4.4. HYDROGEN

4.4.1. Market context and potential

INCREASING IMPORTANCE OF HYDROGEN IN GLOBAL DECARBONIZATION EFFORT

As the world continues to grapple with the effects of climate change, the need for decarbonization has become more urgent than ever. One of the key solutions to reducing carbon emissions is the use of hydrogen as a clean energy source. Hydrogen can be produced from renewable sources, making it a key component in the transition to a low-carbon economy.

One of the key advantages of hydrogen is its versatility. It can be used as a feedstock for the production of chemicals and fertilizers, as well as a fuel for heating and electricity generation. This means that hydrogen has the potential to replace fossil fuels in a wide range of industrial applications, reducing carbon emissions and helping to mitigate the effects of climate change.

Hydrogen is expected to be a crucial lever for decarbonization of hard-to-abate sectors, where reduction of carbon intensity is complicated by a combination of technological and financial challenges.

These sectors include heavy industry, shipping, aviation, and buildings, and account for ~20% of global carbon emissions (with cement and steel manufacturing alone accounting for 14%). As the demand for decarbonization grows, so too will the demand for hydrogen, making it an important part of the energy mix in the coming years.

ROLE OF HYDROGEN IN DECARBONIZATION OF EUROPEAN INDUSTRY

The European Union has set ambitious targets to reduce greenhouse gas emissions and achieve carbon neutrality by 2050. The EU has identified hydrogen and its derivatives as a key enabler for decarbonization, particularly in sectors such as industry, transportation, and heating.

Fit for 55 package, introduced by the EU as part of the European Green Deal strategy, sets out a goal to achieve

55% **reduction in greenhouse gas emissions by 2030**

The programme includes a range of regulations and policies aimed at decarbonizing various sectors, including transport, buildings, and industry. Hydrogen is expected to play a crucial role in achieving the program's goals.

The RePowerEU plan of the European commission proposes increasing energy efficiency, speeding up and scaling up renewable energy generation, including hydrogen.

The EU's hydrogen strategy and RePowerEU envision substantial growth of hydrogen production and use in the EU, setting a 2030 target of 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of imports from the neighbouring regions rich in renewable energy – with Ukraine being one of the strategic partners.

To encourage the adoption of hydrogen in industry, the EU has established various financial and regulatory incentives. As most of the regulatory mandates are associated with monetary penalties for non-compliance, it is expected that renewable hydrogen suppliers could secure a willingness-to-pay premium, with the amount of premium varying between countries, sectors and specific hydrogen end-uses.

SIDEBAR: European regulations and incentives promoting hydrogen production and use

The EU Emissions Trading System (EU ETS) is a key instrument that puts a price on carbon emissions. By including industrial sectors in the EU ETS, the EU incentivizes the reduction of carbon emissions and encourages industries to transition to low-carbon alternatives such as hydrogen.

Hydrogen and its derivative ammonia are covered by **CBAM (Carbon Border Adjustment Mechanism)** – a regulatory measure that aims to address carbon leakage by requiring importers of certain goods into the EU to pay a price equivalent to the ETS for the carbon emissions associated with the production of those goods. This will incentivize production and use of clean hydrogen to reduce emissions and avoid higher costs.

One of the key financing vehicles is the **Innovation Fund,** which provides financial support for large-scale demonstration projects in the field of clean energy, including hydrogen. The fund aims to accelerate the commercialization of innovative technologies and help bridge the gap between research and market deployment.

The IPCEI (Important Project of Common European Interest) programme provides incentives and financial support for strategic projects in the EU. In the context of hydrogen projects, IPCEI offers several incentives to promote the development and deployment of hydrogen in the form of investment support for e.g., green hydrogen projects, electrolyzer manufacturing factories and hydrogen infrastructure.

