UNECE

Sustainable hydrogen production in CIS countries

Workbook 1

23 March 2022

Hydrogen Production Methods – Hydrogen from Coal

Coal produced hydrogen currently accounts for around 25% of the hydrogen production. Hydrogen from coal via gasification is a well-established technology, which has been used for many decades by the chemical and fertiliser industries to produce ammonia, especially in areas where coal is abundant and methane is not.

Coal gasification is an established technique whereby coal gets reacts with pressurised steam and air/oxygen under controlled conditions to produce syngas.

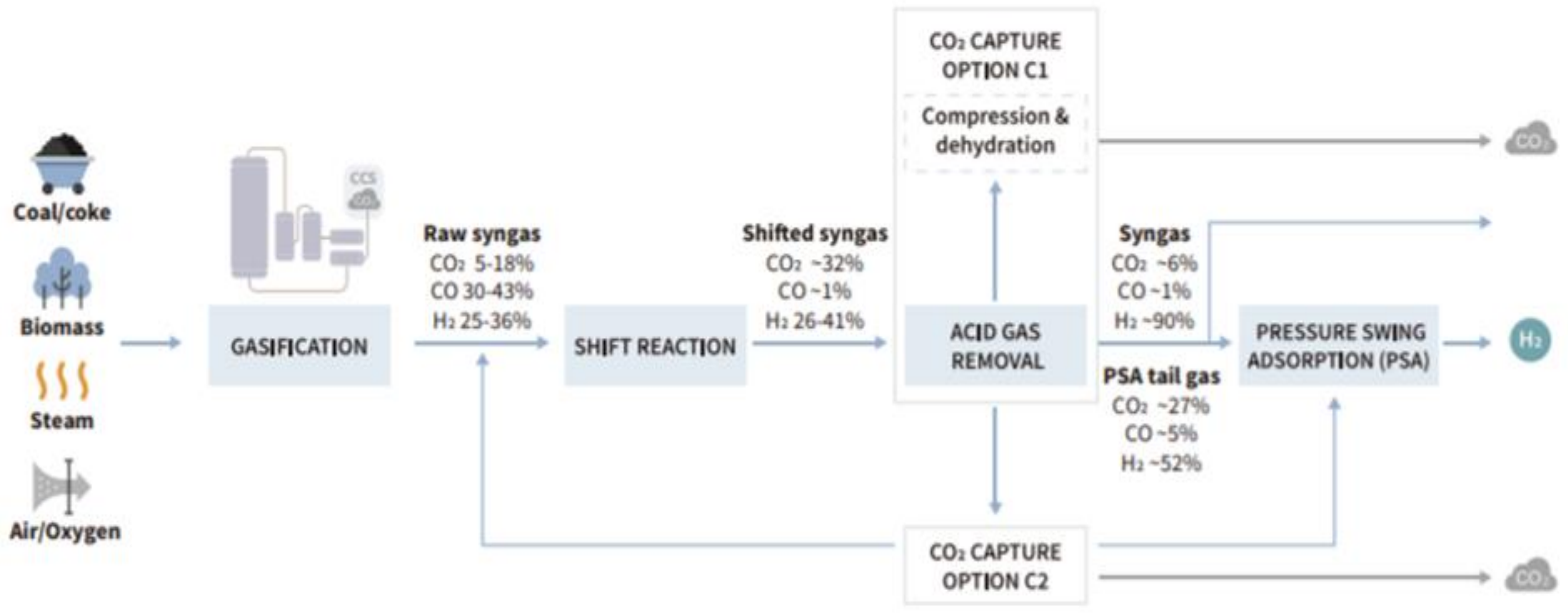
Syngas is a mixture of carbon monoxide and hydrogen, together with impurities, such as carbon dioxide, methane, sulphur compounds and water vapour. After removal of these impurities, the syngas can either be fired directly in a gas turbine or passed with additional steam through a catalytic reactor to convert the CO to CO2 while producing more hydrogen via the water gas shift (WGS) reaction.

The hydrogen and CO2 can then be separated via membranes to provide two near pure gas streams and CO2 can be captured and stored.

Cost of production and CCUS

Hydrogen production through coal gasification with CCUS has about three times lower cost than hydrogen production based on water electrolysis. Coal gasification with CCUS costs typically 1.9-2.4 US$/kg H2 with costs as low as US$ 1.6/kg H2 in China.

Figure 4 Hydrogen production via coal / biomass gasification with carbon capture and storage



Hydrogen Production Methods – Hydrogen from Biomass

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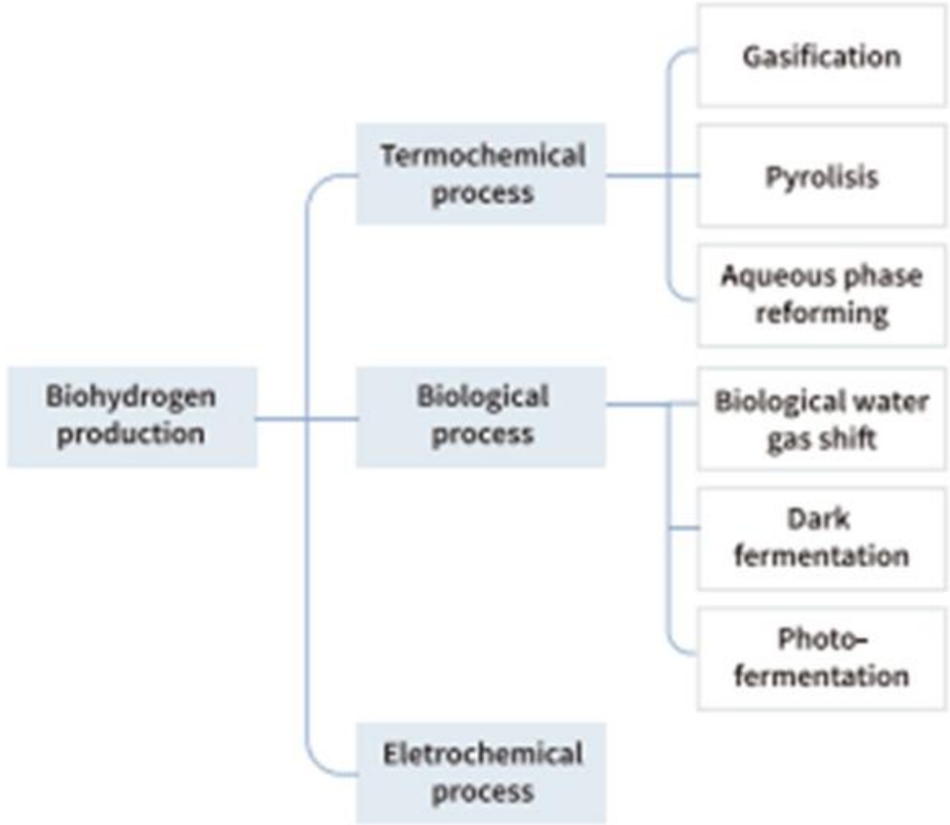
Biohydrogen is the source of energy that uses living microorganisms to make hydrogen via biological processes

Figure 8 Biohydrogen production processes



Thermochemical Process

Thermochemical conversion is the most advanced technology for hydrogen production from biomass. The three primary thermochemical routes are:

- Gasification is a mature technology that uses a controlled process involving heat, oxygen and steam to convert biomass to hydrogen and other products, without combustion, at approximately 1000℃.
- Pyrolysis is similar to gasification but can be performed at lower temperatures and without an oxidising agent.
- Aqueous phase reforming converts mainly oxygenated compounds into hydrogen.

Biological Process

Biological conversion can be divided into three categories: biological water gas shift reaction, dark fermentation, and photo-fermentation. Each process depends on the nature of the enzymes used to catalyse H2 formation.

Electrochemical process

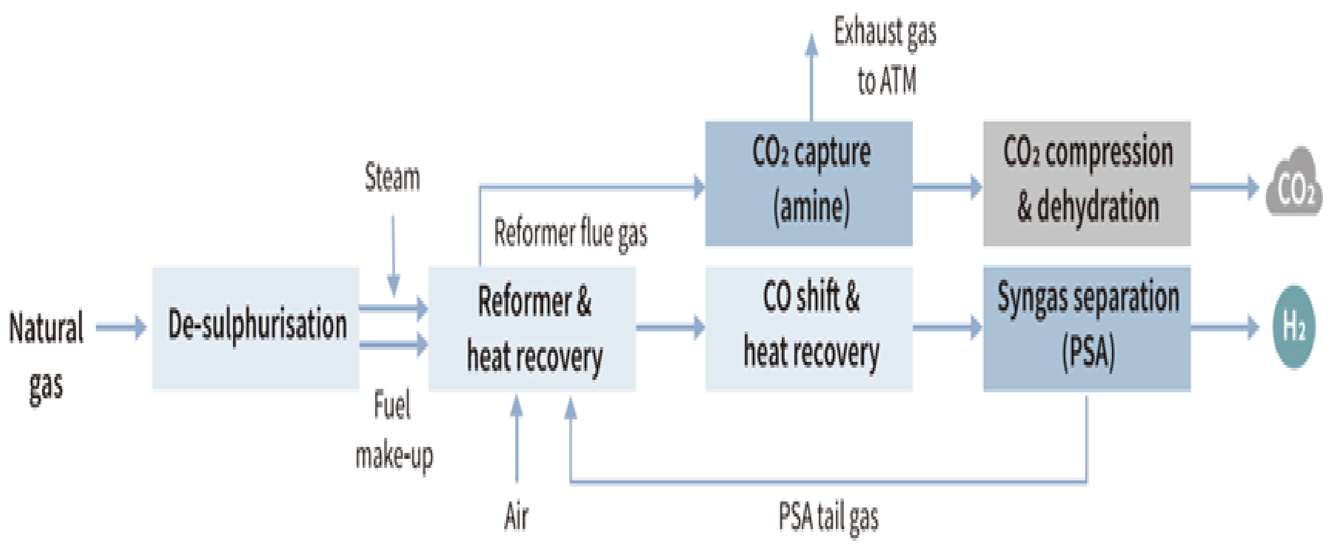
Electrolysis is an electrochemical process widely investigated for hydrogen production by splitting water molecules. The mechanism occurs in an electrolyser (containing a cathode and an anode) and relies on the flow of an electric current through a conductive electrolyte (alkali or polymer) in water.

Hydrogen Production Methods – Hydrogen from Natural Gas

ENERGY

Nowadays natural gas is the main source of hydrogen accounting for about 70% of total hydrogen manufactured. Less than 5% of the hydrogen produced is generated from low–carbon sources. There are three key methods of producing hydrogen from gas.

Figure 2 Steam methane reforming with CCS (Wood, 2008)



Steam Methane Reforming

Steam methane reforming (SMR) is a mature, carbon and energy-intensive process that produces syngas (hydrogen and carbon monoxide) through the reaction of light hydrocarbons (typically methane) with water. In SMR, carbon dioxide (CO2) is generated and released into the atmosphere. Currently, around 96% of hydrogen is produced via SMR of fossil fuels 49% from natural gas, 29% from liquid hydrocarbons, and 18% from coal.

Methane Pyrolysis

Methane pyrolysis, a highly endothermic (requiring a lot of energy) process. Methane is split into gaseous hydrogen and solid carbon. This solid carbon means that no CO2 is produced in this process. The heat needed to drive the process may come from various sources—combustion of hydrocarbons, concentrated solar heat, electricity or another heat source. Metal or carbon-based catalysts are used to accelerate the process.

Electrochemical process

Partial oxidation is the process in which methane and other hydrocarbons in natural gas react with a limited amount of oxygen (not enough to completely oxidize the hydrocarbons to carbon dioxide and water). The reaction produces mainly hydrogen and carbon monoxide (and nitrogen, if the reaction is carried out with air rather than pure oxygen) and a small amount of carbon dioxide and other compounds.

Hydrogen Production Methods – Hydrogen from Nuclear power

Nuclear power is an important source of low-carbon electricity and heat. In the future nuclear power can also be used to produce hydrogen via several low-carbon processes.

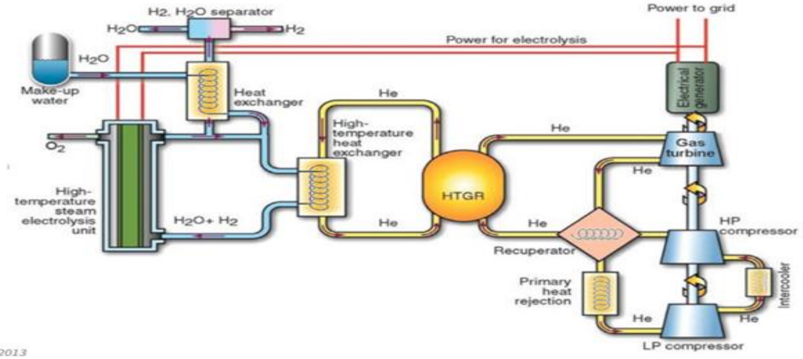
Low-temperature electrolysis

Low-temperature electrolysis of water is the approach based on using current nuclear reactors producing electricity. The low-carbon electricity is used to power electrolysis that generates emissions-free hydrogen at ambient temperatures. Electrolysers are most effective when working continually at a high capacity factor rather than intermittently to diminish costs .

High-temperature steam electrolysis

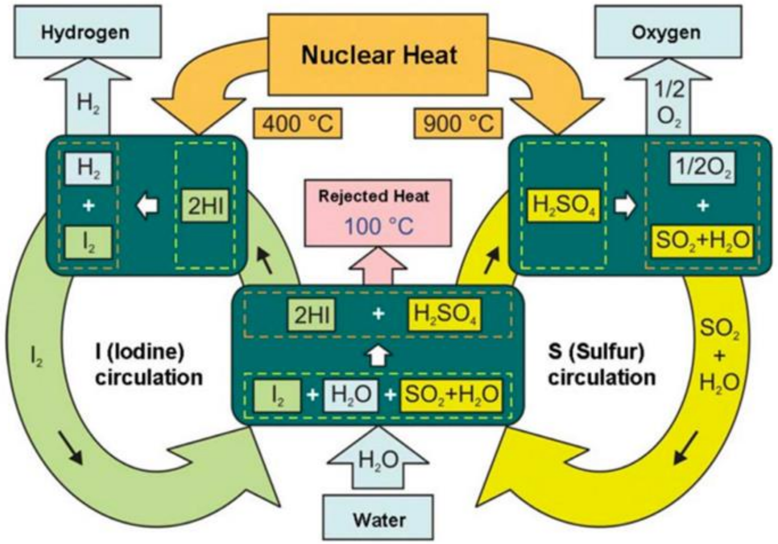
High-temperature steam electrolysis applies low-carbon heat and electricity from nuclear reactors to power steam electrolysis, which is more efficient in producing hydrogen than electrolysis via renewable energy. While this process is more efficient at temperature range (550 – 750℃), it is also possible at temperature (<200℃).

Figure 11 High-temperature steam electrolysis



Source: IAEA, 2013

Figure 12 High-temperature thermochemical production of hydrogen



Nuclear energy for steam methane reforming applies nuclear heat in SMR process. This could reduce natural gas consumption and CO2 emissions by 30% and greatly improve the thermal efficiency of the process.

Industry analysis indicates that using low-temperature heat (150-200°C) to support steam electrolysis is technically feasible and offers efficiency benefits over cold water electrolysis. Steam electrolysis is readily available technology.

Hydrogen Production Methods – Hydrogen from Renewable Energies

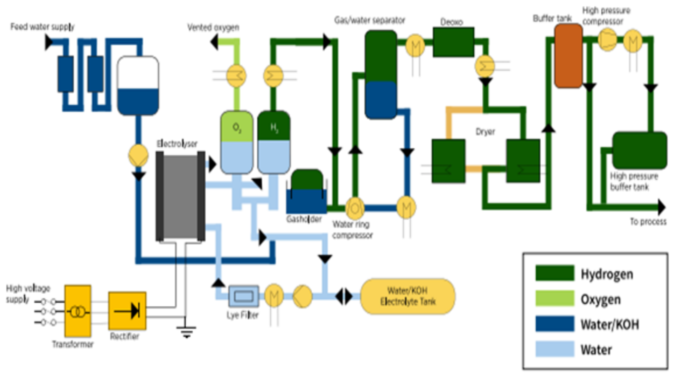
ENERGY

Hydrogen from renewable power has a potential to highly contribute to the global energy system decarbonization. Renewable hydrogen is obtained through the process of electrolysis where electricity is used to split water into its components – oxygen and hydrogen.

Alkaline Electrolysis

The most common electrolyser technology on the market today. This technology applies a solution that requires recirculating of the electrolyte (potassium hydroxide KOH) into and out the stack components to separate hydrogen from water molecules by applying electricity. This technology requires the constant flow of power, so it

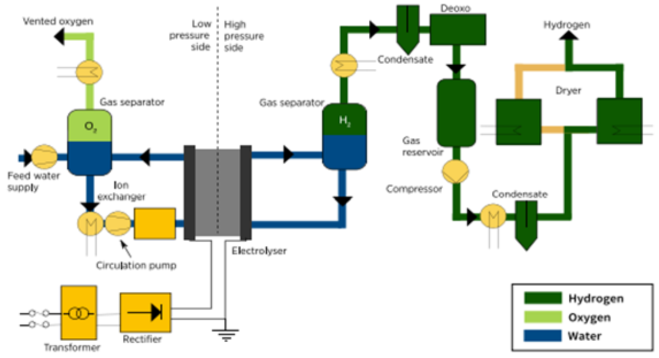
Figure 5 Alkaline electrolyser - typical system design and balance of plant



Proton-exchange membrane

A modern electrolyser technology known for higher efficiency and production rates. In this technology, a solid membrane is used to separate hydrogen. This technology is more simple and agile compared to alkaline electrolysis and allows for operation under different pressures, typically 30bar – 70 bar.

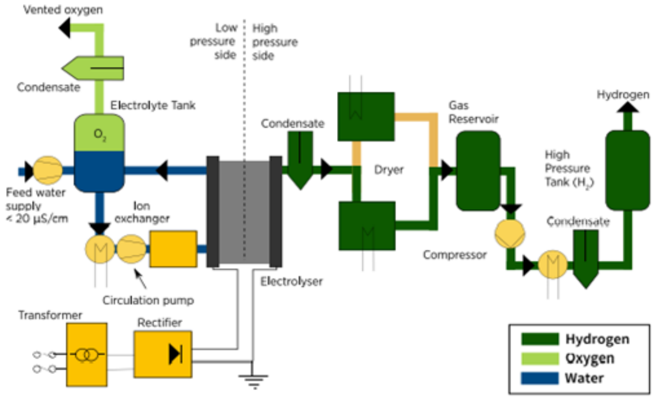
Figure 6 Proton-exchange membrane electrolyser - typical system design and balance of plant



Solid Oxide Electrolysers

The latest generation of electrolysers that is still in the demonstration phase but with great future prospects. This technology produces hydrogen through high-temperature electrolysis of steam.

Figure 7 Solid Oxide Electrolyser - typical system design and balance of plant



Hydrogen Production Methods – Hydrogen from Renewable Energies

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Colors	Black Hydrogen	Grey Hydrogen	Blue Hydrogen	Turquoise Hydrogen	Yellow Hydrogen	Pink Hydrogen	Green Hydrogen
Process	Gasification	SMR	SMR or gasification with carbon capture (85-95%)	Pyrolisis	Sulfur–iodine cycle	Electrolysis	Electrolysis
Source	Coal	Methane	Methane or coal	Methane	Nuclear power	Nuclear power	Renewable Energy

Hydrogen Storage

How to store hydrogen ?

- **Compressed Gas**: Storage of hydrogen in gaseous form requires high **pressures of over 300 bar**. Such pressure is necessary because hydrogen's low density (10 times lighter than methane). **The current technology for compressed hydrogen,** primarily in vehicle on-board storage, **uses pressure vessels operating at 350 - 700 bar**. Four standard types of cylinders are used for hydrogen storage :Type I—all-metal cylinders , Type II—all-metal hoop-wrapped composite cylinders, Type III—fully wrapped composite cylinders with metallic liners and Type IV—fully wrapped composite cylinders (non-load bearing is non-metallic).

