart based on European Biogas Association

By 2050, this potential corresponds to 28 to 65% of today's fossil gas consumption. To achieve this, a significant portion of existing BGPs would have to be converted to biomethane production, new biomethane stations would have to be constructed, and thermal gasification technology—which accounts for up to half of this potential in some cases—would need to be significantly developed.

In the case of low-emission hydrogen, determining the potential for its production is highly challenging because, in practice, it depends on several factors, including the development of electricity prices for green hydrogen production or the speed of price reduction for electrolyzers, which constitute a large portion of investment costs. According to a recent finding by Bloomberg NEF, it appears that this price may decrease significantly more slowly than initially anticipated. **As a result, the combined costs of green hydrogen production could ultimately be up to three times higher than originally predicted.**[43] This fact should be taken into account when updating the relevant strategic documents, which might otherwise prove overly optimistic in the future.

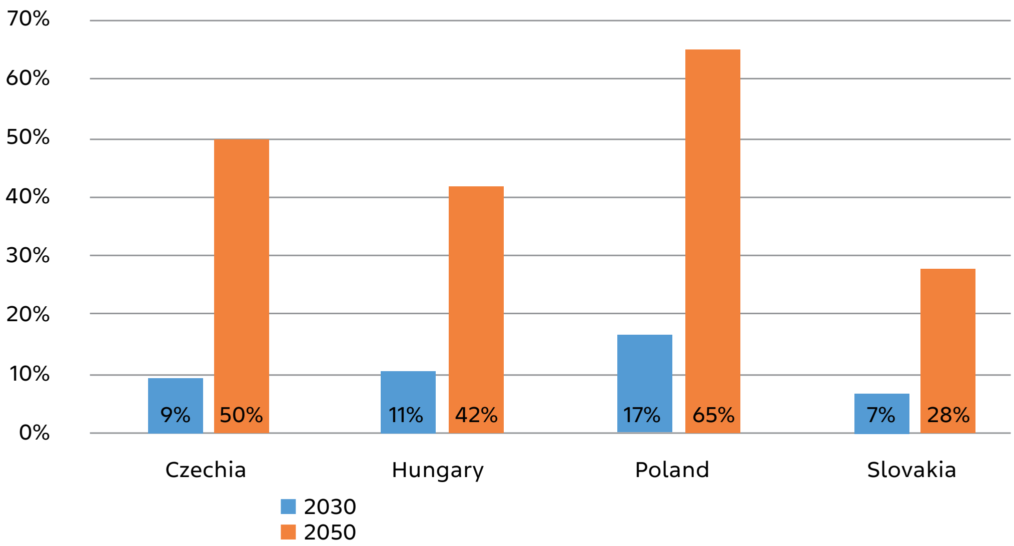
Another issue is the expected consumption of fossil and low-emission gases across various sectors within the given time horizon. Today, most fossil gas is used for heating buildings, whether residential or commercial. Knowing that thorough low-energy renovations can reduce energy consumption for heating buildings by up to 90%, and that even simple measures like roof

42 European Biogas Association: Biomethane production potentials in the EU, https://www.europeanbiogas.eu/wp-content/uploads/2022/07/GfC_Biomethane-potentials_2022.pdf

43 Bloomberg NEF: Green Hydrogen Prices Will Remain Stubbornly High for Decades, https://www.bloomberg.com/news/articles/2024-12-23/green-hydrogen-prices-will-remain-stubbornly-high-for-decades

insulation—which can be carried out in apartment buildings within a single day—can reduce consumption by 20%, the decarbonization of the building sector will primarily rely on implementing such renovations. **Burning biomethane or hydrogen in boilers for space heating purposes represents significant waste of these fuels.**

Figure 13. Comparison of biomethane potential with current (2022) fossil gas consumption



Source: own chart based on European Biogas Association

Conversely, in the industrial sector, considering the ongoing coal phase-out and the properties of biomethane and hydrogen, their use is anticipated primarily in hard-to-abate industrial sectors, which are otherwise extremely difficult or impossible to decarbonize.

In the transport sector, it is necessary to thoroughly evaluate the extent to which the use of these low-emission gases will be needed at all. Improvements in the parameters of currently manufactured batteries, along with the potential of newly developed battery technologies, may render gaseous fuels obsolete. **Additionally, it should be noted that, especially in the case of hydrogen, many transport projects have completely failed in the past for various reasons.**[44] Potential investments in this area should therefore be carefully considered.

What is certain for the future, however, is the growing demand for clean electricity, which, as part of electrification, will affect many sectors. **Biomethane and biogas, in particular, have the potential to be one of the missing pieces in the puzzle of integrating intermittent renewable energy sources.** While today BGPs produce electricity almost exclusively in base-load mode, these gases offer possibilities for short-term and long-term storage and the availability of power that can complement production from solar and wind power plants.