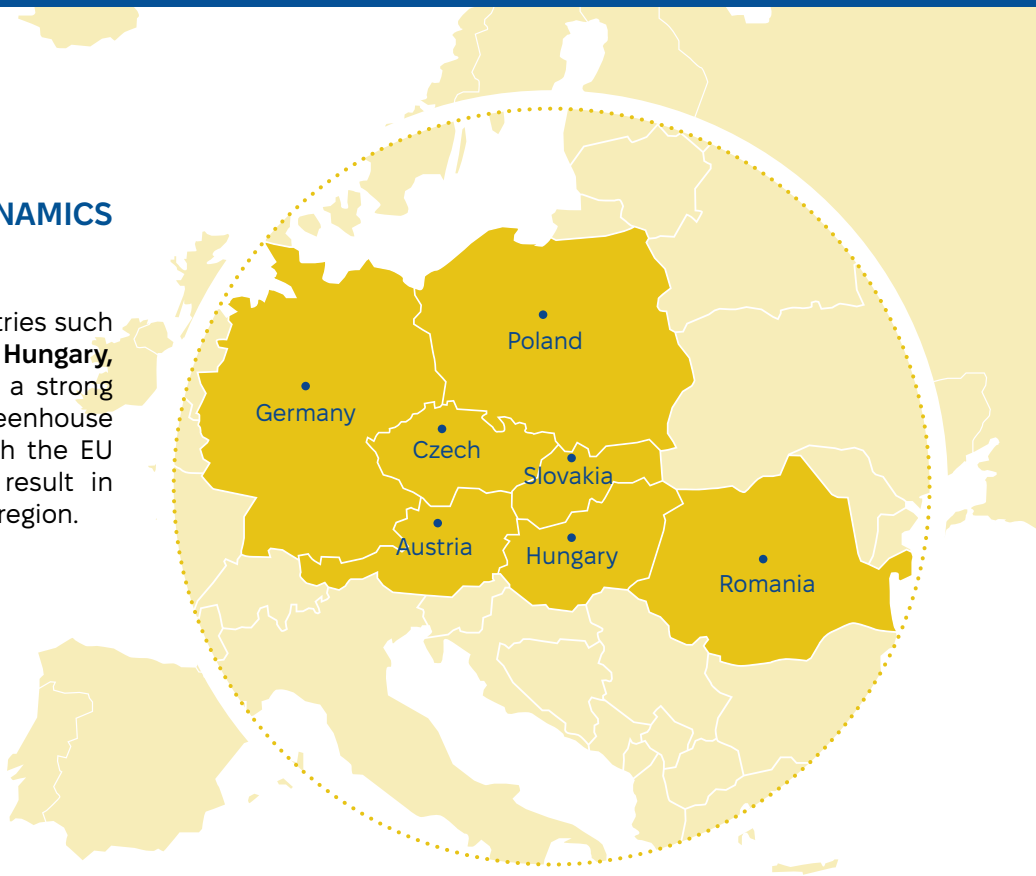
In 2022, the European Commission launched the **European Hydrogen Bank** to create investment security and business opportunities for European and global renewable hydrogen production. In April 2024, the results of the European Hydrogen Bank's first auction were announced. Seven projects across the EU will be awarded a total of €720 million under the Innovation Fund, with a plan to produce 1.58 million tonnes of renewable hydrogen over ten years, avoiding more than 10 million tonnes of CO2 emissions.

Furthermore, the EU has established the **Renewable Energy Directive (RED II / RED III),** which sets binding targets for the share of renewable energy in the EU's energy mix. This directive promotes the use of hydrogen produced from renewable energy sources in industrial processes. It provides a clear signal to industry that renewable hydrogen is a preferred option and encourages investment in renewable hydrogen production facilities.

Application of hydrogen in the transport sector is governed by sector-specific regulation: **FuelEU, FuelEU Maritime, ReFuelEU**. These regulations mandate the use of renewable fuels, driving additional demand for renewable hydrogen.

CENTRAL EUROPE MARKET DYNAMICS AND POTENTIAL

Central Europe, which includes countries such as **Austria, Czech Republic, Germany, Hungary, Poland, Romania, and Slovakia,** has a strong industrial base that contributes to greenhouse gas emissions. Efforts to comply with the EU decarbonization commitments will result in substantial hydrogen demand in the region.