- **Liquified hydrogen**: To store hydrogen as a liquid, at any pressure, it **must be colled below -250 C**. This is 80 degrees lower than LNG. Once liquefied, hydrogen requires energy to be kept in thermally insulated containers. Liquefied hydrogen is several times more dense than compressed hydrogen

- **Storage in materials:** Some hydrogen carriers include methane, methanol, ammonia, methylcyclohexane, sodium borohydride. A chemical reaction is needed to convert these products and release gaseous hydrogen. There are also metal powders that can absorb and release hydrogen (metal hydrides). They can store significant amounts of hydrogen at atmospheric pressure and room temperature, due to forces acting inside the metal crystal lattice. Metal hydrides are the most compact way to store hydrogen. They are more dense than liquid hydrogen.

Table 4 Hydrogen storage options and costs

	GASEOUS STATE				LIQUID STATE			SOLID STATE
	Salt caverns	Depleted gas fields	Rock caverns	Pressurized containers	Liquid hydrogen	Ammonia	Liquid organic hydrogen carriers	Metal hydrides
Main usage (volume and cycling)	Large volumes months-weeks	Large volumes seasonal	Medium volumes, months-weeks	Small volumes daily	Small-medium volumes, days-weeks	Large volumes, months-weeks	Large volumes, months-weeks	Small volumes, days-weeks
Benchmark LCOS [$/kg]	$ 0.23	$ 1.90	$ 0.71	$ 0.19	$ 4.57	$ 2.83	$ 4.50	Not evaluated
Possible future LCOS	$ 0.11	$ 1.07	$ 0.23	$ 0.17	$ 0.95	$ 0.87	$ 1.86	Not evaluated
Geographical availability	Limited	Limited	Limited	Not limited	Not limited	Not limited	Not limited	Not limited

Source: *Bloomberg NEF. (2020). Hydrogen economy outlook. URL: https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf*

Hydrogen Transport – Means of Transportation

ENERGY

To be transportable hydrogen needs to be compressed, liquefied or chemically combined. Safe and cost-efficient transport and distribution of hydrogen is critical for its large-scale deployment. **Hydrogen's low energy density, high diffusivity, and high flammability imply important technological and infrastru ctural challenges.**

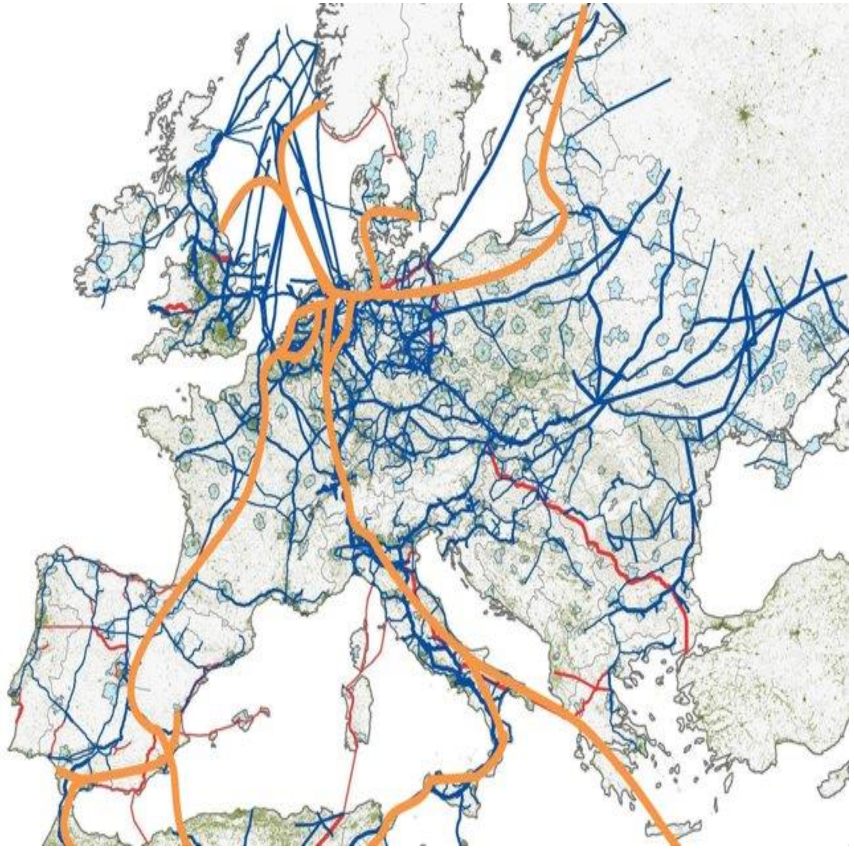
Means of Transportation

- **Road and railway:** A common method of hydrogen transport is in pressure-proof filled cylinders on a truck. These vessels can be either of industrial standard size (up to 150 litres volume), or larger tubes. The handling of such vessels is regulated by the ECOSOC Committee of Experts on the Transport of Dangerous Goods, managed by UNECE. In addition, in 2013 UNECE's World Forum for Harmonization of Vehicle Regulations (WP.29) adopted technical regulations on the safety of hydrogen and fuel cell vehicles that, among other things, deals with on-board hydrogen vessels.

- **Marine Transportation:** The first hydrogen cargo ship – Suiso Frontier – was commissioned in 2019 to transport hydrogen from Australia to Japan in one 1250m3 (=88 tonnes H2) vacuum insulated tank at -253C/1 atm. South Korea is commissioning a 20,000 m3 (=1420 tonnes H2) cargo ship also using vacuum insulated vessels. The economics of liquid hydrogen transport contain many hidden costs, so this technology is still under development and it is unlikely that large-scale maritime hydrogen transport will scale before 2040

- **Pipelines:** Hydrogen can be transported by pipelines as pure compressed hydrogen or as ammonia. Transporting pure hydrogen makes economic sense for a distance of less than 3,500 km; for longer distances ammonia route is a more economically viable option.

European Pipelines Network



A future trans-European hydrogen transmission and distribution pipeline network

Natural gas infrastructure in Europe (blue and red lines) and first outline for a hydrogen backbone infrastructure (orange lines

Source: Hydrogen Europe 2019

Hydrogen blending into the existing gas network has multiple advantages and can be a cost-effective transitional option in the short term in regions without parallel or duplicated networks or without (potentially) available gas infrastructure capacity. The retrofitting and repurposing of existing gas networks can be combined and complemented with the construction of new dedicated hydrogen infrastructure.

Hydrogen Transport - Cost

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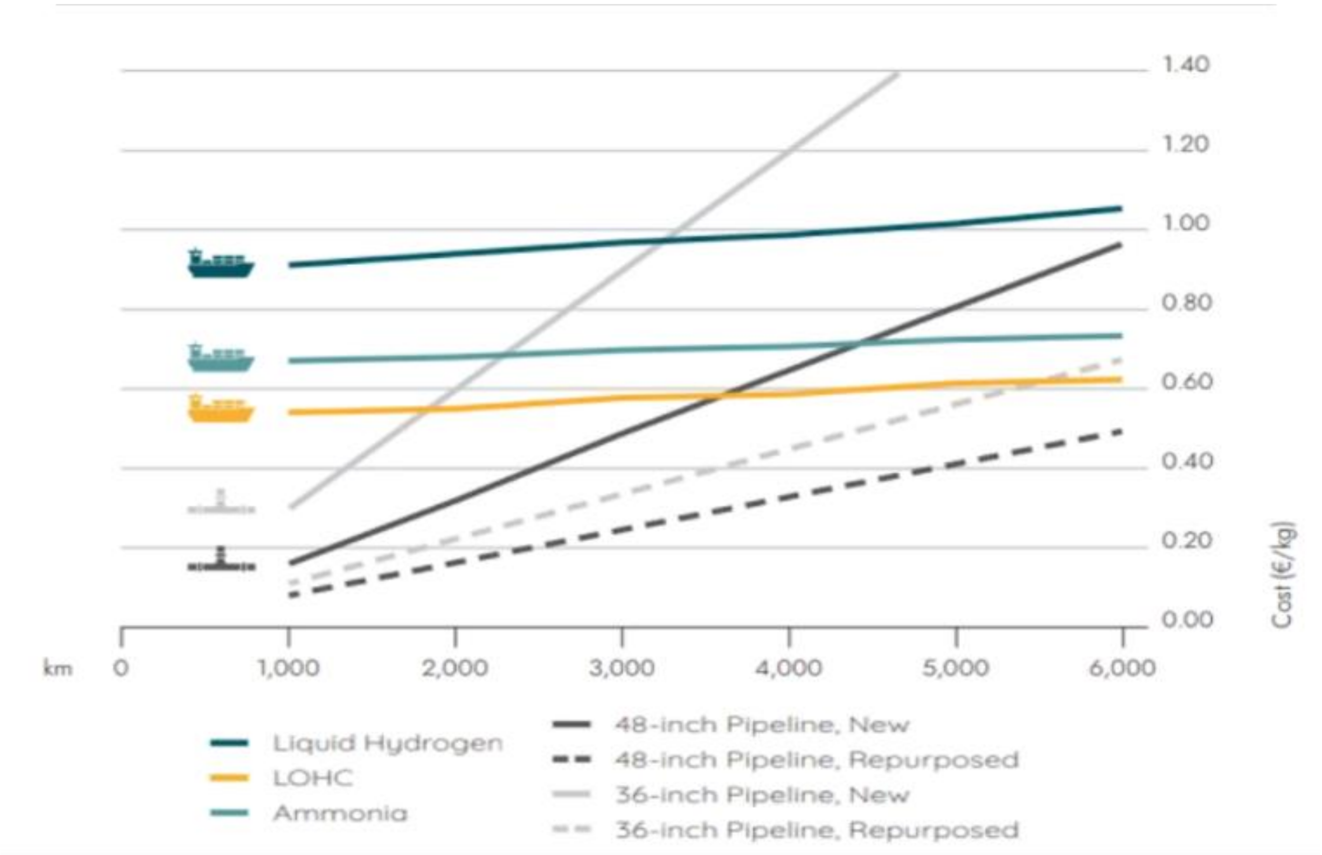
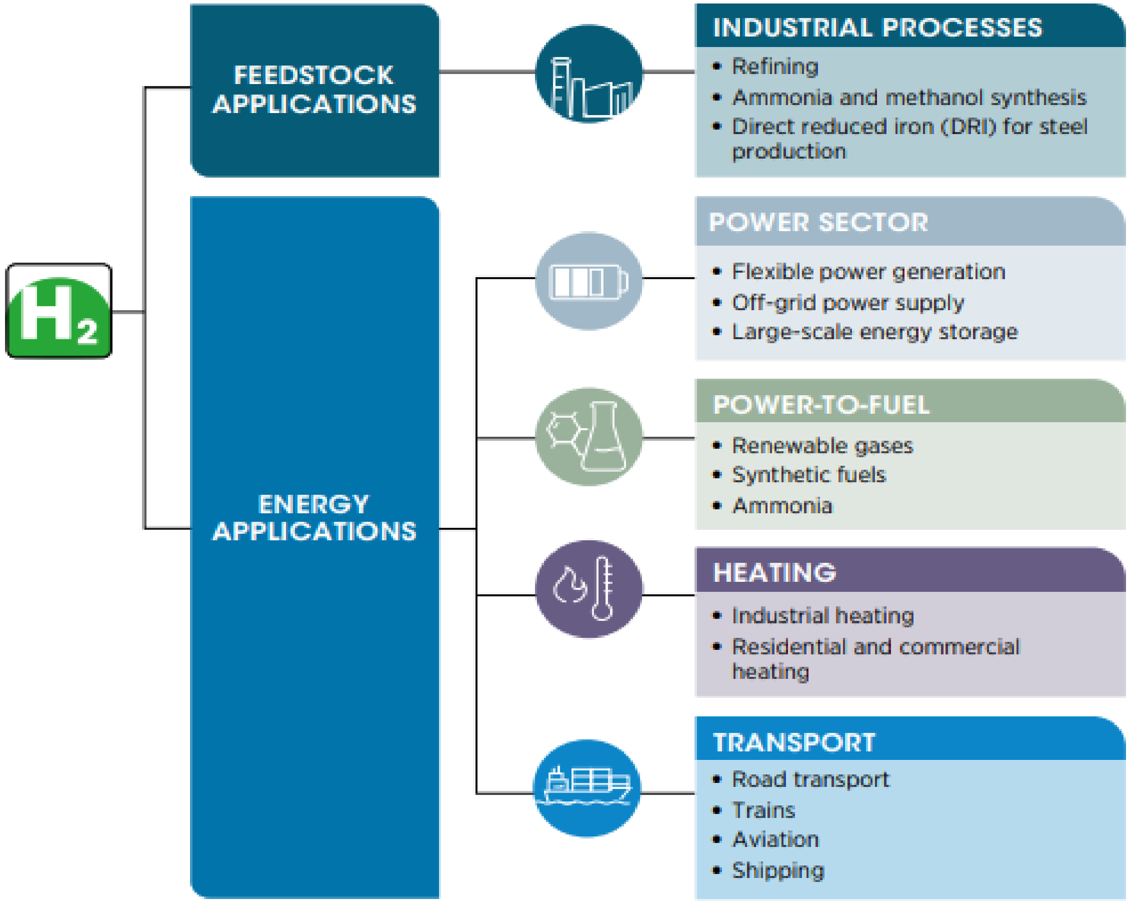


- Hydrogen experts have widely agreed that the price of **hydrogen produced should be no higher than 1.5 euro/kg**. 1kg of hydrogen provides 120MJ of energy while 1kg of diesel is 50 cents and provides 40MJ of energy. This comparison excludes the effects of the carbon pricing mechanism.

- According to recent researches, hydrogen pipelines are the most cost-efficient option for long-distance, high-volume transport. The corresponding expenditures range from €0.11 to 0.21/kg per 1,000 km, thus outcompeting the costs of transport by ship for all reasonable distances within Europe and neighbouring regions

Application of Hydrogen across sectors



Source: IRENA (2020b).

Hydrogen can help achieve a clean, secure and affordable energy future and decarbonize a range of sectors :

- **Transportation:** Hydrogen applications in transport are possible with use of internal combustion engines (ICE) or turbines, and with use of fuel cells.
- **Power generation:** Hydrogen application in power sector is limited today, but there is potential for increasing role in the future. Hydrogen powered gas turbines could be a source of flexibility in electricity system. Also, Solid Oxide Fuel Cells can offer the highest conversion efficiency. In addition, hydrogen can become a long-term storage option to balance seasonal variations in electricity demand.
- **Industry:** In industry hydrogen (mainly in the form of methane) applications include demand for industrial heat or feedstock. At present, hydrogen is used in large-scale industrial processes like oil refineries, petrochemicals, ammonia production, methanol production, and steel production. In oil refineries, hydrogen is used to remove sulphur crude oil and produce lighter oil products from heavy oil. Hydrogen with a source of carbon will replace natural gas and to a smaller degree oil as the basis for production of synthetic gases under the concept of power-to-X conversion that includes power-to-ammonia, power-to-chemicals, and power-to-methane.
- **Buildings**: hydrogen can play an important role in decarbonisation of buildings. It can be applied in buildings for power and heating appliances.

Application of Hydrogen across sectors

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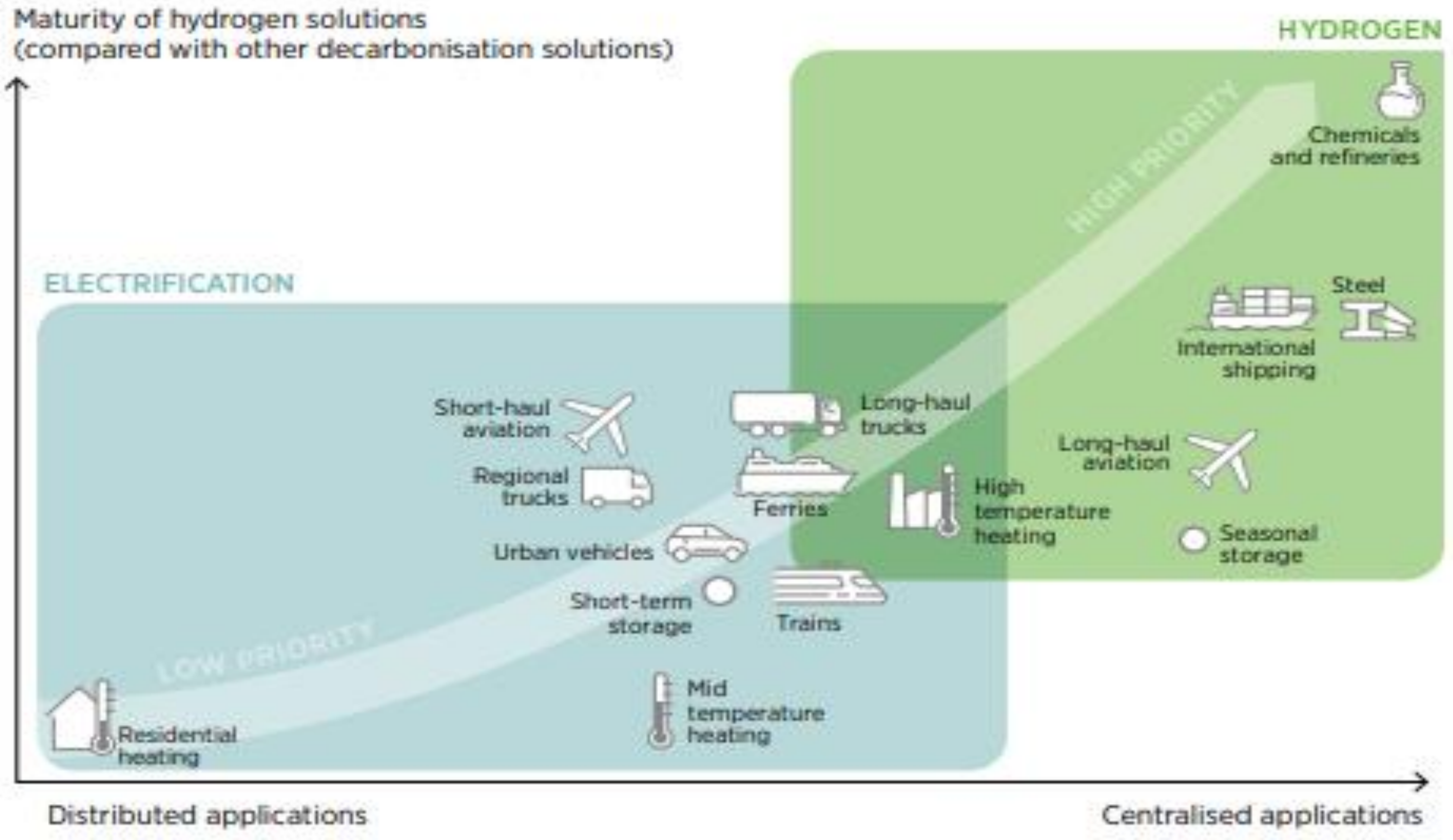

Sources: IRENA (forthcoming-b).

Background information on EU Green Taxonomy

EU Green Taxonomy – History

ENERGY

July 12th 2020 — European Regulation 2020/852

Defines three categories of economic activities : Sustainable, Transitional and Enabling one.

Sustainable activities have to contribute to one of the Regulation's six environmental objectives, do no significant harm to any of the other five and adhere to minimum social safeguards and comply with technical standards which are elaborated in delegated acts

June 4th 2021 — First delegated Act – Climate Delegated Act

Details the technical standards activities must meet to be deemed sustainable.

Regarding Hydrogen, hydrogen production should "*complies with the life-cycle GHG emissions savings requirement of 73.4% for hydrogen [resulting in 3tCO2eq/tH2] and 70% for hydrogen-based synthetic fuels relative to a fossil fuel comparator of 94g CO2e/MJ*" and the power generation from renewable non-fossil hydrogen is deemed sustainable if it meets the 100 g CO2e per kWh threshold

July 6th 2021 — Second Delegated Act

The rules set out in the Delegated Act allows companies to translate the technical screening criteria of the Climate Delegated Act into quantitative economic performance indicators - the KPIs - which will be publicly disclosed.