44 Cleantechnica: How Many Hydrogen Transit Trial Failures Are Enough?, https://cleantechnica.com/2024/10/24/how-many-hydrogen-transit-trial-failures-are-enough/

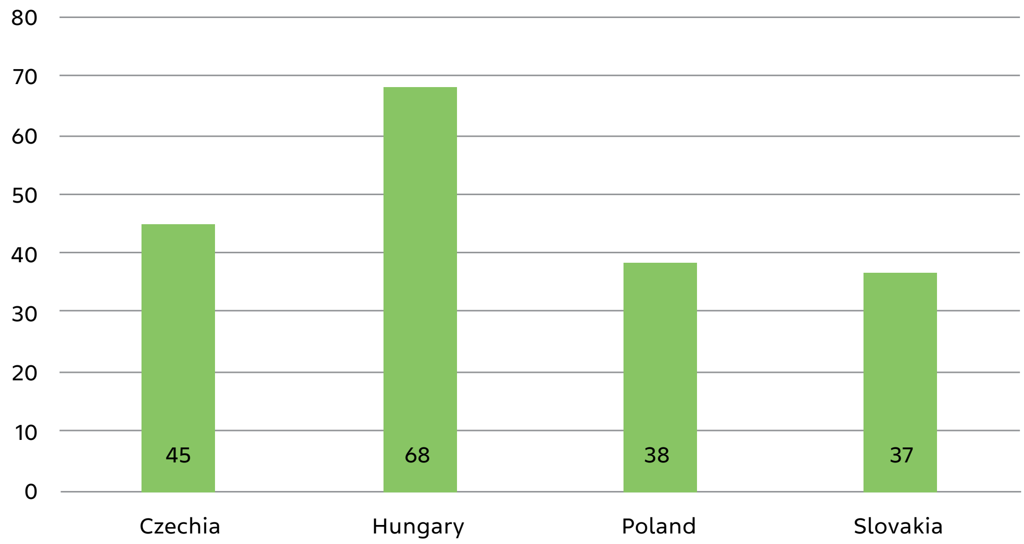
Biogas stations that are not planned for conversion to biomethane production (e.g., due to excessive distance from the gas pipeline network) can be modified by increasing the volume of gas storage and boosting the installed capacity of a cogeneration unit. This unit could then **provide power balancing services instead of operating in base-load mode.**

Because electricity demand does not always align with heat demand, which most BGPs supply to end users as part of CHP, they would also need to be expanded to include heat storage, for example, in the form of insulated hot water tanks combined with heat pumps (HP) to maximize the efficiency of the stored heat. These HPs could simultaneously utilize waste heat generated during CHP operation (e.g., condensing heat from water vapor in exhaust gases, cooling circuit heat, generator cooling heat, etc.).

When storing heat in hot water, this system could also include electric boilers, enabling the provision of balancing services to **include negative power balancing services** too, storing surplus intermittent RES production. This solution could take advantage of periods with low or negative electricity prices, whose occurrence has been increasing recently. This would help mitigate the self-cannibalization of renewable energy sources, positively impacting their economic balance while reducing curtailment.

In the case of biomethane production, given its compatibility with fossil gas, one of the available technologies offers the possibility of its **long-term storage in existing large-capacity reservoirs**.

Figure 14. Gas storage capacity in V4 countries (in TWh)



Source: own chart based on European Council

Their capacity is sufficient to power gas power plants in the future, whether equipped with turbines or fuel cells, enabling them to generate electricity during times when the sun does not shine, and the wind does not blow, even during prolonged "dunkelflaute" periods.

Considering current hydrogen production, it will be necessary to address the decarbonization of this sector in the future. In some cases, CCUS technology can be used, though the question remains as to how well it can be developed under our conditions. **In other cases, importing green hydrogen from**

countries with better production conditions, in the form of ammonia (NH_3), may be more advantageous. Ammonia requires less demanding storage and transportation than hydrogen. Since ammonia is an intermediate product, e.g., in fertilizer production, energy and costs can also be saved by not needing to convert it back into hydrogen. A portion of synthetic fertilizers produced today from fossil-based hydrogen could also be replaced in the future by stabilized digestate, a byproduct of BGPs operation.

On a general level, however, efforts should be made to maximize domestic production of low-emission gases. The reasons are primarily economic. While billions of euros currently flow abroad for the purchase of fossil resources, local production of low-emission gases keeps these funds within domestic economies. **Biogas and biomethane production in agricultural BGPs can represent an important source of income for farmers,** who otherwise struggle with the sale of their traditional products, often due to the impacts of European policies.

Another significant advantage is the scalability of low-emission gas production. The construction of BGPs allows for a continuous increase in production, which is particularly advantageous compared to large power plant units whose construction takes years and often relies on imported components (e.g., limited production capacity and availability of gas turbines or nuclear power plant components must be addressed). In the case of biogas, biomethane, or hydrogen production, most of the necessary components can be produced locally without dependency on imports.

Given the evolving security situation, we must also consider previously unthinkable scenarios. Decentralization of energy production through local low-emission gas production, combined with electricity and heat generation using these gases, **contributes significantly to resilience, including against terrorist or military attacks.**