EXPECTED HYDROGEN DEMAND

Assuming further acceleration of decarbonization commitments and regulatory incentives, hydrogen demand in Central Europe could reach up to

~5
million tonnes per year by 2030
heavily concentrated in chemicals, refining and transport sectors

By 2040, hydrogen demand in Central Europe is expected to almost triple, reaching up to

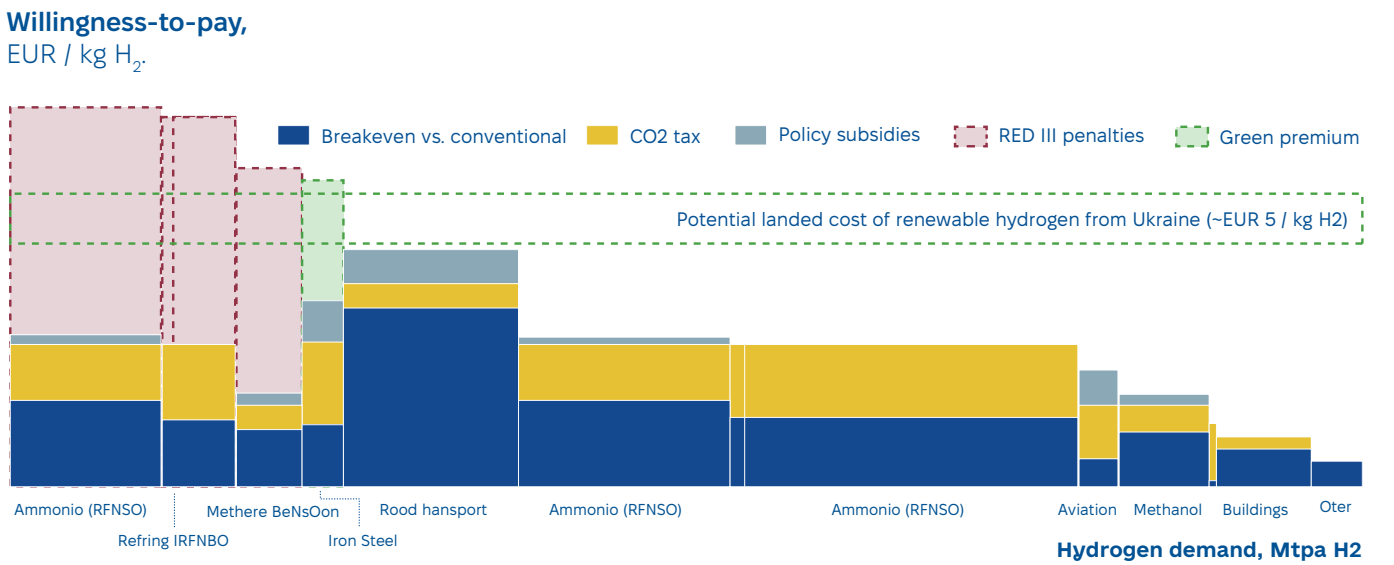
~14
million tonnes per year

Renewable hydrogen use in most end-use applications is expected to be significantly more expensive than conventional processes. To encourage decarbonization by increasing hydrogen penetration in various sectors, regulatory incentives are critical.
Hydrogen demand and willingness-to-pay for renewable hydrogen in Europe is expected to be driven by carbon tax (ETS / CBAM) and other regulatory incentives. Drivers of renewable hydrogen demand differ across specific hydrogen end-uses. Key sectors where high willingness-to-pay for renewable hydrogen could be expected include:

- **Industry.** Hydrogen use in industry (e.g., refining, chemicals and fertilizer industry) is subject to RFNBO (Renewable fuel of non-biological origin) mandate under RED II / III regulation (Renewable Energy Directive of European Parliament), which sets targets of 42% RFNBO use in industry by 2030 and 60% by 2035. The mandate is to be implemented by imposing penalties for non-compliant volumes, which could potentially increase willingness-to-pay for the mandated volume of renewable hydrogen in these sectors by EUR 3-7 / kg H2;
- **Iron and steel.** Renewable hydrogen use in green steelmaking (to produce direct reduced iron / hot briquetted iron for use in electric arc furnaces) could be associated with additional green premium, driven by decarbonization commitments in some steel end-use sectors (e.g., automotive);
- **Transport.** Hydrogen use for fuel production for transport (maritime, aviation and road transport) is subject to quotas under FuelEU, ReFuelEU and FuelEU Maritime regulations. Specific quotas and sub-quotas differ for various sectors, potentially driving renewable hydrogen demand of 1-5% of total fuel use. The penalties associated with these mandates could potentially increase willingness-to-pay for the mandated volume of renewable hydrogen in these sectors by EUR 3-8 / kg H2;
- **Power and heat.** In power and heat sector the cost of renewable hydrogen-based solutions is significantly higher than the cost of conventional fuel use (e.g., natural gas). However, industry commitments (e.g., Germany's Hydrogen Power Plan – Kraftwerksstrategie) as well as announced plans for a capacity mechanism to be established by 2028 could drive hydrogen demand in the sector. In particular, peak power capacity could generate demand for renewable hydrogen, as fuel costs for peak power production are a relatively small part of total system cost of ownership.

In these market segments characterized by higher willingness-to-pay (driven by regulatory incentives), up to ~1-2 million tonnes per year of renewable hydrogen demand could be expected by 2030[43]

Figure 3: Expected hydrogen demand and willingness-to-pay in Central Europe by 2030
(preliminary, more detailed analysis will be part of activities of Platform for Ukraine Hydrogen Export Corridor Project Development)



[43] Estimated hydrogen demand including total hydrogen demand in Germany. More detailed analysis of expected addressable demand volume will be part of activities of Platform for Ukraine Hydrogen Export Corridor Project Development

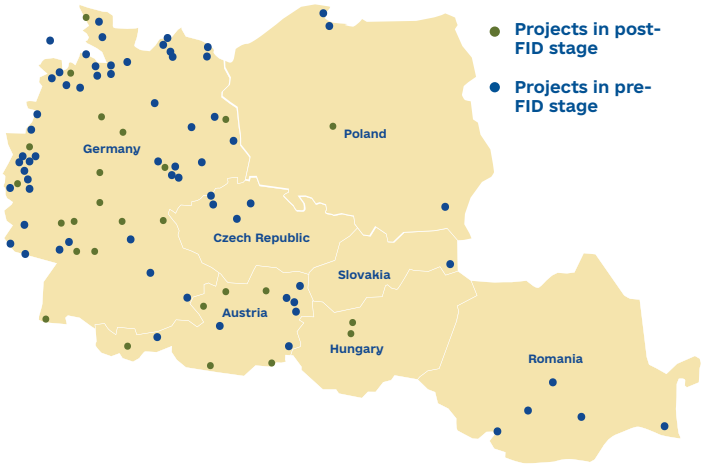
ANNOUNCED SUPPLY CAPACITIES

On the hydrogen supply side, >150 new hydrogen projects were announced in Central Europe. However, only ~40 pilot-scale projects with a total production capacity of ~50 thousand tonnes of hydrogen per year have passed FID.

Taking into account the probability of such projects reaching operation launch, projected hydrogen supply in Central Europe is not expected to be sufficient to cover demand.

Central Europe as a region is expected to become a net importer of hydrogen. However, separate countries (e.g., Romania) could become self-sufficient or even export low-carbon hydrogen to other European countries.

Figure 2: Announced hydrogen projects in Central Europe



ADDITIONAL VOLUMES REQUIRED TO CLOSE THE GAP

To close the gap, significant additional renewable energy and electrolyzer capacity is required. To meet an additional annual demand of 1 million tonnes of renewable hydrogen, significant increases in renewable energy and electrolyzer capacity are needed: ~50 TWh per year of renewable electricity, 7-10 GW of electrolyzer capacity, and 15-25 GW of renewable energy capacity.