February 06th 2022 — Complementary delegated Act – CDA

Details the technical standards that nuclear and natural gas activities must meet to be deemed sustainable.

Regarding gas : the life-cycle GHG emissions from the generation of electricity using fossil gaseous fuels are lower than 100 g CO2e/kWh. Life-cycle GHG emissions are calculated based on project-specific data, where available, using Recommendation 2013/179/EU or, alternatively, using ISO 14067:2018 or ISO 14064-1:2018. Different criteria are set up for facilities for which the construction permit is granted by 31 December 2030

EU Green Taxonomy – Consequences for Hydrogen

ENERGY

European Green Taxonomy History

- Introduced in 2020 by the European Regulation 2020/852 of the European Parliament and of the Council to facilitate sustainable investment and give better visibility to producers of renewable electricity.
- According to the Technical Expert Group on Sustainable Finance, the European Union (EU) Green taxonomy is defined as "*a classification system, establishing a list of economic activities that are considered environmentally sustainable for investment purposes*". It is not a mandatory list to invest in, nor a standard, nor an exclusion list and does not harmonize the existing market practices and strategies with regards to sustainable finance.
- The EU Taxonomy is composed of two delegated Acts and one Complementary delegated Act ruling on nuclear and natural gas.

EU Green Taxonomy on Hydrogen

Hydrogen can be deemed sustainable if :

Hydrogen production "*complies with the life-cycle GHG emissions savings requirement of 73.4% for hydrogen [resulting in 3tCO2eq/tH2] and 70% for hydrogen-based synthetic fuels relative to a fossil fuel comparator of 94g CO2e/MJ*"

The power generation from renewable non-fossil hydrogen is deemed sustainable if it meets the 100 g CO2e per kWh threshold.

Concerning H2 manufacturing activities involving carbon capture and storage, the CO2 transported from the installation where it is captured to the injection point does not lead to CO2 leakages above 0.5 % of the mass of CO2 transported.

EU Green Taxonomy content

Three kind of Economic Activities :

•**Sustainable activities:** To be considered as such, activities should meet three criteria: it must substantially contribute to one of six environmental objectives, do no significant harm to any of the other five and adhere to minimum social safeguards and comply with technical standards which are elaborated in delegated acts

•**Transitional activities**: Activities that lead to a "*substantial reduction in greenhouse gas emissions in other economic activities and sectors for which there are no technologically and economically feasible low-carbon alternatives*".

•**Enabling activities**: directly "*enables other activities to make a substantial contribution to one or more of those objectives. Such enabling activities should not lead to a lock-in of assets that undermine long-term environmental goals, considering the economic lifetime of those assets, and should have a substantial positive environmental impact*."

European Guarantees of Origin

A threshold for "*low-carbon hydrogen*" has been suggested by the CertifHy GOH framework. It is specified that to qualify as "*low-carbon*", hydrogen production GHG footprint should be equal to or lower than 36.4 gCO2eq/MJ H2. As long as the Fit for 55 Package is not being passed with a new threshold, this serves as a regulation.

EU Hydrogen Taxonomy – Summary

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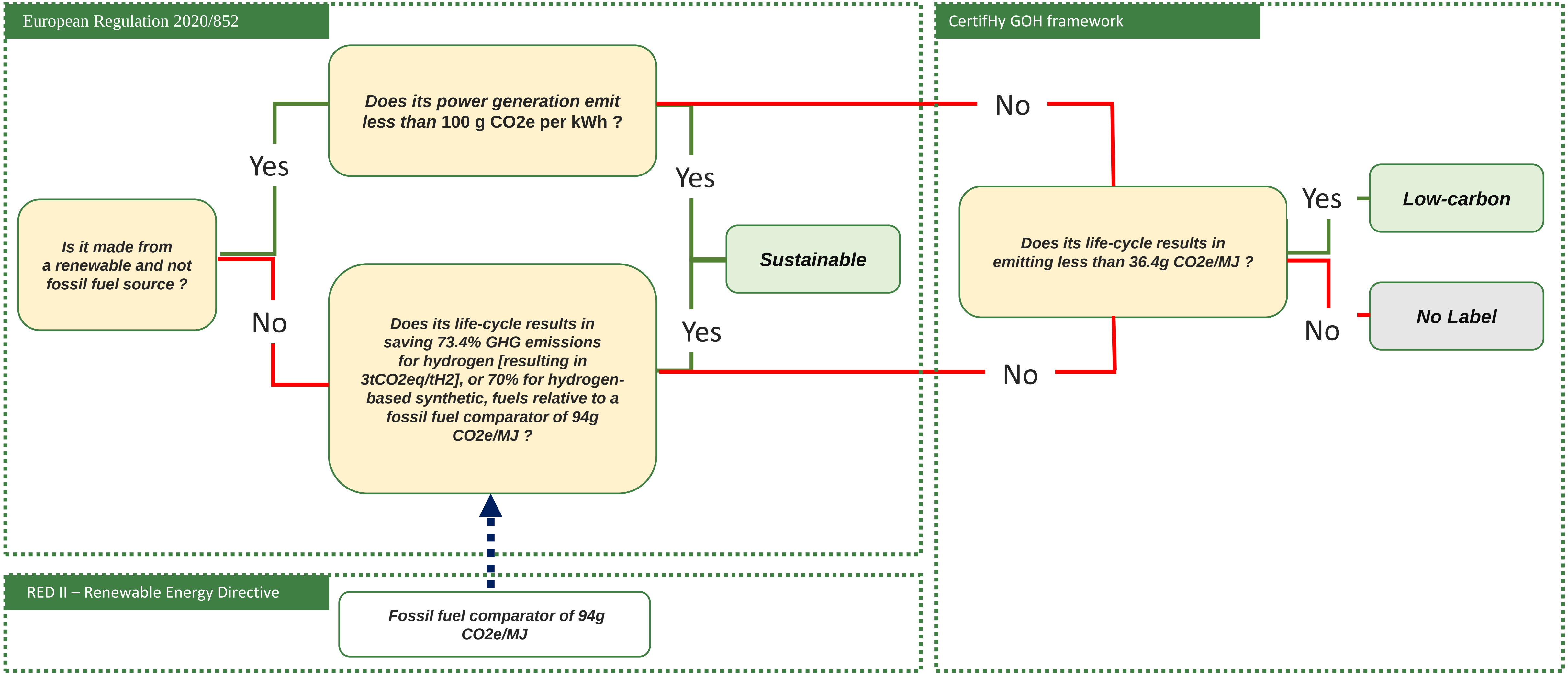

Background information about project beneficiary countries

CIS countries - Armenia

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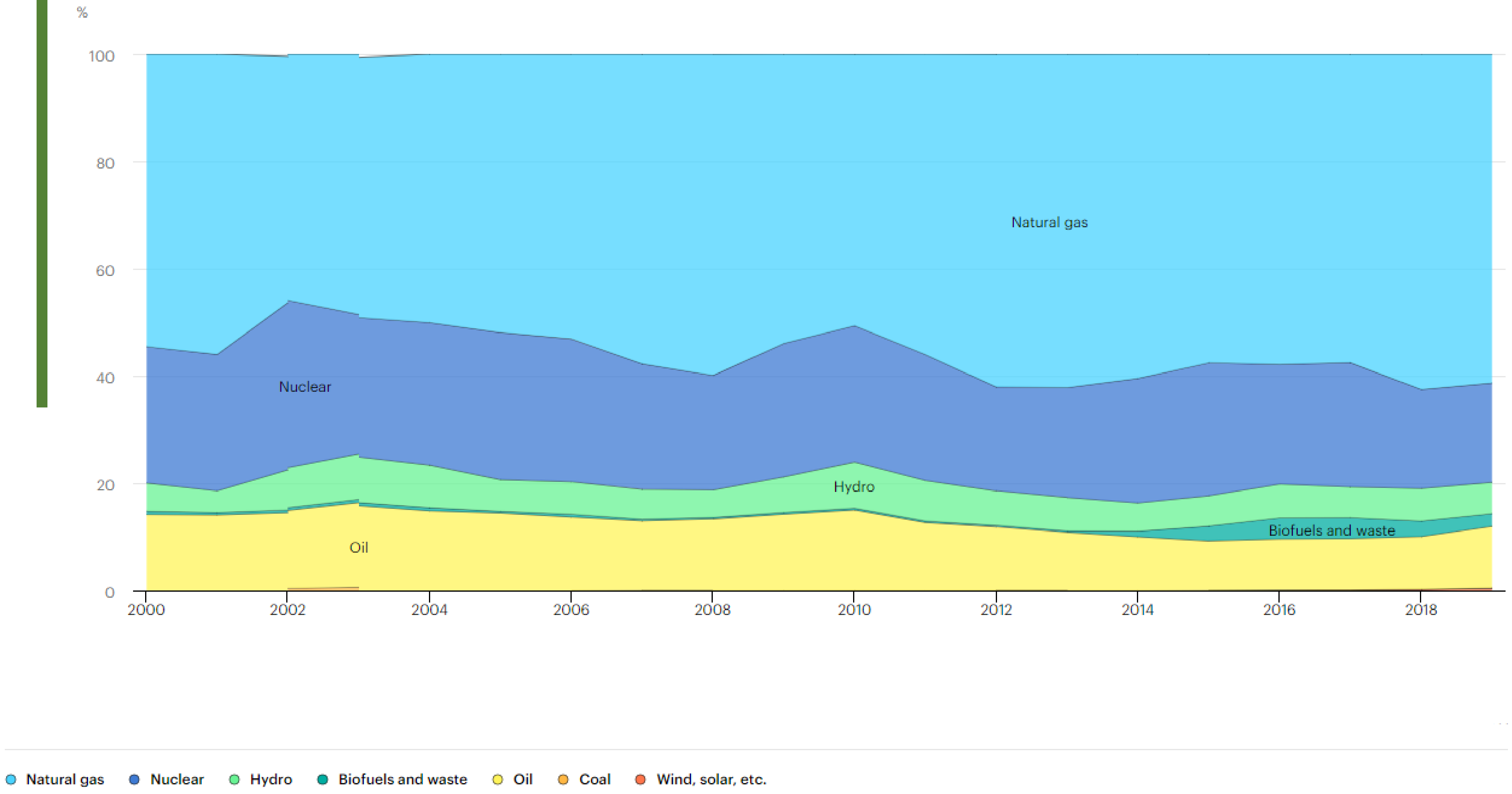


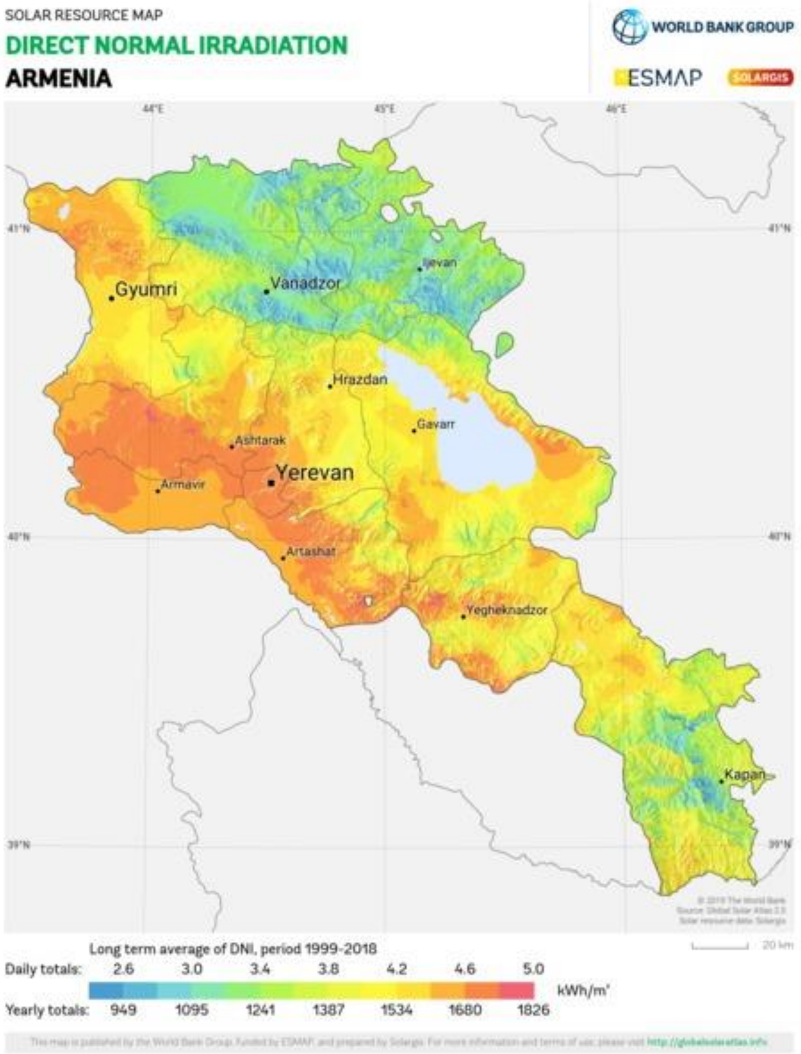
Resources

- Armenia could generate up to 3**.4688 Mtoe** in 2019 (TES) including 24.834 M MWh generated from natural gas and 7. 49 M MWh from nuclear power.
- Although Armenia does not produce any fossil fuels, it manages to cover 24% of energy demand with domestic energy production. This production (0.67 Mtoe in 2019) comes mostly from nuclear and hydro energy
- Armenia's energy demand was equal to 3.40 Mtoe in 2019.

ENERGY

Resources

- Armenia has no proven reserves of natural gas or oil, and hard coal deposits are a modest 154 Mt, with resources of 163 Mt and further potential of 317 Mt. There are six known coal mines and some shale oil deposits, but the economic viability of mining these deposits has not been determined. There is currently no coal or shale oil production in the country.
- Given its more than 400 mostly small, steep mountain rivers of at least 10 km in length, Armenia's hydropower potential is significant.
- Armenia has significant solar energy potential: average annual solar energy flow per square meter of horizontal surface is 1 720 kWh (the European average is 1 000 kWh), and one-quarter of the country's territory is endowed with solar energy resources of 1 850 kWh/m2 per year.

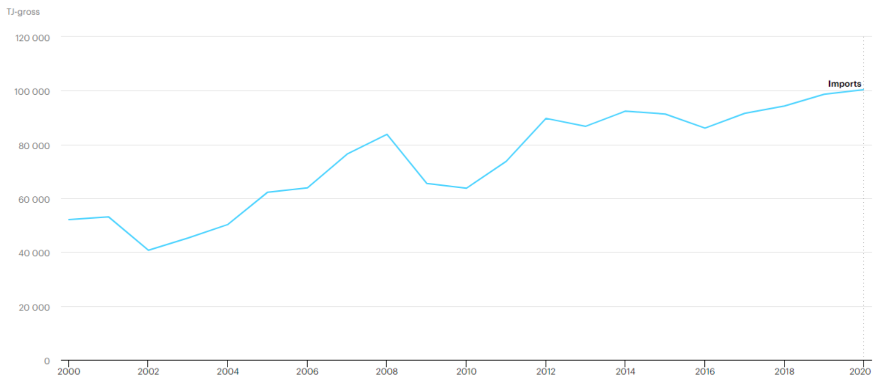


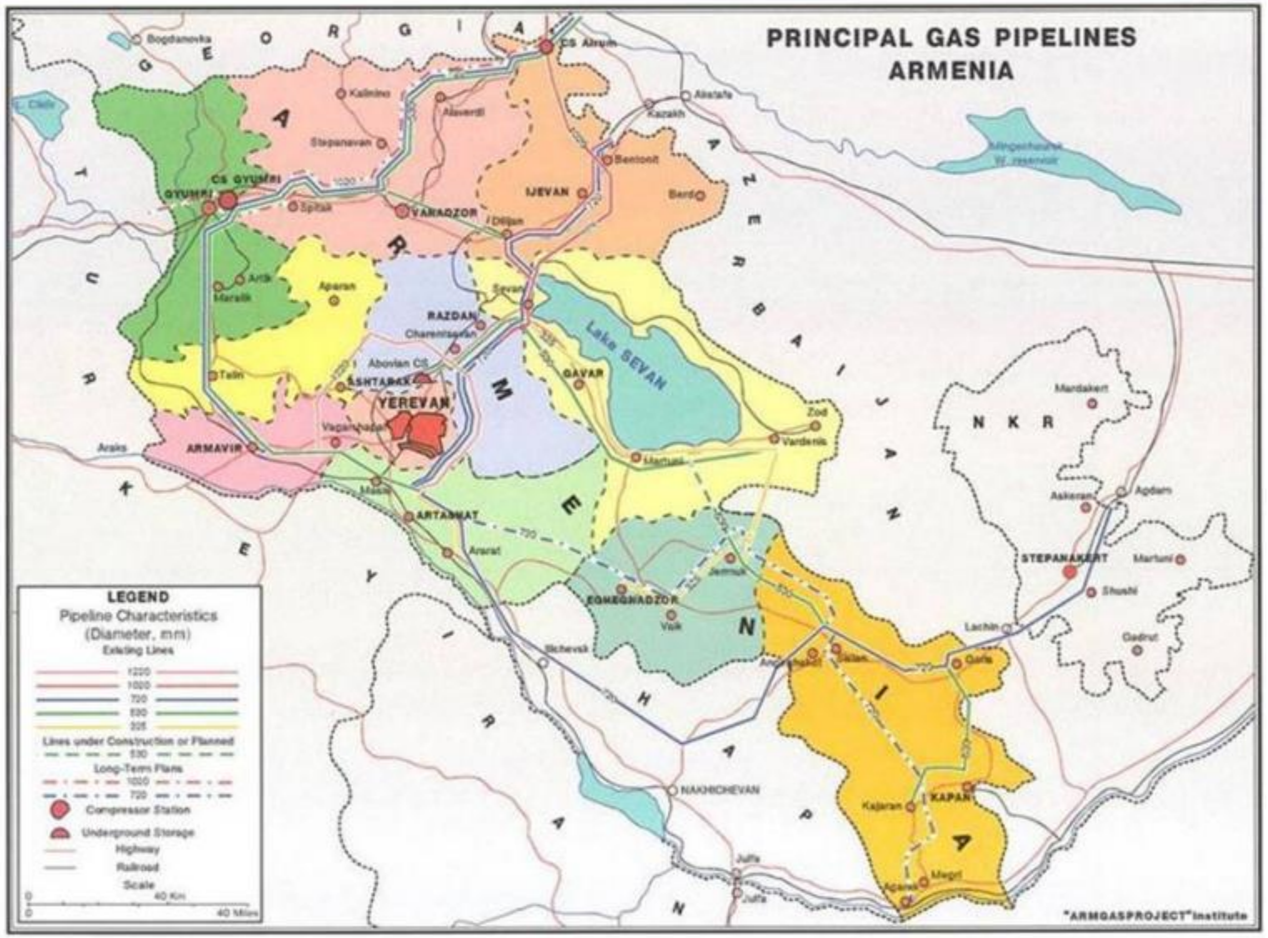
CIS countries - Armenia

Infrastructures

- Armenia imports natural gas and oil for most of its energy needs (78% of total energy supply in 2018), mainly from the Russian Federation. Natural gas is imported from Russia via pipeline through Georgia, but also from Iran through a barter agreement under which it exports electricity in exchange
- Natural gas represents over 80% of Armenia's energy imports (2.1 Mtoe out of 2.6 Mtoe in 2019), followed by oil products (0.5 Mtoe in 2019)
- Armenia's gas transmission network comprises 1 682 km of pipelines, a Soviet-era connection with Russia through Georgia, and a 2.3 bcm connection with Iran built in 2009 to barter gas imports for electricity. An additional pipeline connection with Azerbaijan exists but is not in operation

Natural gas imports vs. exports, Armenia 2000-2020





CIS countries - Armenia

Policies

- Armenia has yet to adopt a national hydrogen strategy according to IEA.
- In 2011, Armenia adopted a Renewable Energy Roadmap which was completed in 2014 by the "Scaling Up Renewable Energy Program for Armenia (SREP Armenia)".
- The SREP goal is to is to catalyze private investment in renewable energy technologies such as helping to finance the country's first 40-50 MW of utility-scale solar PV projects through private investors, while minimizing the tariff-impact by using SREP funds.