This build-out would require **1,000 to 2,800 km²** of land

CHALLENGE FOR RENEWABLE HYDROGEN CAPACITY BUILD-OUT IN CENTRAL EUROPE

Extensive build-out in Central European countries faces multiple challenges, including high population density, land use concerns, and difficulties in finding suitable areas for onshore wind and solar power. Larger turbines may provoke stronger local opposition, and long permitting lead times and grid complexity further hinder renewable energy expansion.

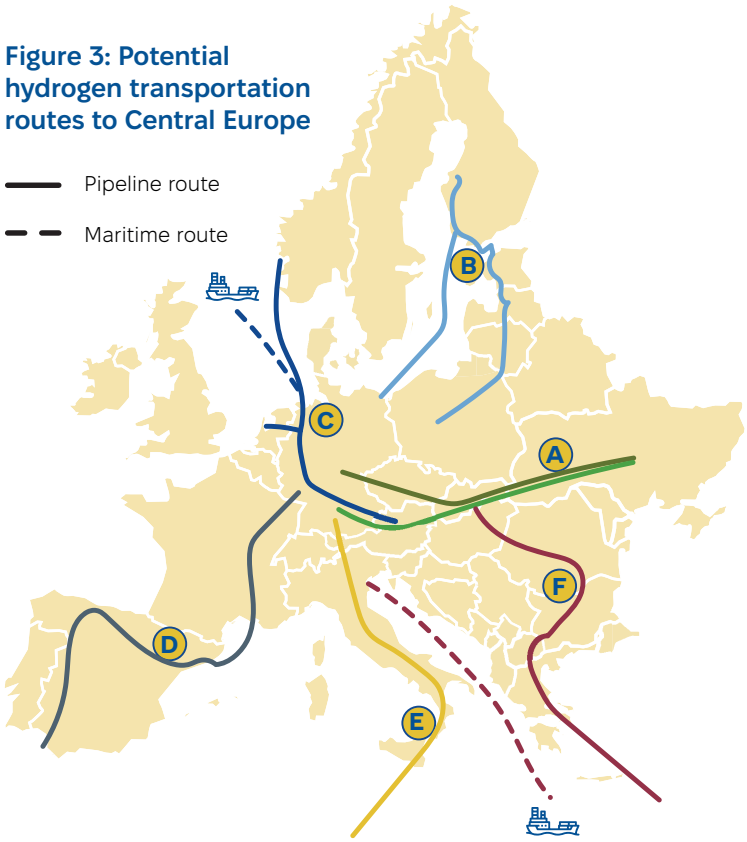
Considering the combined impact of these factors, Central Europe is expected to become a net importer of clean hydrogen.

HYDROGEN IMPORT OPPORTUNITIES

Central Europe could source a significant part of its hydrogen demand from its European neighbours, importing gaseous hydrogen by pipeline from countries with low gas prices or abundant hydro, wind, and solar power such as Norway, Portugal, Spain, Sweden, and Ukraine. The remaining hydrogen can be delivered by offshore pipeline or ship (liquified or in form of derivatives) from Middle East and North Africa, or by ship from Australia and North America.

While substantial part of hydrogen imports into Central Europe could be in the form of derivatives (ammonia, methanol, direct reduced iron), there will also be substantial demand for gaseous or liquidised hydrogen for direct use by Central European industry and power sector.

Figure 3: Potential hydrogen transportation routes to Central Europe



SIDEBAR: Overview of key potential routes for hydrogen imports into Central Europe

A. **Ukraine – Central Europe Hydrogen Corridors** are aimed at building-out infrastructure to transport renewable hydrogen from Ukraine to Central Europe.

Ukrainian gas transmission system operator is working together with transmission system operators of neighbouring countries to determine feasibility of repurposing gas pipelines for hydrogen transport.The most mature initiative on this route is Central European Hydrogen Corridor (CEHC) – an initiative of four gas transmission system operators (Gas TSO of Ukraine, eustream of Slovakia, NET4GAS of Czech Republic and OGE of Germany) to build-out hydrogen pipeline corridor to deliver ~1.5 million tonnes of hydrogen per year from Ukraine to Central Europe. The project is in pre-feasibility phase, with estimated commercial operation start by 2030. CEHC is part of the East and Southeastern corridor of European Hydrogen Backbone plan for pan-European hydrogen infrastructure build-out.

Another initiative on building-out hydrogen transportation corridor from Ukraine to Central Europe is H2EU + Store, which involves renewable energy producers, transmission system operators, gas storage operators and potential off-takers in Ukraine, Slovakia, Austria and Germany. The status of the initiative is unclear, as no updates have been made since 2021. H2EU + Store is mentioned in the European Hydrogen Backbone plan for pan-European hydrogen infrastructure build-out as a potential alternative to CEHC.

B. **Nordic-Baltic Hydrogen Corridor** connects the areas in Sweden and Finland, where low-cost hydrogen production is supported by favourable onshore and offshore wind resources, as well as high land and water availability, with demand clusters in Germany.

The Nordic-Baltic Hydrogen Corridor project was included in the PCI list as part of the "Baltic Energy Market Interconnection Plan for Hydrogen" (BEMIP Hydrogen) and was granted the status of the Project of Common Interest in the EU.

Pre-feasibility study for the project is expected to be completed by mid-2024.

Also, the Czech-German Hydrogen Interconnector (CGHI) is part of the 1st PCI / PMI list and enables hydrogen transport to demand centers in South Germany.

C. **North Sea Corridor** aims to enable hydrogen supply from high offshore wind potential areas in the North Sea to hydrogen demand areas in western parts of Germany. The corridor includes pipeline projects for transporting hydrogen from Nordic countries to Germany.

The Offshore hydrogen transport (H2T) project envisions development of a pipeline from Norway in close collaboration with the German and Norwegian government. On behalf of the German and Norwegian Governments, German Energy Agency and Gassco have conducted a feasibility study on a hydrogen value chain from Norway to Germany in 2023.

The Hydrogen Network Netherlands, which is a part of North Sea Corridor and could support transportation of hydrogen from Port of Rotterdam inland, has already taken FID. The construction of the Hydrogen Network Netherlands has started on 27th of October, 2023.

D. **Southwest Europe and North Africa Corridor** aims to transport hydrogen to demand centres in Germany and beyond, through the H2ercules project. Within this corridor, H2med is the overarching project connecting hydrogen networks in Portugal, Spain, France, and Germany. The project with the overall budget of EUR 2.50 billion aims to launch commissioning by 2030, with the target to transport ~2 million tonnes of renewable hydrogen per year.

E. **North Africa and Southern Europe** corridors are intended to deliver low-carbon hydrogen from North Africa and Southern Italy towards Central Europe. Overarching initiatives such as the SunsHyne Corridor and the SoutH2 Corridor combine multiple national projects into bigger alliances.

Major part of these routes will go through the Italian Hydrogen Backbone, consisting of approximately 2,300 kilometres of pipeline (of which 75% is to be repurposed).SoutH2 initiative is the most mature one on this route, aiming to transport up to 4 million tonnes of hydrogen per year, with planned operation start in 2030.

F. **East and Southeastern Corridor** enables the transport of hydrogen from Greece through Bulgaria, Romania, Hungary, Slovakia, Czech Republic and Austria to Central Europe. Projects already under development include the RO/HU H2 corridor and the HU/SK H2 corridor. Each of these projects is currently in the pre-feasibility phase and are all aiming to be operational in 2030. The gas TSOs of Greece, Bulgaria, Romania, Hungary, Slovakia, Czech Republic and Germany have initiated cooperation within the South-East European Hydrogen Corridor SEEHyC, which also plans to be operational in 2030.

4.4.2. Overview of hydrogen opportunity in Ukraine

UKRAINE'S POTENTIAL AS HYDROGEN SUPPLIER TO CENTRAL EUROPE

Ukraine is poised to become a key hydrogen supplier to Central Europe due to its abundant renewable energy resources and high potential to its further development, significant zero-carbon energy capacity from hydro and nuclear sources, competetive hydrogen production and transportation costs, and extensive natural gas pipeline network connected with the EU countries.