Hydrogen production enablers

- Armenia has a significant potential for producing green hydrogen thanks to its solar energy potential.
- Armenia nuclear powerplant could be used to produce hydrogen from nuclear power either though electrolysis or sulfur-iodine cycle
- Demand side: transport, gas-powered power plants
- Need for policy framework

CIS countries - Azerbaijan

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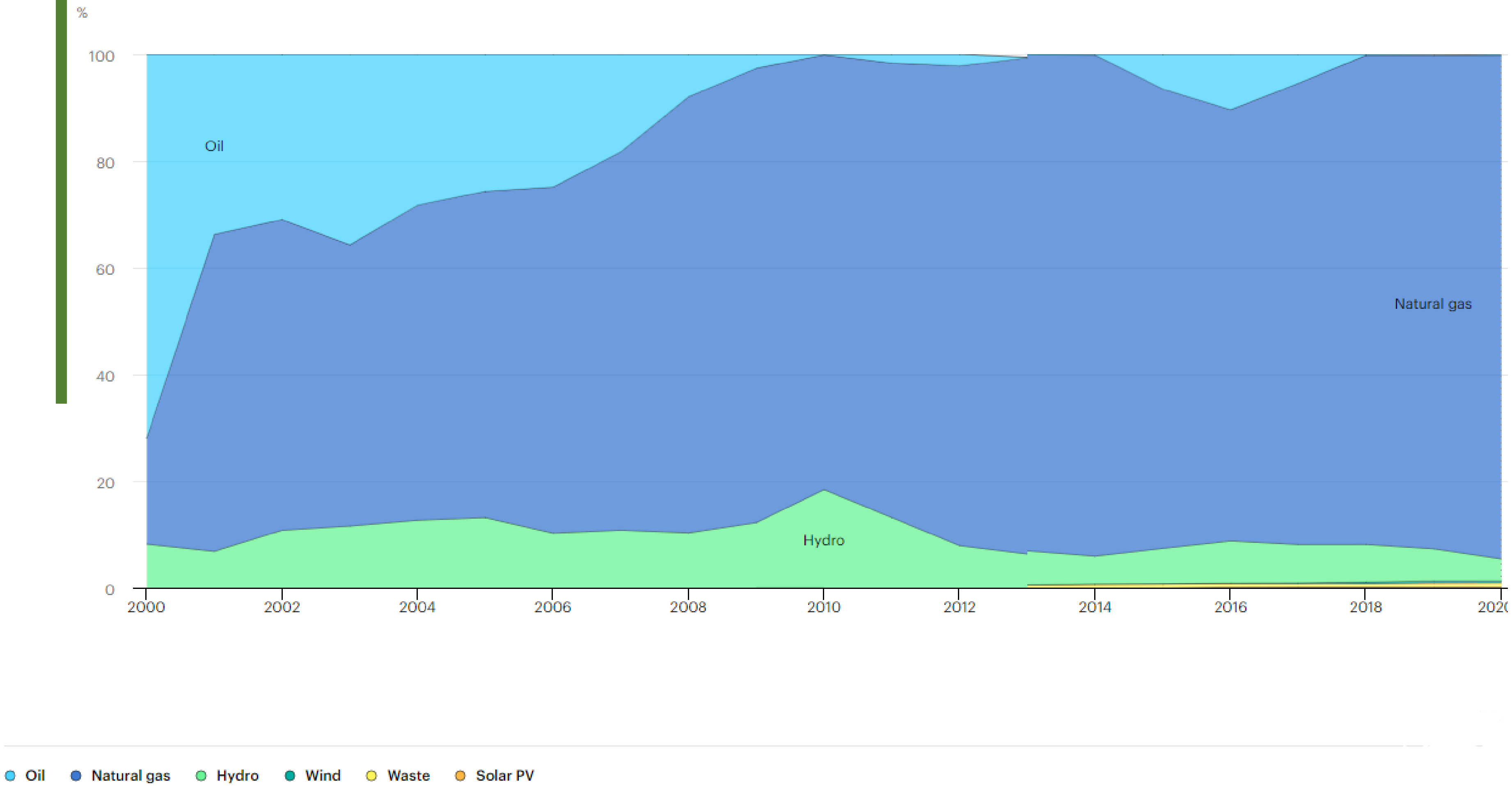


Resources

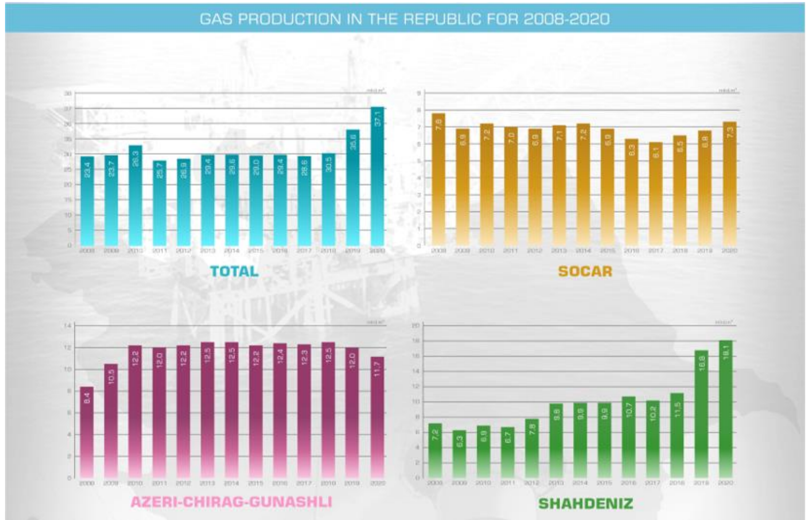
- Azerbaijan can generate **7516,5 MWh** of electricity including **6237,7 MWh** from gas-fired power station and **1 278,8 MWh** from Renewable Energies.

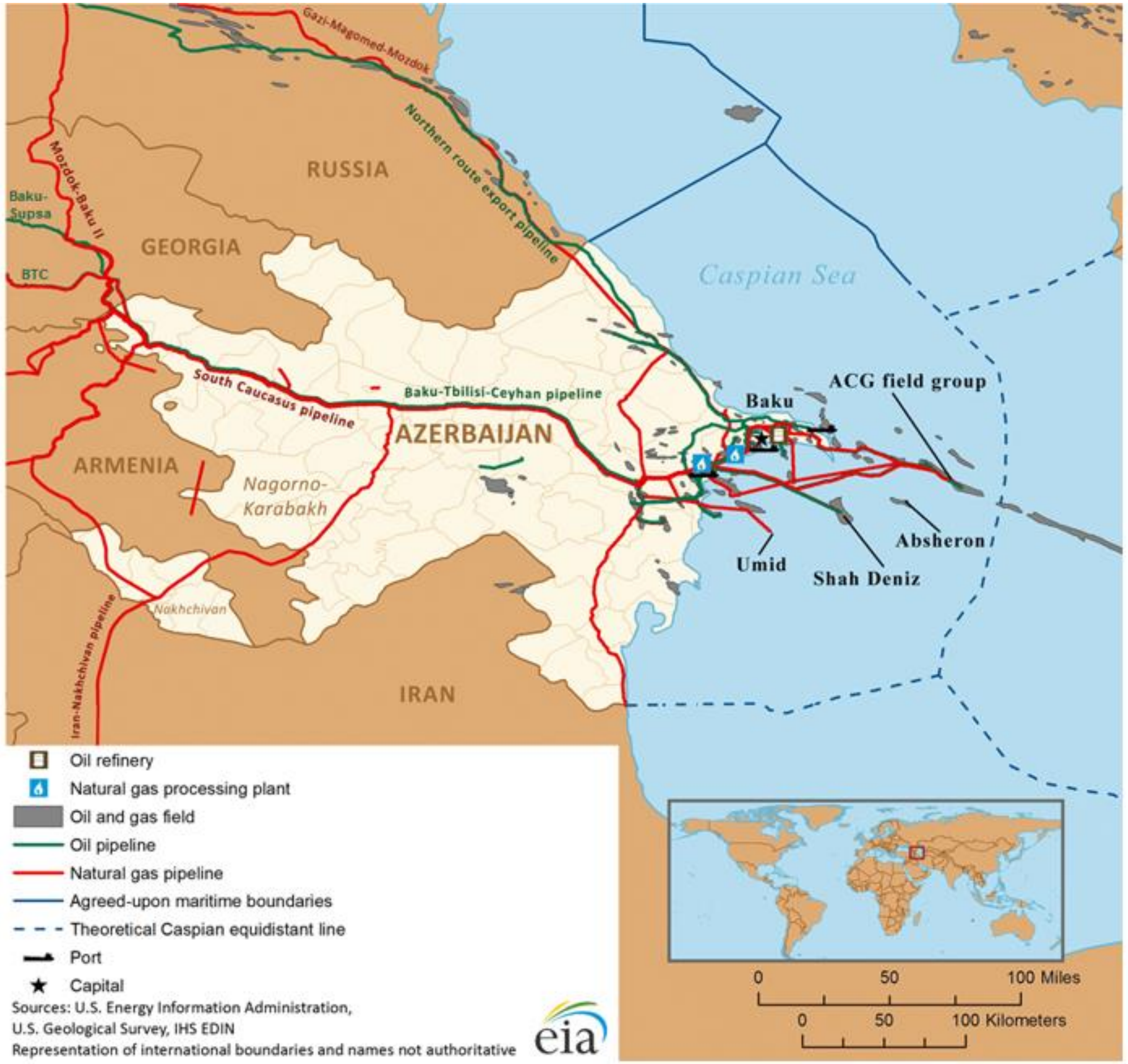
- This production satisfy the interior demand which was equal to **18 666,2 M kWh** in 2019 and should meet the **25.5 B kWh** by 2025.

CIS countries - Azerbaijan

Resources

- Azerbaijan has played a historically important role as an oil producer. Most of its hydrocarbon production comes from offshore fields in the Caspian Sea.
- The country's largest hydrocarbon basins are located offshore in the Caspian Sea, particularly the Azeri–Chirag-Gunashli (ACG) fields.
- Most of Azerbaijan's reserves are associated with the Shah Deniz field, which forms the beginning of the Southern Gas Corridor (SGC). The SGC will bring natural gas from the Caspian to southern Europe via the Baku–Tbilisi-Erzurum (BTE) and to the Trans–Anatolian and Trans Adriatic pipelines. The SGC has significantly increased Azerbaijan's importance as a natural gas producer and exporter.





ENERGY

Infrastructures

- Azerbaijan has three crude oil export pipelines. The country also exports small amounts of oil by rail. Most of its oil is exported through the BTC pipeline.
- Azerbaijan has been a net exporter of natural gas since 2007. Most of Azerbaijan's natural gas exports are shipped through Georgia to Turkey through the South Caucasus Pipeline (SCP), also called the Baku–Tbilisi-Erzurum (BTE) pipeline. The BTE runs parallel to the BTC oil pipeline for much of its route

Source: U.S. Energy Information Administration based on IHS Markit Midstream Database (IHSM EDIN)

CIS countries - Azerbaijan

Policies

- Azerbaijan has yet to adopt a national hydrogen strategy according to IEA.
- However, in October 2021, Azerbaijan's Energy Ministry presented a green legislative package which includes the use of wind energy potential of the Caspian sea.
- Energy Minister Parviz Shahbazov added in an article, entitled *"A new era of Azerbaijani energy begins in Karabakh and East Zangazur*", that "These include the production of `green' hydrogen by supplying electricity to electrolysis plants within the offshore wind energy project, and `blue' hydrogen as a result of the application of carbon capture technologies associated with the production of natural gas at sea".

Hydrogen production enablers

- Azerbaijan can benefit from its large pipeline infrastructure in order to export produced hydrogen. For instance, Azerbaijan is developing the infrastructure for hydrogen deliveries via the Trans Adriatic Pipeline (TAP).
- Azerbaijan can apply CCUS to produce blue hydrogen from its natural gas reserve and exports.
- Azerbaijan has a significant potential developing offshore wind energy which can be used for green hydrogen production.

CIS countries - Belarus

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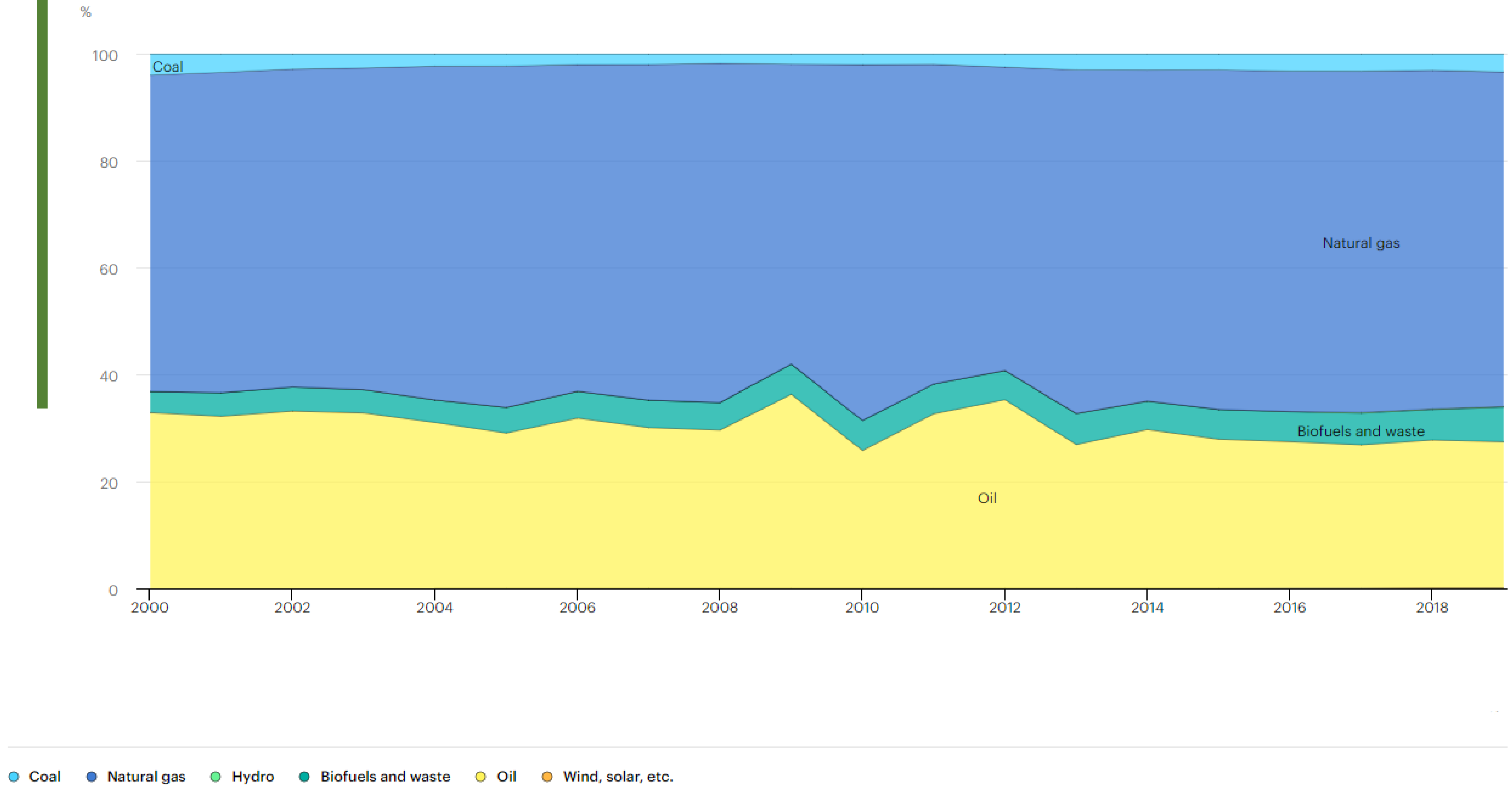


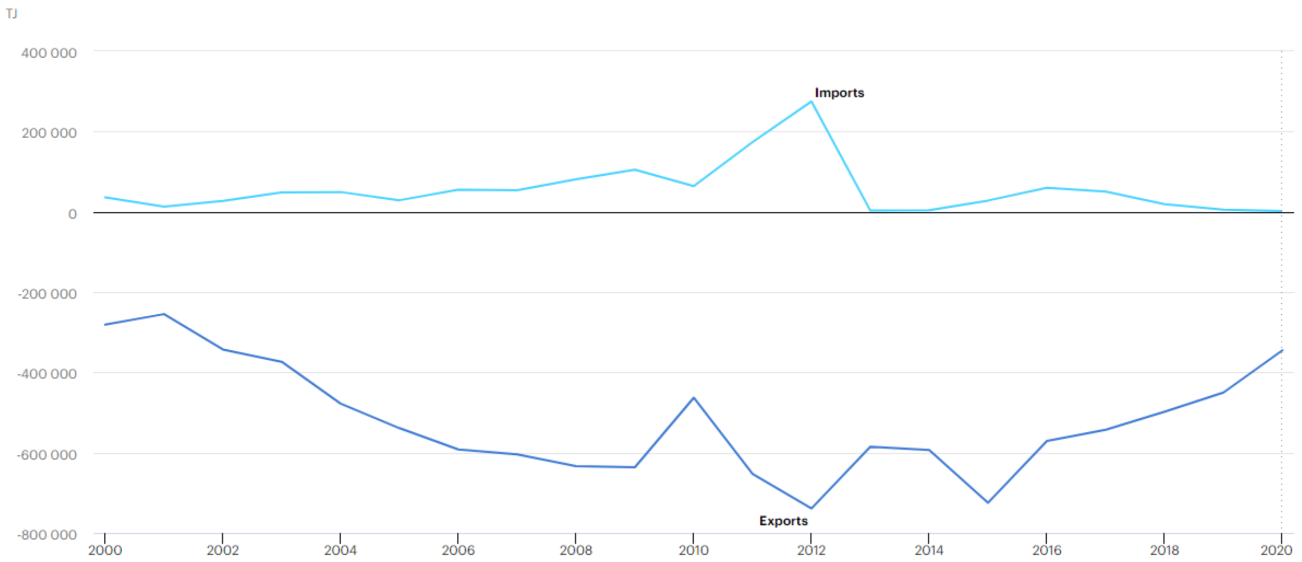
Resources

- Belarus could generate up to **24.4041 Mtoe** in 2019 (TES) including 1.90 B MWh generated from natural gas and 82.83 M MWh from oil.
- Around 15% of Belarus energy demand is covered by domestic production (4.05), consisting of peat (544 kilotonnes of oil equivalent [ktoe] or 2354 kt in 2018), and small amounts of crude oil (1 678 ktoe in 2018) and natural gas production (128 ktoe in 2018).
- Belarus's energy demand was equal to 27 Mtoe in 2018.

Resources

- Belarus has 27 Mt of crude oil reserves and 30 Mt of recoverable resources according to 2012 estimates of the Federal Institute for Geosciences and Natural Resources (BGR). Natural gas reserves are estimated at 3 bcm, and recoverable resources at 10 bcm.
- Explored reserves of peat are estimated at 4 billion tonnes (Bt): 41 peat deposits cover a total area of 34 000 hectares (ha), and recoverable resources are estimated at 84.6 Mt. The 15 100 ha of mining resources hold 30.8 Mt. Peat production in Belarus was 0.551 Mtoe in 2018.
- Solar power potential is significant, mainly in the south and southeast of the country. In terms of global horizontal irradiation and direct normal irradiation, most of Belarus receives only 1 100 kilowatt hours per square meter . Total solar potential is therefore estimated at 49.7 Mtoe/year.

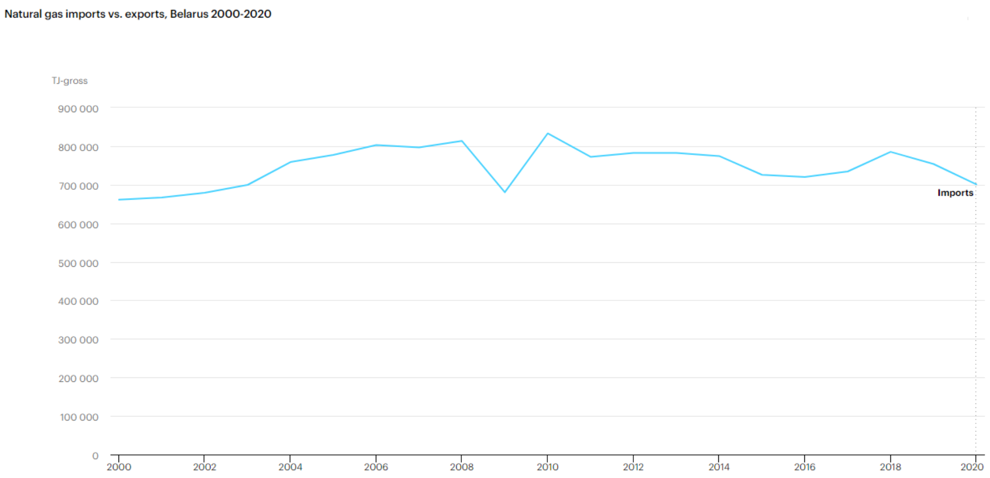
Oil products imports vs. exports, Belarus 2000-2020

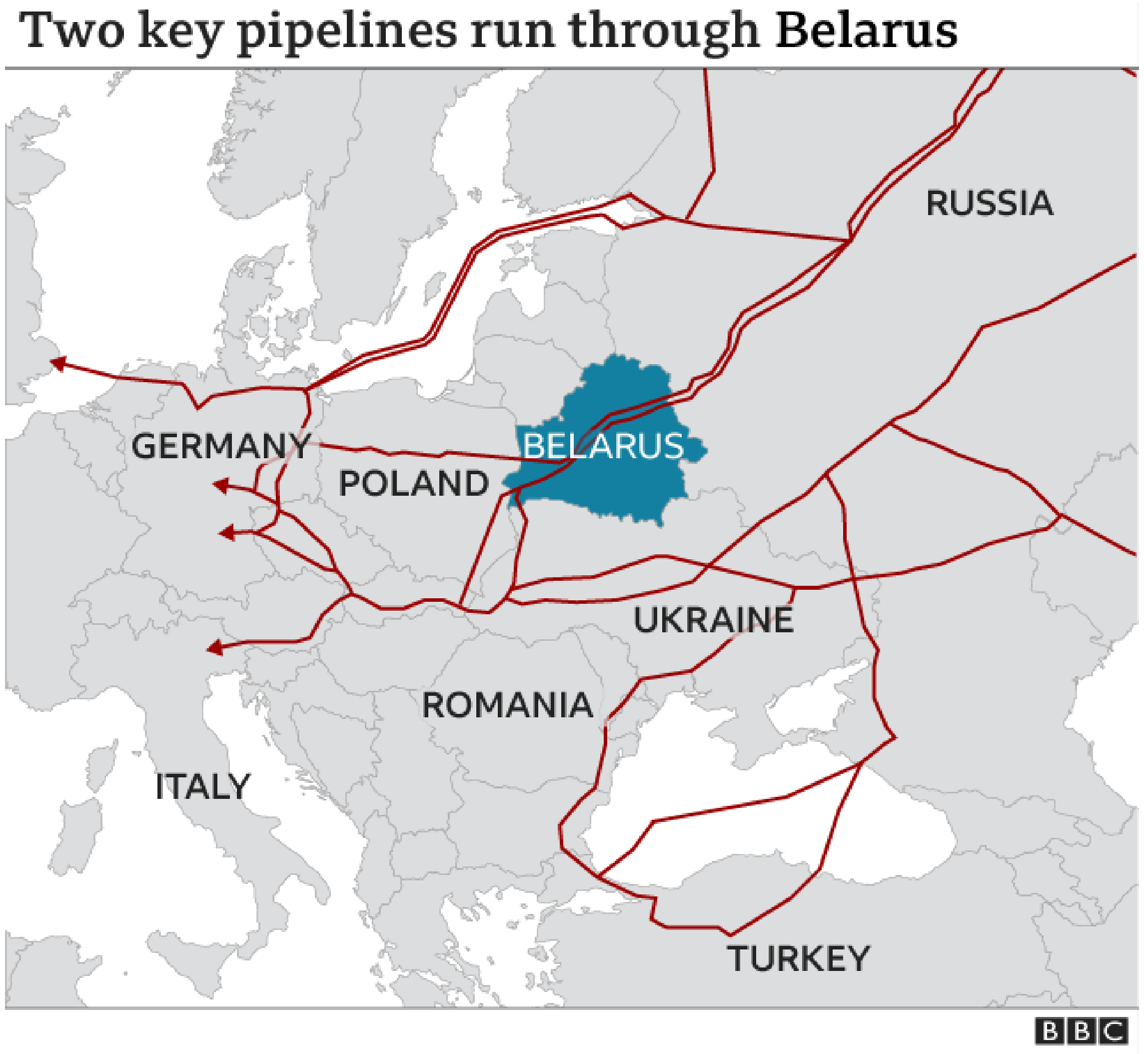


ENERGY

Infrastructures

- As a net oil and gas importer, Belarus relies heavily on imports of natural gas, oil products to meet most of its energy needs. The country is one of the world's largest importers of natural gas: it imported 17 Mtoe (20 billion cubic metres [bcm]) of natural gas, in 2018. Belarus imports similar quantities of crude oil (17 Mtoe in 2018), but most oil is re-exported in the form of oil products (11.4 Mtoe). Russia is the main supplier of crude oil refined in Belarus, and in turn Belarus is Ukraine's primary supplier of oil products.
- Belarus transits gas from Russia to Ukraine, Poland, Lithuania and Russia's Kaliningrad region (through Lithuania). Belarus also transit gas for Germany through the YamalEurope transmission pipeline.
- Oil transportation in Belarus is carried out through the Druzhba pipelines system: the Unecha-Polotsk, with a capacity of 29 Mt/year, the Unecha-Mozyr (80 Mt/year) and the Surgut-Polotsk (40 Mt/year).





CIS countries - Belarus

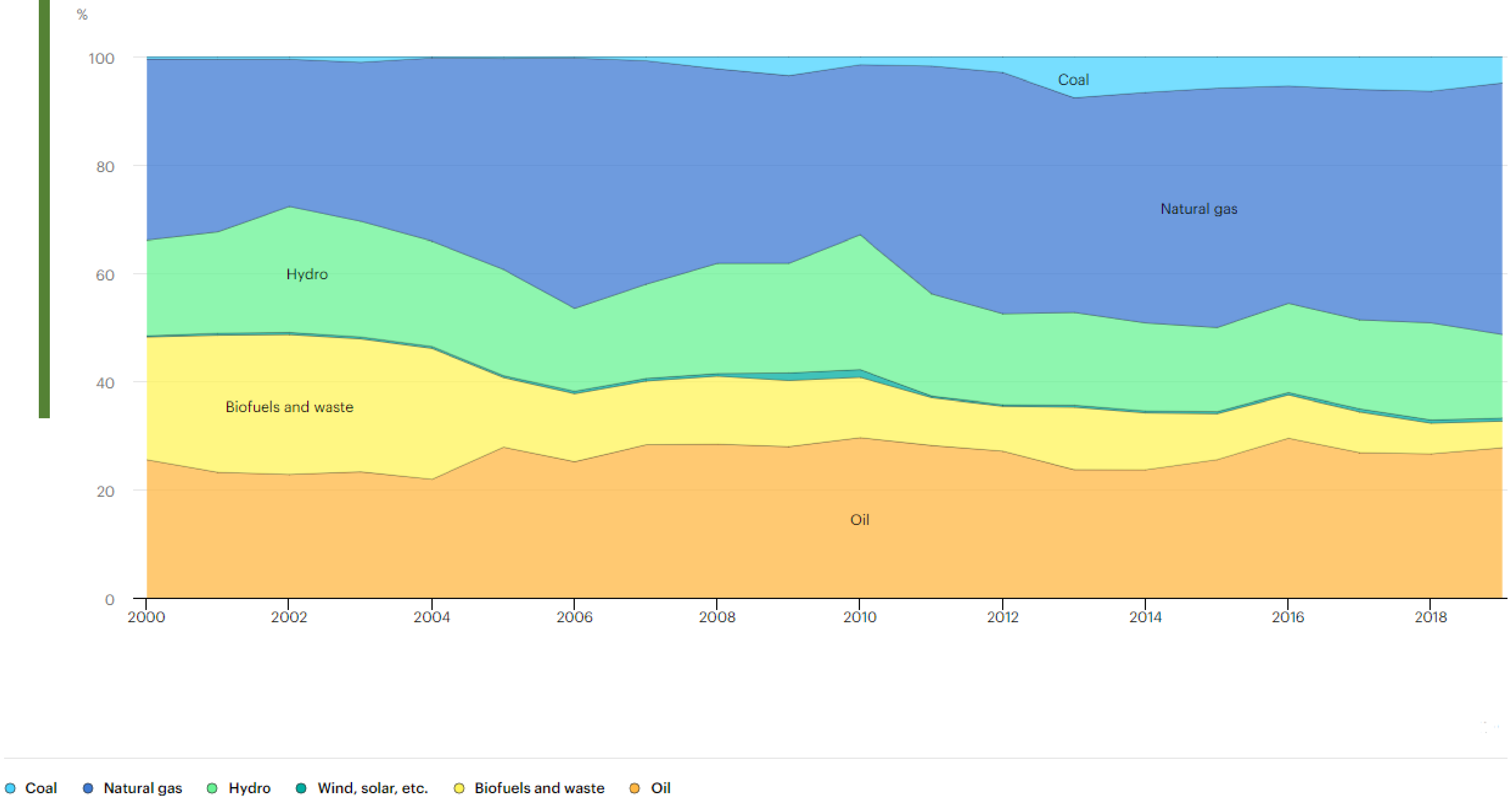
Policies

- Belarus has yet to adopt a national hydrogen strategy according to IEA.
- In 2007, Belarus' government passed an hydropower and wind development programme.The Oblast plans to build over 700 wind turbine towers with the capacity of 1 MW and three small hydropower plants.
- In 2011, Belarus's government passed a "National Program of Local and Renewable Energy Sources Development" which aims to increase the share of local energy sources in the energy balance to achieve a total of 30 %. The Government also passed a law on sustainable energies which aims to promote sustainable energies through certificates, tax reliefs and guaranteed connection of renewable energy installations to the national grid.

Hydrogen production enablers

- Belarus has a potential for producing green hydrogen thanks to its domestic wind potential and ongoing developments of wind power capacity. This would need to be significantly scaled.
- Belarus could export green hydrogen through existing natural gas pipelines and infrastructures.
- Production of hydrogen from natural gas with CCS would also be possible but not self-sufficient as depends on imports of natural gas
- Phasing in of nuclear power and current project developments imply potential of hydrogen from nuclear power in Belarus

ENERGY



Resources

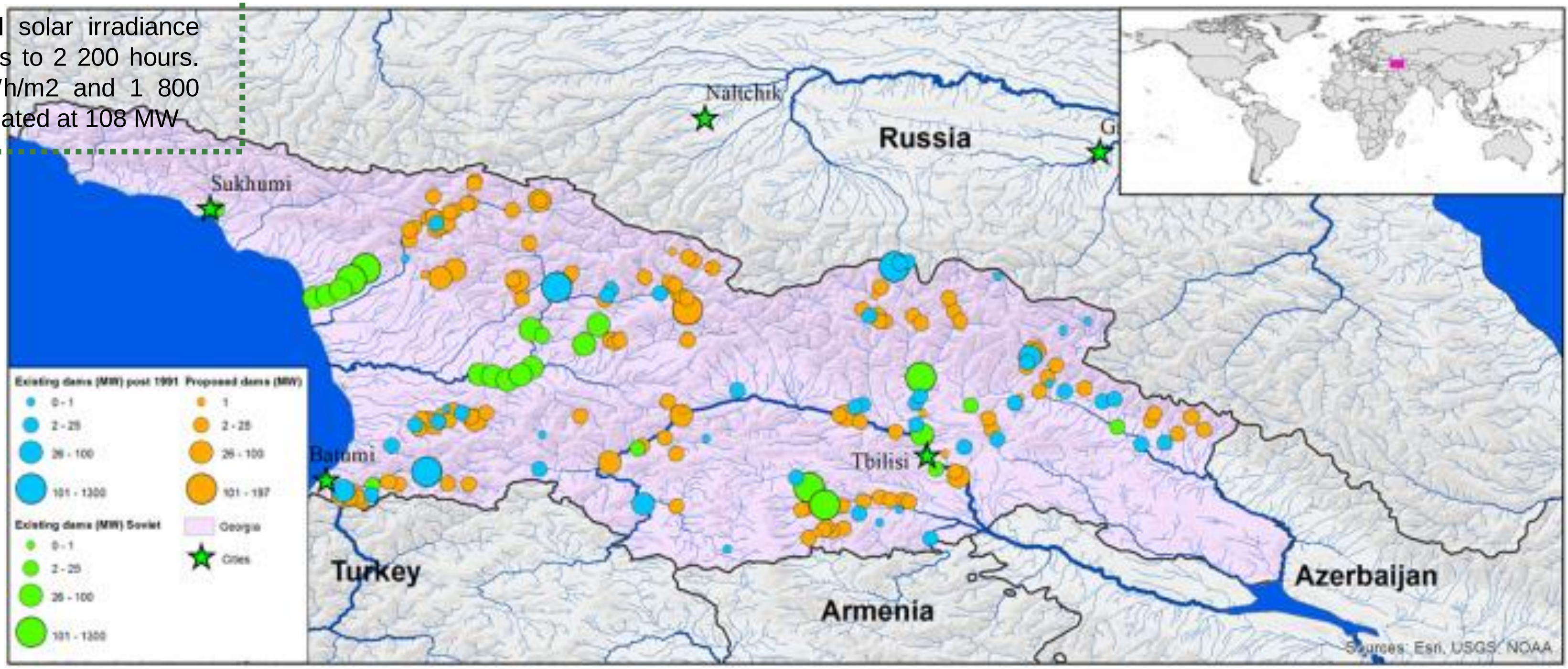
- Georgia could generate up to **4.7366 Mtoe** in 2019 (TES) including 26.951 M MWh generated from natural gas and 16. 067 M MWh from oil.
- Georgia’s energy production covers less than one-fourth of its energy demand (21.4% in 2019). Most of Georgia’s domestic energy production (1.09 Mtoe in 2019) comes from hydro and biofuels/waste (0.768 Mtoe biofuels and 0.245 Mtoe waste)
- Georgia's domestic consumption was equal to 5.1 Mtoe in 2019.

Resources

- Hydro resources are one of the most important natural riches in Georgia. Approximately 300 rivers are significant for energy production, with total annual potential capacity of 15 000 MWh and production potential of 50 TWh.

- Reserves of crude oil were estimated at 5 Mt in 2012 with resources of 50 Mt, and natural gas reserves at 8 bcm with 102 bcm of resources. Hard coal reserves were 201 Mt in the same year, with 700 Mt of brown coal resources.

- Solar energy potential in Georgia is high, with annual solar irradiance ranging from 250 to 280 days, amounting to 1 900 hours to 2 200 hours. Solar irradiance in Georgia varies between 1 250 kWh/m2 and 1 800 kWh/m2 annually, and total solar energy potential is estimated at 108 MW.



ENERGY

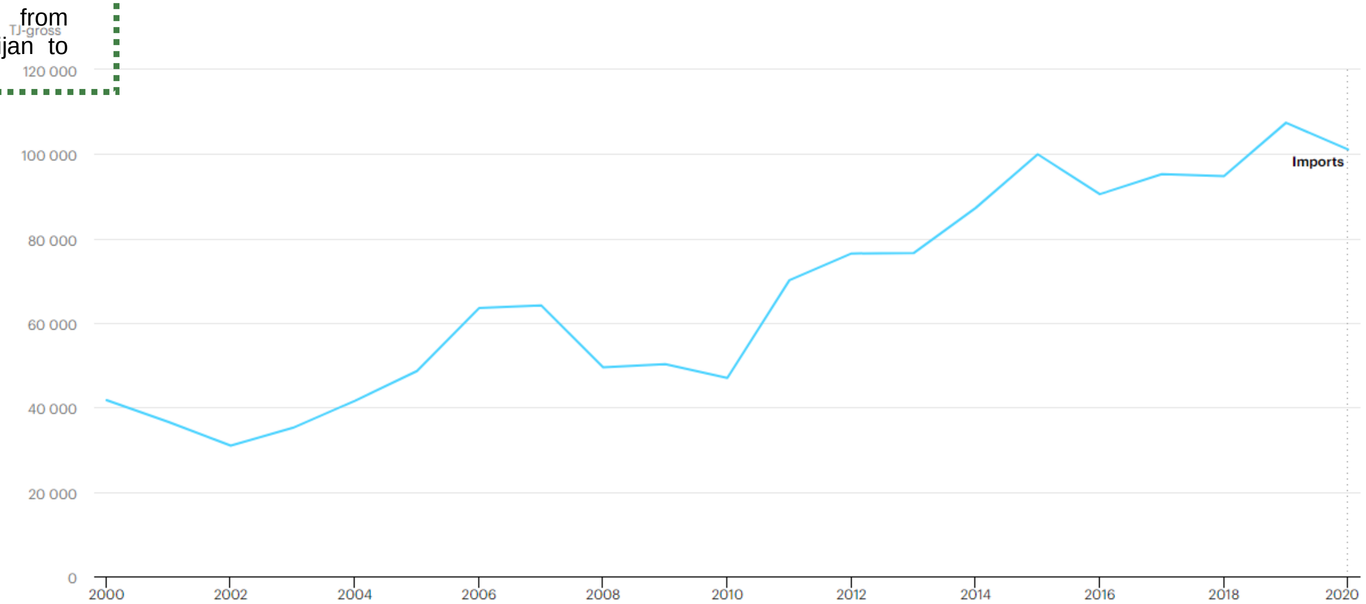
Infrastructures

- As a net oil and gas importer, Georgia relies heavily on imports of natural gas, oil products and hard coal to meet most of its energy needs; net imports in total primary energy supply rose from 47% in 2002 to 80.2% in 2019 to meet rising energy demand.

- In 2019, Georgia's net imports in term of energy were about 172.5 TJ (47 916.67 MWh).

- Georgia has gas pipeline connections with Armenia, Azerbaijan, Russia and Turkey, and oil connections with Azerbaijan and Turkey as well as a Black Sea oil terminal in Supsa. It imports natural gas from Azerbaijan and Russia, and transits gas from Russia to Armenia and from Azerbaijan to Turkey. Georgia’s oil product imports come from Azerbaijan and Russia, and it transits crude oil from Azerbaijan to Turkey.