CURRENT STATE HYDROGEN IN UKRAINE

While there are no post-FID hydrogen projects in Ukraine, multiple companies have announced plans to develop hydrogen production. In summer 2020 DTEK became the first Ukrainian company to join the Hydrogen Europe association. Hydrogen Ukraine LLC announced two hydrogen valleys (H2U Hydrogen Valley Zakarpattia and H2U Hydrogen Valley Reni), which have been placed on the Mission Innovation Hydrogen Valley Platform. Eco-Optima co-founded the H2EU+Store project with Austrian gas storage operator RAG Austria, which aims to build-out a hydrogen corridor to export renewable hydrogen produced in Ukraine to consumers in Europe. Ukrainian state-owned hydropower operator Ukrhydroenergo signed a memorandum with German technology company Andritz Hydro on cooperation in the implementation of green hydrogen production projects. Other companies with announced hydrogen projects include UDP Renewables and Zakhidnadraservis.

RENEWABLE ENERGY POTENTIAL

Hydrogen production becomes feasible and economically viable due to the availability of renewable energy sources, its favourable geography and high potential for further expansion (wind power potential capacity ranges from 250 GW to 320 GW, while solar power potential could reach up to 70 GW). Even during the full-scale war, Ukraine has commissioned more than 700 MW of additional renewable energy capacity, including solar, wind and biogas power plants. For more information, please refer to paragraph 4.3. "Energy".

Ukraine's favourable onshore wind resource is concentrated in the southern part of the country (e.g., Odesa, Kherson, Mykolaiv and Zaporizhzhia regions). Existing projects in these regions reach ~40% capacity factors. Regions in the north-western part of the country (e.g., Volyn) also exhibit high theoretical wind energy potential, with several projects in development, but only few operational projects in these regions.

While Ukraine's solar energy potential is not extraordinary, with capacity factors of existing projects averaging around ~15%, solar energy generation profiles could be complementary to onshore wind profiles. This could allow to hybridize renewable energy projects, in particular, in the southern part of the country, and ensure higher electrolyzer capacity utilisation, ultimately decreasing hydrogen production costs.

Another factor in favour of renewable energy development in Ukraine is significant land availability. Ukraine has the largest land mass among European countries. Meanwhile, the country's population before the war was 5th largest in Europe, resulting in relatively low population density. Additionally, there is little "Not in My Backyard" attitude among local communities. This could allow to build out large-scale renewable energy projects for hydrogen production.

EXISTING ZERO-CARBON ENERGY CAPACITY

In the transition period, while renewable energy capacity is ramping up, at-scale production of clean hydrogen could be supported by Ukraine's extensive existing nuclear power capacity. Ukraine's nuclear power plants could receive approval for lifetime prolongation, following some investment into maintenance of blocks. This could potentially extend the weighted average remaining lifetime of Ukraine's nuclear power plants to until 2050.

Historically, Ukrainian nuclear power plants exhibited comparatively low capacity utilisation factors: **63-75%** compared to **75-90%** capacity utilisation in neighbouring countries using similar technology (Czech Republic, Hungary, Slovakia). Increase in capacity utilisation through optimization of planning and implementation of less restrictive maintenance protocols could enable substantial additional nuclear power generation in Ukraine.

IMPLICATIONS FOR HYDROGEN PRODUCTION COSTS

Estimated levelized cost of electricity production (LCOE) for new renewable energy projects in Ukraine could be in the range of

EUR 35-45 / MWh for solar PV projects[44]

EUR 30-40 / MWh for onshore wind[45] projects

For existing nuclear power capacity (assuming lifetime prolongation), LCOE could be in the range of **EUR 20-35** / MWh[46].