Natural gas imports vs. exports, Georgia 2000-2020



Georgia

Policies

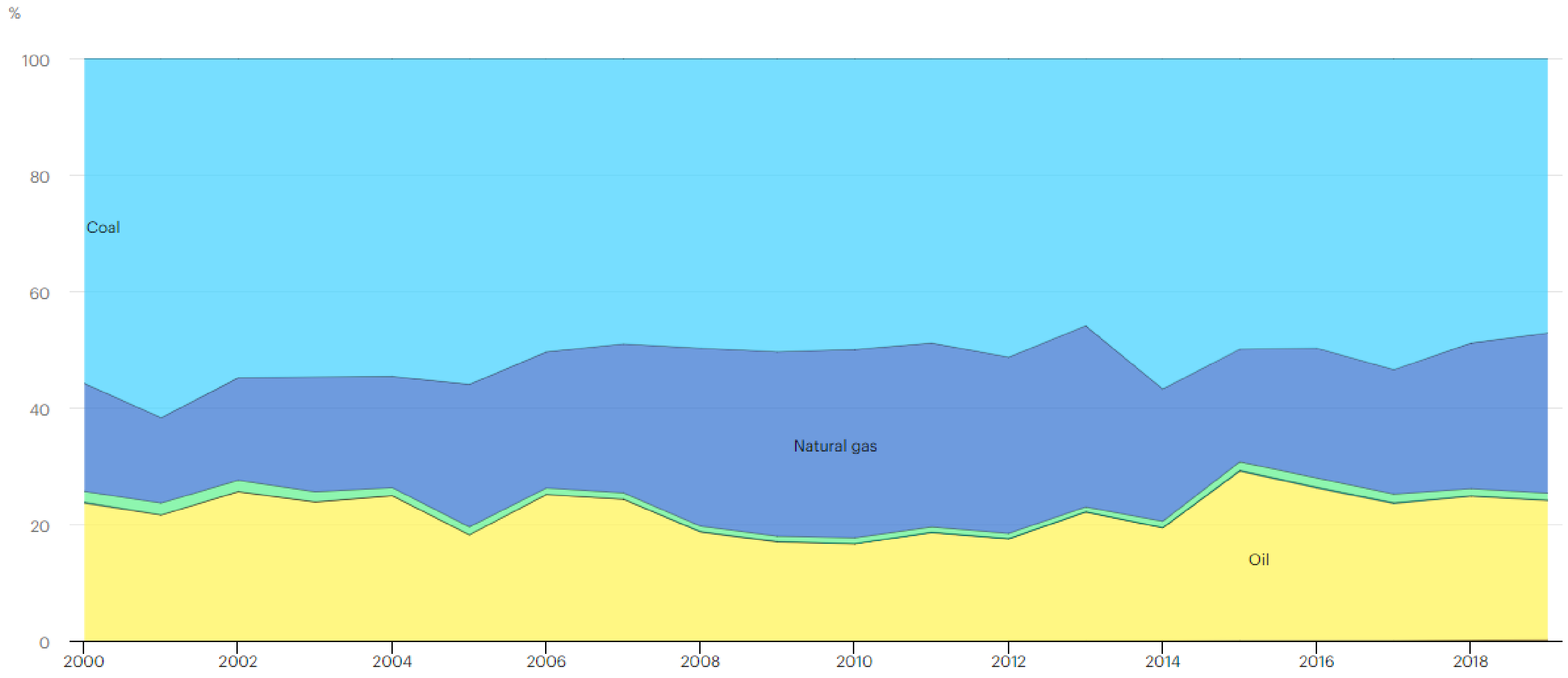
- Georgia has yet to adopt a national hydrogen strategy according to IEA.
- In 2020, Armenia government signed an agreement with the European bank for reconstruction and development to explore the country's potential for generating green hydrogen which could then be blended and transported to end-users through existing gas pipelines. The EBRD will "*provide technical cooperation support to assess the investment requirements in Georgia for green hydrogen generation, as well as to upgrade existing assets to transport blended hydrogen to end-users*".

Hydrogen production enablers

- Georgia has a significant potential for producing green hydrogen on the back of its hydropower infrastructure.
- Water access during summer months could be used to produce hydrogen through electrolysis from renewable energy and transported through pipeline network.
- Georgia has a significant potential for producing green hydrogen with its solar energy potential but has yet to develop the infrastructures.

CIS countries - Kazakhstan

ENERGY



Coal · Natural gas · Hydro · Biofuels and waste · Oil · Wind, solar, etc.

Resources

- Kazakhstan's total energy production (178 million tonnes of oil equivalent [Mtoe] in 2018) covers more than twice its energy demand.
- Kazakhstan is also a major energy exporter. In 2018, it was the world's 9thlargest exporter of coal, 9th of crude oil and 12th of natural gas.
- Kazakhstan's energy demand was equal to 76 Mtoe in 2018.

CIS countries - Kazakhstan

ENERGY

Resources

• Kazakhstan's estimated total petroleum and other liquids production was 1.77 million barrels per day (b/d) in 2017.

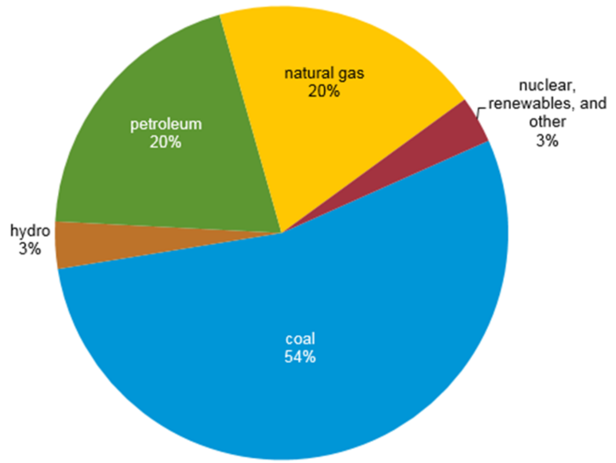
• In 2018, Kazakhstan was the world's 9th-largest coal producer (108 million tonnes [Mt]). It ranked 17th in the world for crude oil production (91.9 Mt), and 24th for natural gas (38.7 bcm).. Kazakhstan have three major crude oil refineries–Pavlodar, Atyrau, and Shymkent–with crude oil distillation capacity of 340,000 b/d as of January 1, 2018, according to OGJ.

• It is the first energy producer among EU4Energy focus countries (16th in the world in 2018). It produces more than twice as much crude oil as Azerbaijan but around half the natural gas produced in Turkmenistan

•Kazakhstan's current oil production is dominated by two giant onshore fields in the northwest of the country and one offshore field in the Caspian Sea. The onshore Tengiz and Karachaganak fields together produced about half of Kazakhstan's total petroleum liquids output in 2017. The offshore Kashagan field started ramping up production in 2017, producing about 225,000 b/d in December.

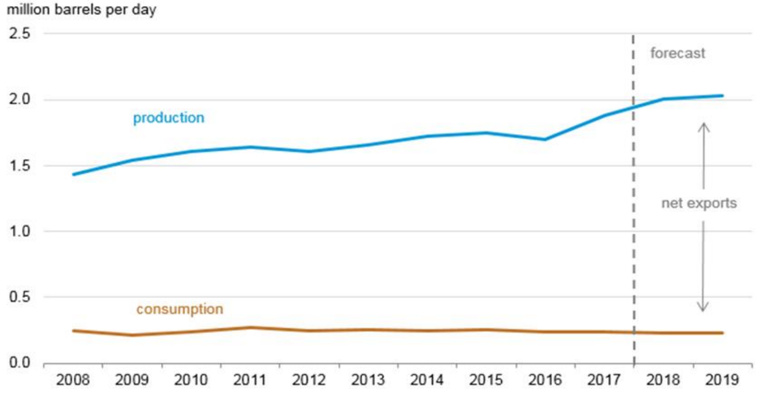
Coal	Dry natural gas	Petroleum & other liquids	Nuclear, renewables, & other
Production	Production	Production	Production
2.849	1.04	4.15	0.101
Consumption	Consumption	Consumption	Consumption
2.063	0.538	0.626	0.125

Figure 1. Kazakhstan energy consumption by fuel, 2015



Source: U.S. Energy Information Administration

Figure 2. Kazakhstan's petroleum and other liquids production and consumption



Sources: U.S. Energy Information Administration, *Short-Term Energy Outlook*, August 2018
Note: 2017 data are preliminary

CIS countries - Kazakhstan

Policies

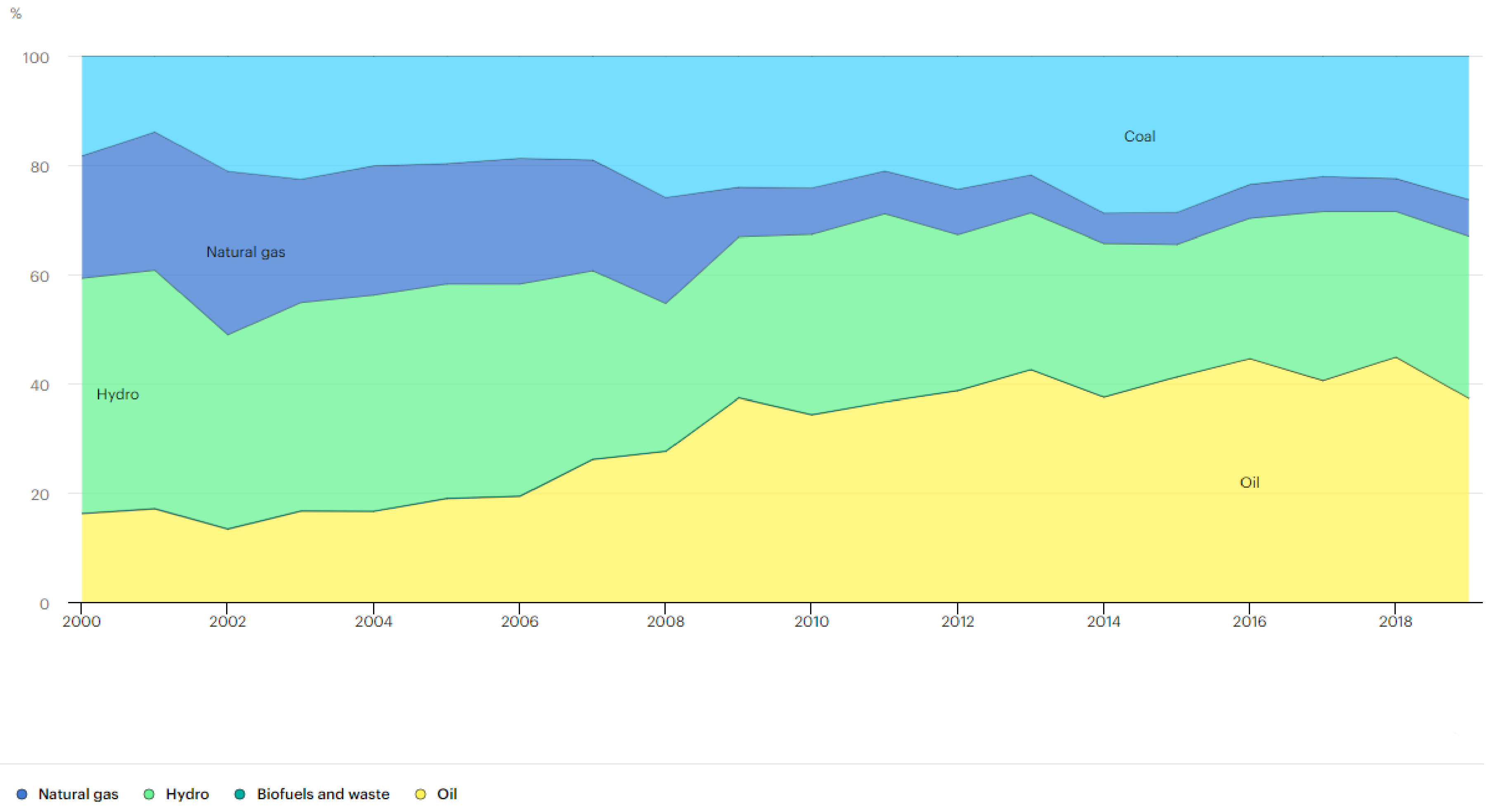
- Kazakhstan has yet to adopt a national hydrogen strategy according to IEA.
- In 2012, the government launched the Kazakhstan 2050 Strategy defining the course for long-term economic development. It identifies social, economic and political reforms aimed at placing Kazakhstan among the top 30 global economies by 2050. The strategy stipulates that alternative and “green” energy technologies must generate up to 50% of all consumed energy by 2050. It also declares that all mining companies should transition to environmentally friendly production only
- In May 2013, the Green Economy Concept was adopted, setting the ambitious target of 50% electricity generation from sources other than coal or oil, including gas, nuclear and renewable energy, by 2050
- The Kazakhstani company KazMunayGas has adopted a Low-Carbon Development Program in an attempt to reduce GEG emissions to 15% of the level of 2019 by 2031 through measures to decarbonise the economy such as hydrogen production and development of renewable energy sources

Hydrogen production enablers

- Abundant natural resources in Kazakhstan would enable production of both low- and zero-carbon hydrogen
- Kazakhstan has a potential for producing green hydrogen as shown by the project from Akimat of the Mangistau region and the German-Swedish group of companies Svevind to build wind and solar power plants with a capacity of 30 GW feeding electrolyzers for the production of up to 2 million tons of hydrogen per year.
- Kazakhstan has a potential for producing low-carbon hydrogen through CCUS based on its large coal and oil reserve and production.

CIS countries - Kyrgyzstan

ENERGY



Resources

- Kyrgyzstan could generate up to **2.9623 Mtoe** in 2019 (TES) including 17.42 M MWh generated from oil, 13.86 M MWh from hydro energy and 3.15 M MWh from natural gas.
- In 2018, Kyrgyzstan's domestic energy production was 2.3 Mtoe, consisting mostly of hydropower (53%) and coal production (37%). Kyrgyzstan also produces some crude oil and natural gas. Domestic production covers roughly half of annual consumption, with imports necessary to meet the remaining demand
- Kyrgyzstan's energy demand was equal to 4.2 Mtoe in 2019.

Policies

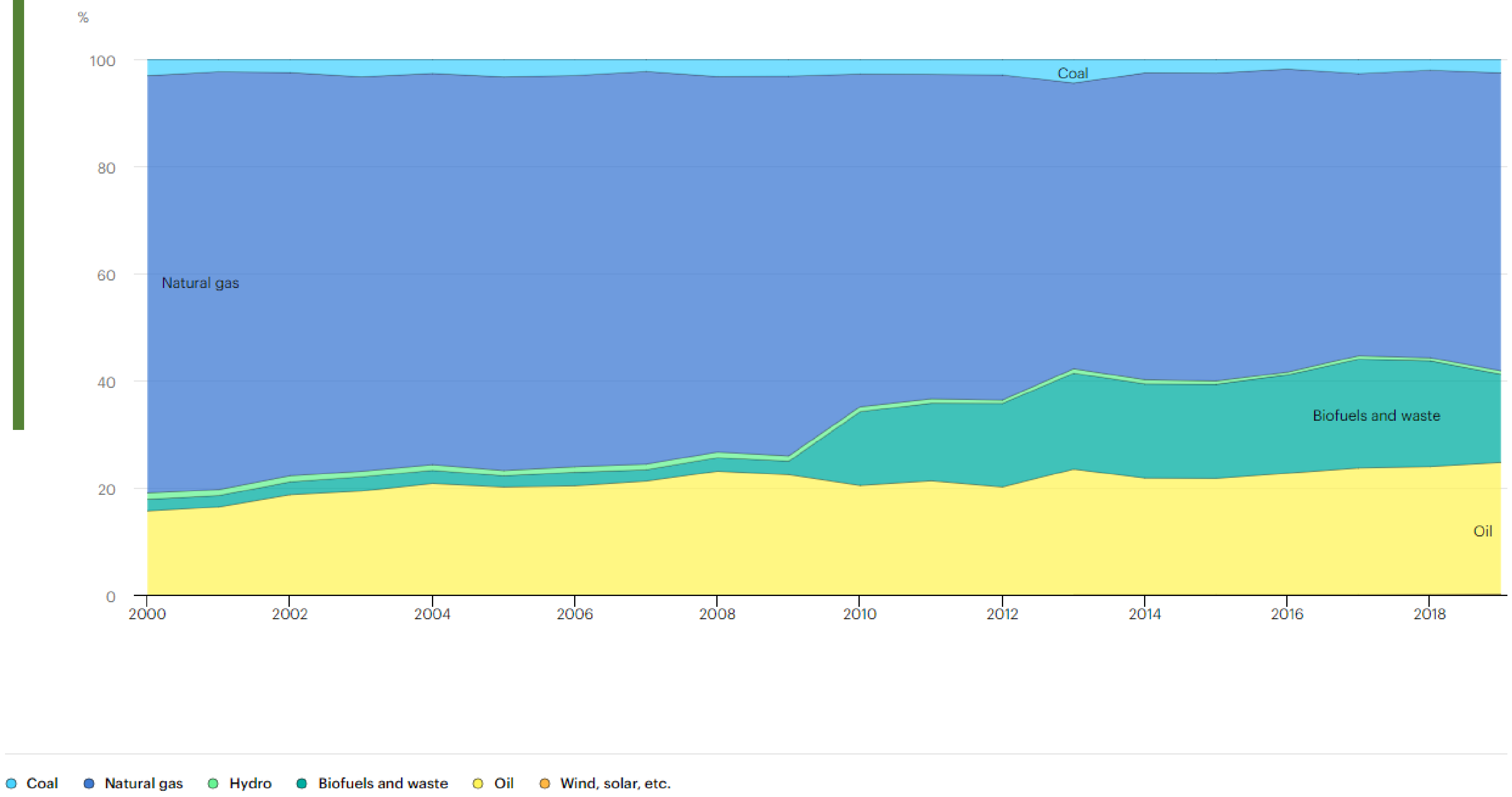
- Kyrgyzstan has yet to adopt a national hydrogen strategy according to IEA.
- Kyrgyzstan's government passed a National Energy Program for 2008-2010, with its integrated plan for fuel-energy complex development to 2025 which aims to improve energy efficiency and Increase hydro and coal-fired generation capacity to augment the national electricity supply and increase exports. The Government of Kyrgyzstan is currently in the process of revising its NDC, the Renewables Readiness Assessment (RRA) with resource potential assessment (Solar PV and Wind) as well as capacity building on Renewable Energy target setting will strengthen this process significantly.
- Kyrgyzstan ratified the Kyoto Protocol in February 2003, and a number of Clean Development Mechanism (CDM) projects have been identified but not yet registered. In October 2013, the government adopted the Priorities for Adaptation to Climate Change up to 2017 programme, aimed at developing adaptation measures in water, agriculture, health, environmental emergencies, forestry and biodiversity
- In November 2019 Kyrgyzstan ratified the Paris Agreement. The State Agency on Environmental Protection and Forestry has developed a first draft of “green economy” document – Concept for Long-term Development of the Kyrgyz Republic with Low Greenhouse Gas Emission until 2050.

Hydrogen production enablers

- Kyrgyzstan’s hydropower infrastructures and untapped potential (less of 10% of total hydro potential has been exploited) could power the production of green hydrogen through electrolysis. Long-term challenges imply effect of country-wide droughts
- In order to attract renewable energy investments, the government adopted a Law on Renewable Energy (2008) to provide a framework for the continued development of renewable energy resources and various incentives and privileges for renewable energy producers

CIS countries – Republic of Moldova

ENERGY



Resources

- Moldova could generate up to **3.2932 Mtoe** in 2019 (TES) including 25.49 M MWh generated from natural gas, 11.269 M MWh from oil and 7.551 M MWh from biofuels and waste.
- Around 20% of Moldova energy demand is covered by domestic production, consisting almost fully of solid biomass; total domestic energy production was 0.82 Mtoe in 2018, of which 0.79 Mtoe solid biofuels
- Georgia's domestic consumption was equal to 4.1 Mtoe in 2018.

CIS countries – Republic of Moldova

ENERGY

Resources

- Although it possesses limited lignite, phosphorite and gypsum deposits, Moldova is considered relatively resource-poor due to its lack of important coal, gas or oil reserves.
- The potential of renewable energy sources (RES), especially wind and solar, is not being fully exploited.
- Because of the country's intensive agricultural activity, solid biomass is regarded as one of the most important sources of renewable energy, with the potential to be extensively exploited for energy production.
- Moldova's two largest rivers are the Dniester and the Prut, both of which rise in the Carpathian Mountains in Ukraine.

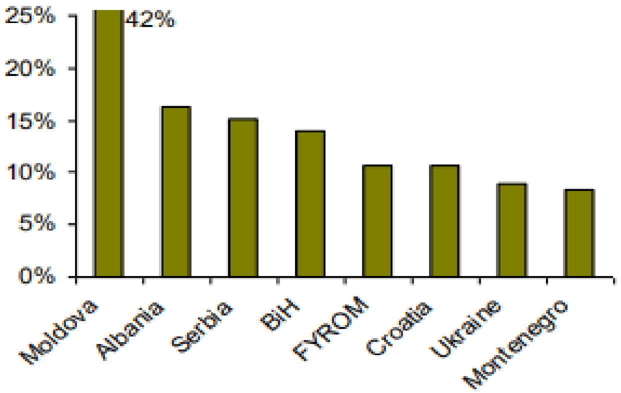
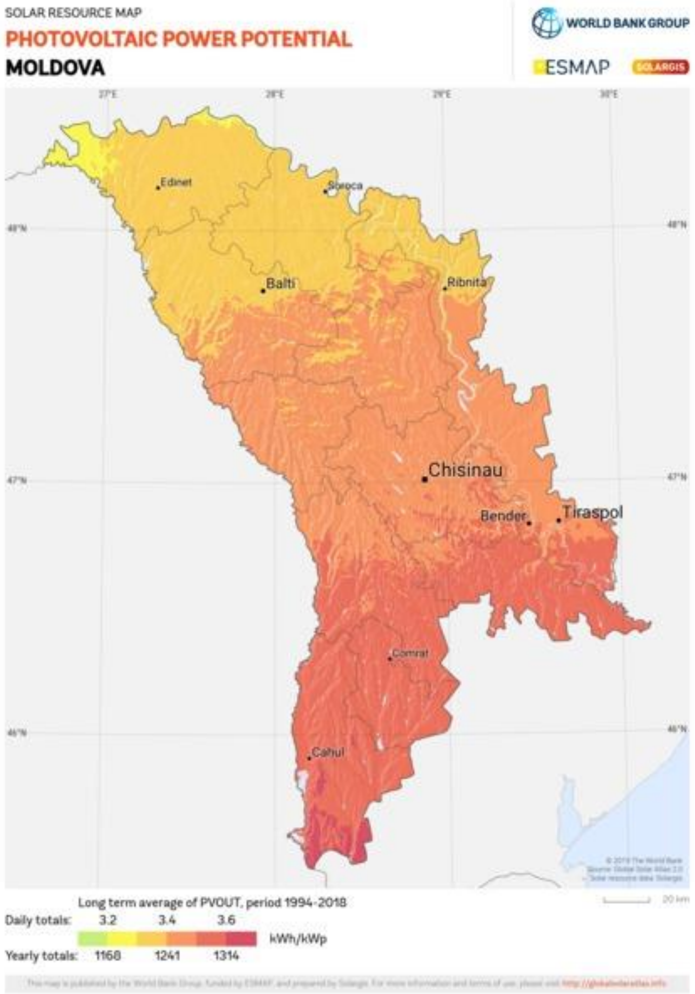
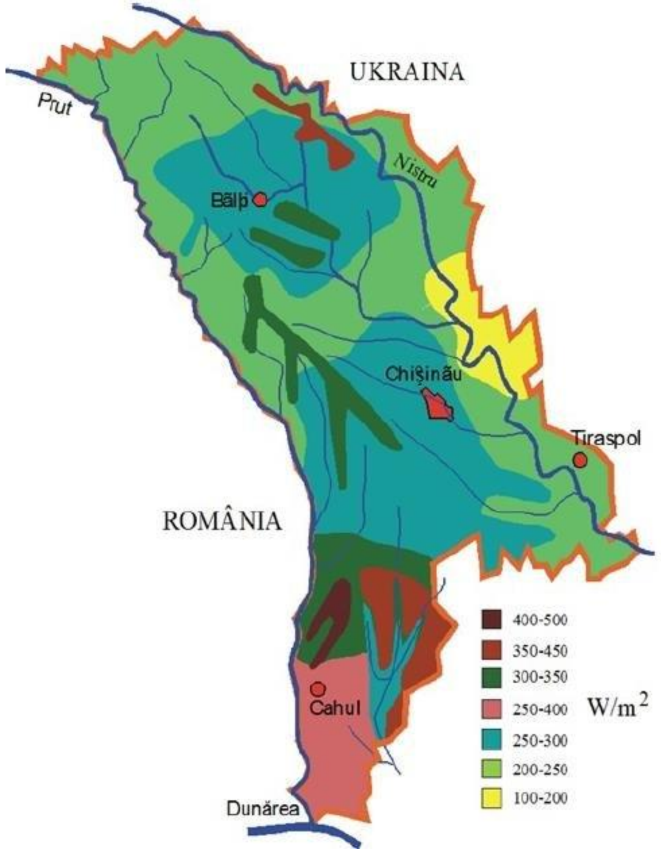


Fig. 4. Estimated biomass potentials as a percentage of each country's TPES.





CIS countries - Republic of Moldova

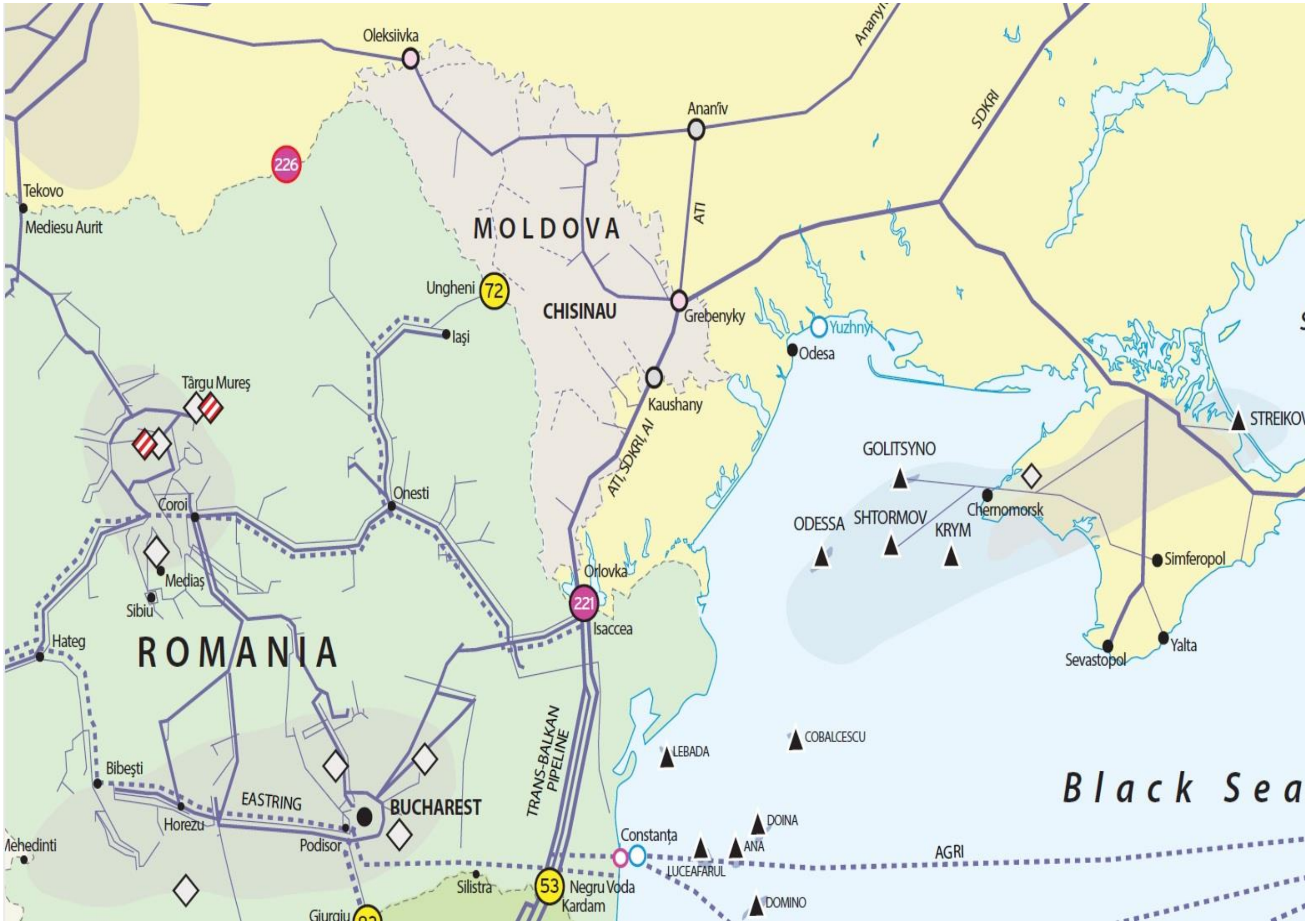
ENERGY

Infrastructures

- Moldova is connected to the Ukrainian gas transportation system that transits all gas imports to Moldova from Russia on a bilateral contract. Moldova also transits gas to the border with Romania, to be sold on European markets in Turkey and the Balkans. The total length of Moldova’s three transit pipelines is 247 km with a total capacity of 34.6 bcm/y. Another pipeline interconnection with Ukraine in northern Moldova connects two parts of the Ukrainian network

- All natural gas consumption (2.1 Mtoe, or 2.9 billion cubic metres (bcm) in 2014) is met through imports, mainly from Russia. A gas interconnector to Romania is under construction to reduce dependence on Russian gas.

- As of the end of 2019, several small (2 kW to 500 kW) solar projects have been built or are under construction in Moldova, with a cumulative capacity of 4.0 MW, while several industrial wind installations with a total capacity of 35.6 MW have been built.



CIS countries – Republic of Moldova

Policies

- Moldova has yet to adopt a national hydrogen strategy according to IEA.
- In 2013, Moldova passed the "*Energy Strategy of Moldova 2030*" which aims to 20% renewable energy sources in TFC; 10% biofuels in transport; 10% renewables in electricity generation; reduce energy intensity by 10%; reduce losses in transmission and distribution networks to 11% in electricity, by 39% in natural gas and by 5 p.p for heat from the 2009 level and reduce greenhouse gas (GHG) emissions by 25% from the 1990 level.

Hydrogen production enablers

- Moldova has a significant potential for producing green hydrogen with its hydropower and solar potential.
- Moldova could become a hydrogen exported using the gas pipeline connected to EU

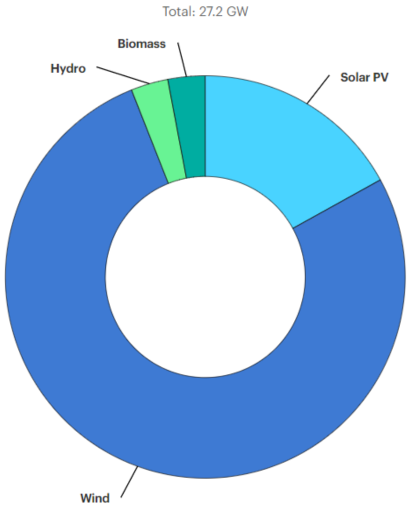
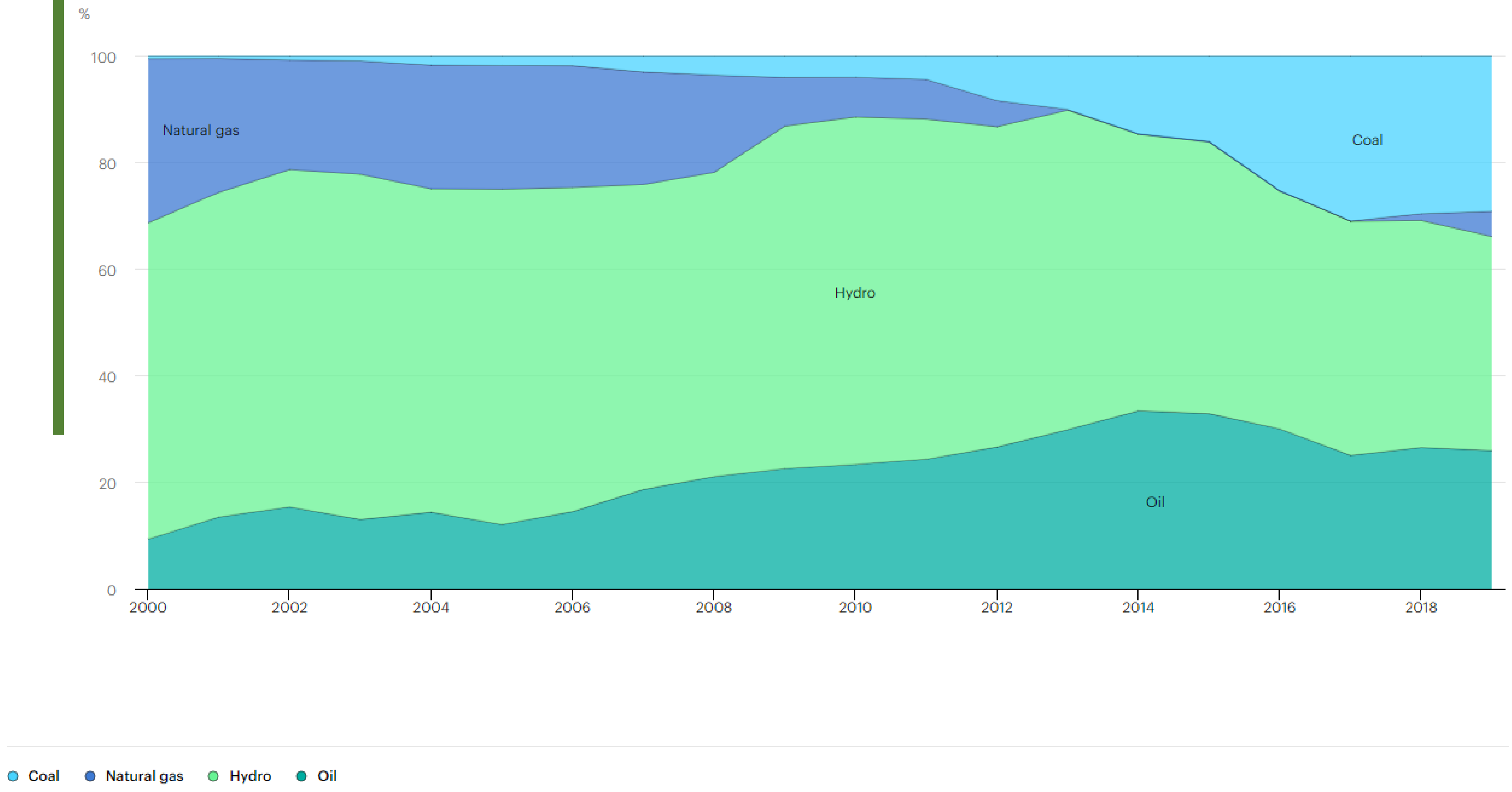


Figure 1 : Moldova Renewable Energy Potential

CIS countries - Tajikistan

ENERGY



Resources

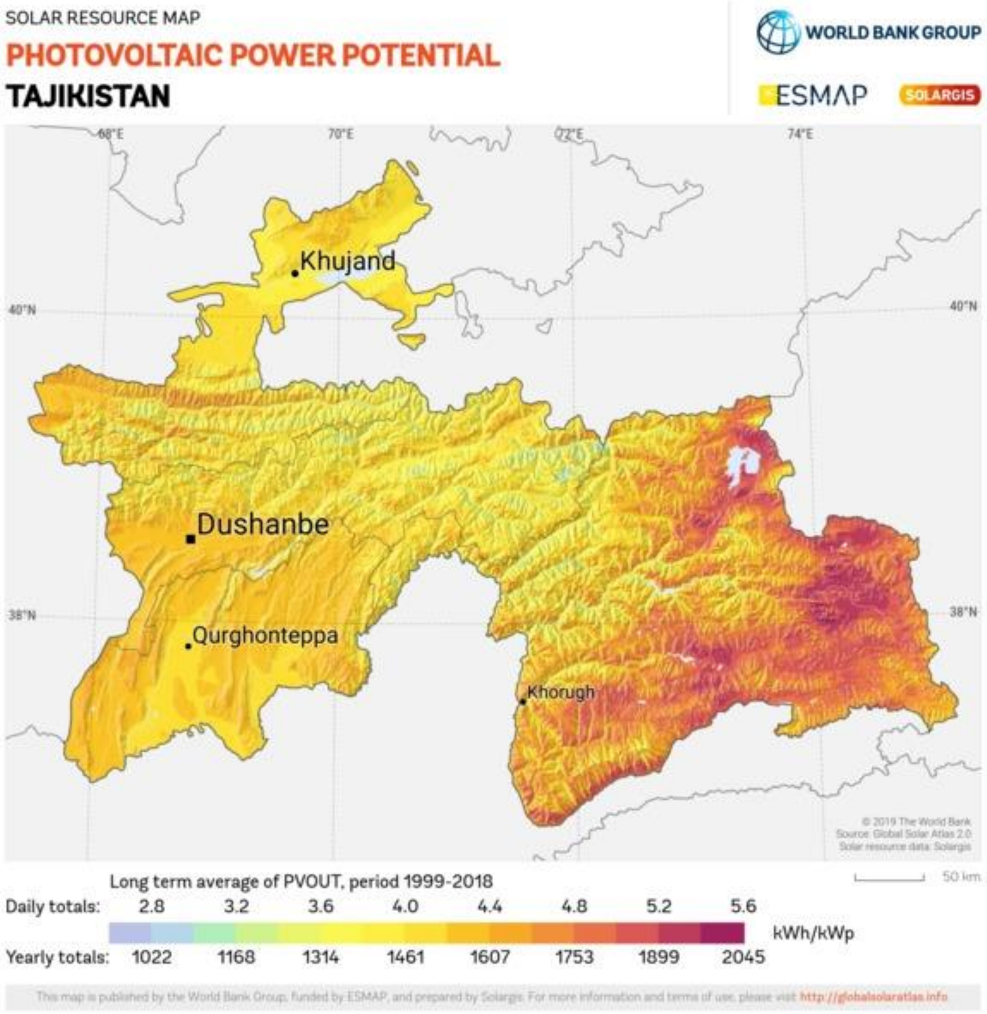
- Tajikistan could generate up to 4.**1092 Mtoe** in 2019 (TES) including 19.17 M MWh generated from hydropower, 13.993 M MWh from coal and 12.37 M MWh from oil.

- Tajikistans energy demand was equal to 1.29 Mtoe in 2018.

CIS countries - Tajikistan

Resources

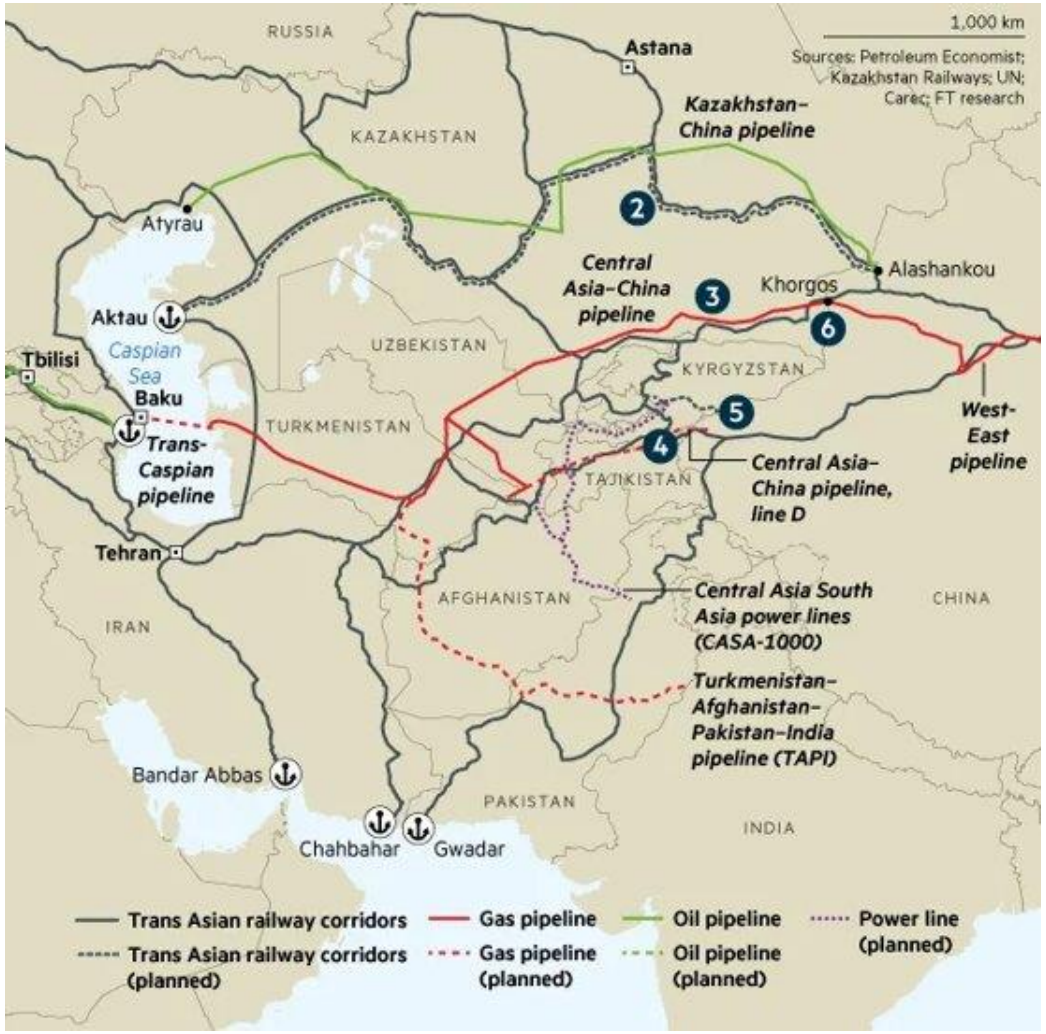
- Calculations of the Ministry of Energy and Water Resource of Tajikistan have shown that the potential for the use of solar energy is **3,103 billion kWh per year**.
- Tajikistan holds **40 millions barrels of proven oil reserves as of 2016**, ranking **88th** in the world and accounting for about 0.0% of the world's total oil reserves of 1,650,585,140,000 barrels. **The annual consumption of oil in Tajikistan is around 1 million Tonnes**.
- Tajikistan **has enormous hydro power potential as it possesses 4% of the world's hydro** power resources and 53% of Central Asia's resources. Yet these resources remain to be sufficiently developed. More than 90% of electricity generating capacity is hydroelectric, but only an estimated 5% of its potential is in use.



CIS countries - Tajikistan

Infrastructures

- The electrification rate is 95%. Hydro-electricelectricity generates around 20 billions kWh per year. Prices vary but people typically pay 1.5 US cents/kWh. The **TajikAluminum Company (TALCO)**, is the largest consumer in Tajikistan and uses from 30 to 40 % of total electricity consumption.
- Many components of the transmission and distribution system are in bad condition and need to be replaced. Network and commercial losses result in up to 17'% losses. Rural populations experience more difficulties in accessing electric power due to bad conditions of the system, instability of voltage, and high losses



CIS countries - Tajikistan

ENERGY

Total Energy: **Production** 0.216 **Consumption** 0.258

	Coal	Dry natural gas	Petroleum & other liquids	Nuclear, renewables, & other
Production	0.046	0.001	0.001	0.169
Consumption	0.047	0.006	0.046	0.159

CIS countries - Tajikistan

Policies

- Tajikistan has yet to adopt a national hydrogen strategy according to IEA.
- In 2010, Tajikistan's government passed a Law on Use of Renewable Energy Sources which provides definitions on how the "renewable energy" is defined and understood from the legal perspective in Tajikistan and stipulates how it can be efficiently incorporated to the energy system of the country.
- The following year the government also passed a strategy called "Sustainable Energy for All Tajikistan 2013-2030" which aims to increase energy production from renewable energy sources up to 20% against the baseline (year 2010) and increase indigenous energy sources in energy sector from 59.3% in 2010 to 80% in 2030.
- In 2021, IEA developed its energy policy Roadmap on Cross-Border Electricity Trading for Tajikistan as part of its work through the EU4Energy Programme. The Roadmap examines tangible steps Tajik policy makers can take to facilitate effective cross-border integration of electricity markets, benefiting not only Tajikistan, but also the surrounding region.

Hydrogen production enablers

- Tajikistan has a potential for producing green hydrogen with its solar potential and the development of its hydropower infrastructures.
- Tajikistan could export green hydrogen through its upcoming natural gas pipelines and infrastructures.
- Tajikistan's power supply is vulnerable to supply shocks and seasonal shortages that provide strong drivers for the development of alternative, renewable sources of energy.

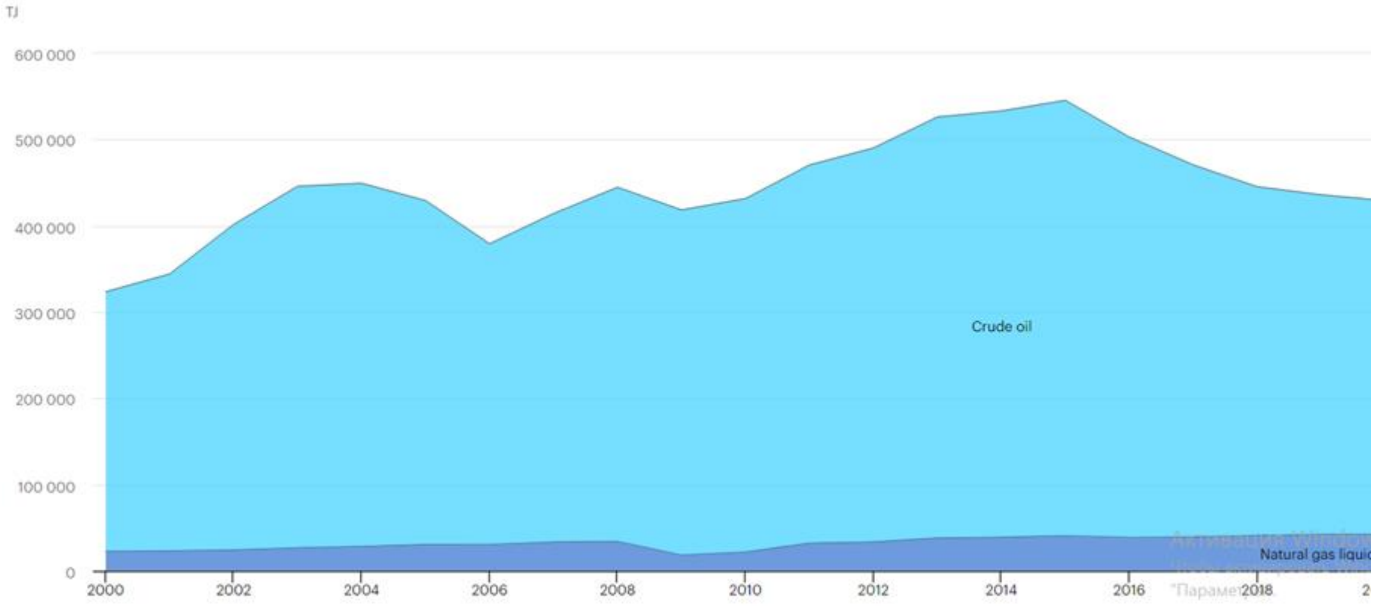
CIS countries - Turkmenistan

Infrastructures

•Turkmenistan has two oil refineries, the Seidi and Turkmenbashi, with a total crude oil distillation capacity of almost 237,000 b/d.

•Turkmenistan has a small domestic crude oil pipeline network linking onshore oil fields with the Turkmenbashi refinery and Caspian ports. Turkmenistan has virtually no international oil pipeline infrastructure except a pipeline between the Seidi refinery in northeastern Turkmenistan and the Shymkent refinery in Kazakhstan via Uzbekistan.

Oil production, Turkmenistan 2000-2020



CIS countries - Turkmenistan

ENERGY

Policies

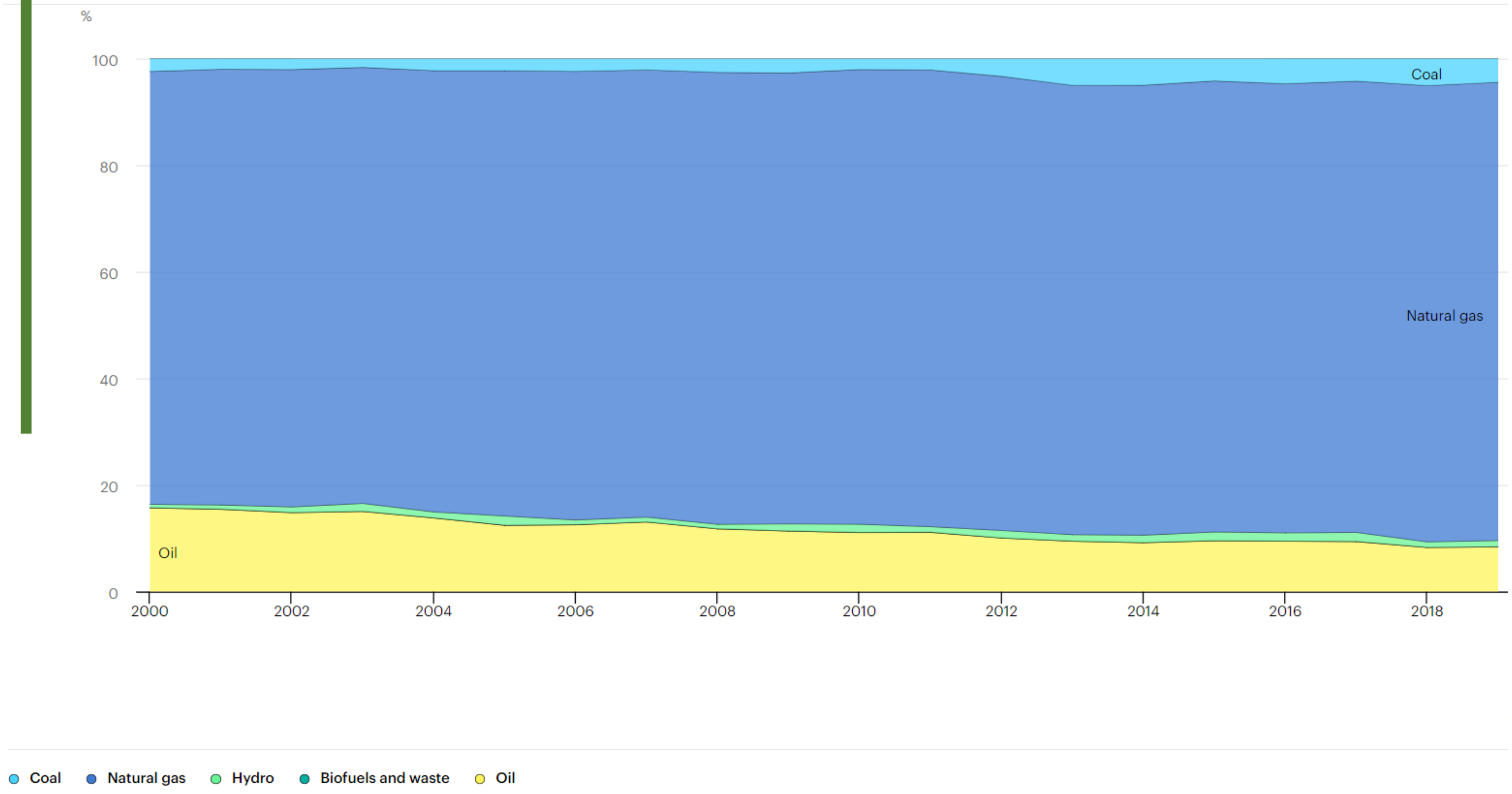
- Turkmenistan's government announced in January 20022 that it designed a draft Roadmap for the development of international cooperation of Turkmenistan in the field of hydrogen energy for 2022-2023.
- The document suggests developing a National Strategy for the Development of Hydrogen Energy with the involvement of international experts, as well as to create an IRENA Center for Hydrogen Energy in Turkmenistan and open a similar experimental center on the basis of the International Oil & Gas University named after Yagshigeldy Kakayev.

Hydrogen production enablers

- Considering the huge reserves of natural gas in Turkmenistan, Turkmenistan has a significant potential to produce blue hydrogen through CCUS and SMR.
- Turkmenistan has a potential for exporting hydrogen through its natural gas infrastructures and the transcaspian pipeline.
- Turkmenistan recently drafted Roadmap for the development of international cooperation of Turkmenistan in the field of hydrogen

CIS countries - Uzbekistan

ENERGY



Resources

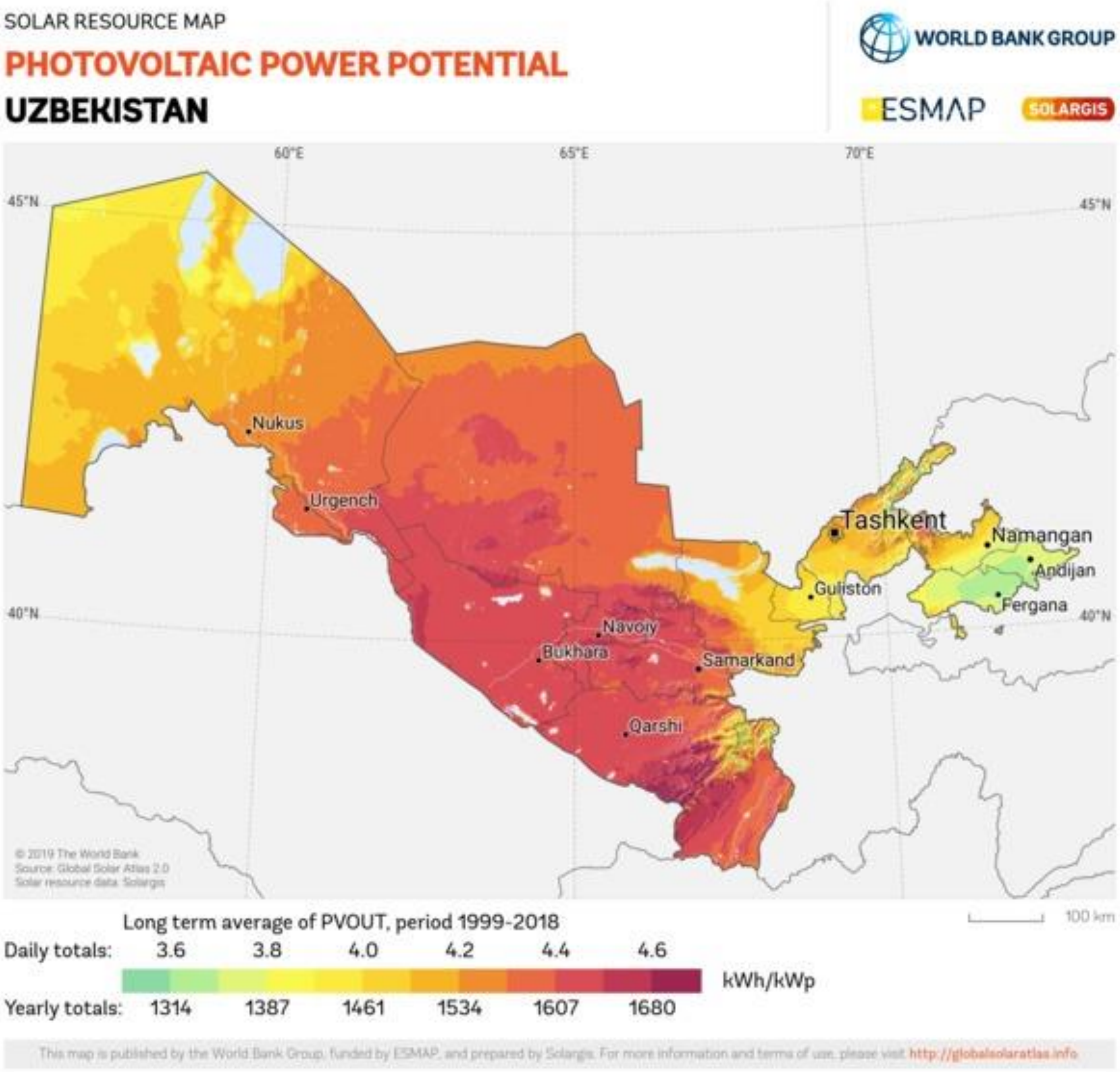
- Uzbekistan could generate up to 46**.953 Mtoe** in 2019 (TES) including 469.63 M MWh generated from natural gas and 45.87 M MWh from oil.
- Uzbekistan generated 61.6 terawatt hours (TWh) of electricity in 2019, mostly from natural gas (>85%). The share generated from coal is expected to increase in the future to around 10% (currently around 3%).
- Uzbekistan's energy demand was equal to 29.5 Mtoe in 2018.

CIS countries - Uzbekistan

Resources

- According to expert estimates, the country has one-third of all Central Asia's mineral resources, and in terms of gas production it is among the world's 20 leaders. According to the State Committee for Geology and Mineral Resources, explored reserves of oil and gas condensate contain 178.1 Mt; natural gas 2 239.9 bcm; and coal 1 950.1 Mt. In 2018, the Organization of the Petroleum Exporting Countries (OPEC) estimated Uzbekistan's oil reserves at 594 million barrels of natural gas and 1 564 trillion cubic metres (tcm) of natural gas
- Uzbekistan has 47 kt of uranium reserves and 74 kt of resources, with 121 kt of remaining potential. Its reserves account for 12.3% of the total of these four countries, and 2.2% of total reserves globally
- Renewable energy produced mainly by HPPs currently accounts for slightly more than 10% of the country's total electricity production. Despite their significant potential, RESs such as solar and wind power are not being fully exploited.

Economist.com

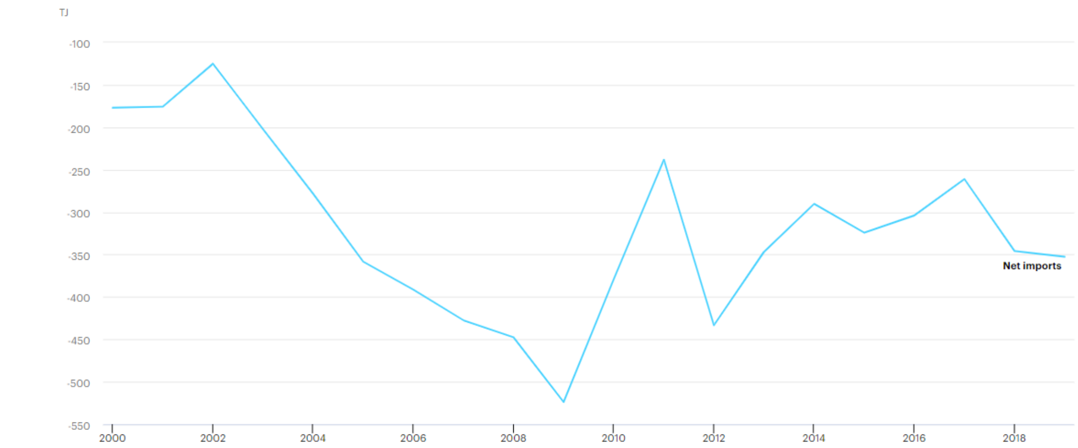


ENERGY

Infrastructures

- Since the early 2000s, Uzbekistan has been exporting 10-15 bcm of natural gas annually (15 bcm in 2018: 8 bcm to China; 4.5 bcm to Russia; 2.5 bcm to Kazakhstan; and 500-550 mcm to other Central Asian countries)
- On top of its domestic oil production, Uzbekistan imports additional crude oil for its refineries (around 30% of total input in 2018). Refining output satisfies domestic market demand and allows for small quantities to be exported (0.13 Mt in 2018).

Net energy imports, Uzbekistan 2000-2019



Major Energy Facilities in Uzbekistan

CIS countries - Uzbekistan

Policies

- Uzbekistan has yet to adopt a national hydrogen strategy according to IEA.
- In 2021, Uzbekistan's government published a presidential decree "*On measures for the development of renewable and hydrogen energy in the Republic of Uzbekistan*" that will lead to the construction of a hydrogen energy infrastructure, driving energy efficiency and security in the Central Asian country.
- The decree allows for the creation of the National Research Institute of Renewable Energy Sources. The institute will conduct scientific research needed to develop the proposed hydrogen energy infrastructure and facilitate the introduction of further renewable energy sources into Uzbekistan’s energy mix.
- A research centre for hydrogen energy and a laboratory for testing and certification of renewable and hydrogen energy technologies will also be created as part of the Institute.

Hydrogen production enablers

- Uzbekistan's significant hydrocarbon potential could allow it to produce blue or turquoise hydrogen through CCUS.
- This could be extended to green hydrogen production as well using vast solar power potential in the country.
- Uzbekistan is a major uranium supplier and has started considering nuclear power infrastructure that could also provide one of the routes to produce hydorgen.
- Uzbekistan could become a hydrogen exporting country through the use of its already existing natural gas infrastructure.