This could enable renewable hydrogen production cost (LCOH) of **~EUR 4-4.5** / kg H2[47], which is highly competitive in the European market

DEVELOPED GAS TRANSMISSION SYSTEM

Delivery of renewable hydrogen produced in Ukraine to Central European industrial hubs could be enabled using Ukraine's extensive gas transportation system. Ukraine's natural gas transmission system (GTS) consists of ~39 thousand kilometres of pipelines, 72 compression stations and 13 storage facilities with a total capacity of over 30 billion m³ of underground storage (with 80% of storage capacity located near borders with Central European countries). It is connected with systems of Slovakia, Poland, Romania, Moldova, and Hungary, and possesses export capacity to Europe of ~147 billion m³ per year.

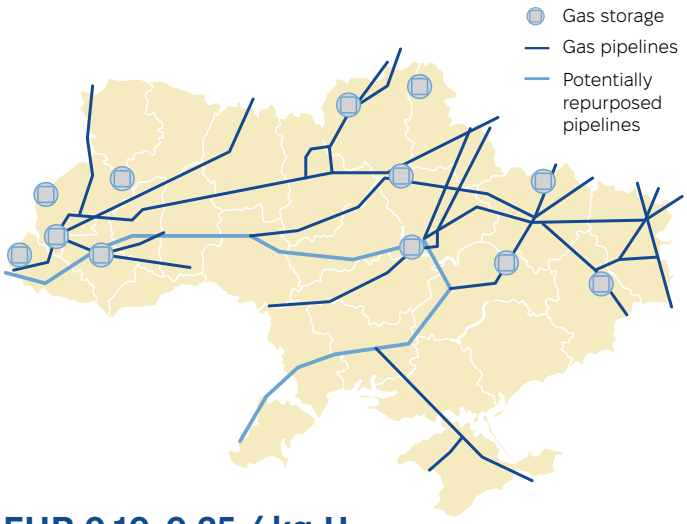
Historically, a significant part of GTS capacity was used for natural gas transit from Russia to European countries. However, following build-out of alternative gas transit routes (South Stream, North Stream I), utiliiation of GTS significantly decreased. Furthermore, following Russia's military invasion of Ukraine and resulting response from European states, including limitations on natural gas imports from Russia, transit of natural gas through Ukraine's territory decreased further (only 14.4 billion m³ in 2023). The current five-year deal with Russia's Gazprom on transit of Russian gas to Europe expires at the end of 2024; the Ukrainian side has no intentions to prolong it or sign a new deal.

This opens possibilities for repurposing some of the existing pipelines for hydrogen transport. Several large pipelines could be considered for repurposing to transport blended or pure hydrogen to Central Europe, for example:

- Urengoy–Pomary–Uzhhorod pipeline exiting Ukraine on the border with Slovakia, length of the Ukrainian section is 1,160 km and it has capacity of 29.7 billion m³ per year;
- Progress pipeline running mostly parallel to the Urengoy–Pomary–Uzhhorod pipeline, length of the Ukrainian section is 1,120 km and it has capacity of 28.5 billion m³ per year;
- Ananyiv–Tiraspol–Izmail pipeline exiting Ukraine on the border with Romania, its length is 256 km and it has capacity of 23.7 billion m³ per year.

Additionally, existing pipeline routes in Ukraine could be used to place new hydrogen pipelines, leveraging existing land use rights (right of way).

Figure 4: Ukraine's gas transmission and storage system



EUR 0.10-0.25 / kg H_2.

the range of the cost of hydrogen transportation from Ukraine to Central Europe using repurposed natural gas pipelines, according to the estimates of gas transmission system operators

This could enable highly competitive landed cost of Ukrainian renewable hydrogen in Central Europe, with the region's land-locked position presenting a significant challenge for alternative hydrogen delivery routes.

Repurposing of natural gas pipelines for pure hydrogen transport has been extensively studied in the context of planned projects. European Hydrogen Backbone, an initiative of European gas transmission system operators, assesses costs of retrofit of large-diameter onshore hydrogen pipelines for pure hydrogen transport as ~EUR 0.88 million per kilometre of pipeline, with additional cost for retrofit of compressors of ~EUR 4 million per MW.

[44] Assuming 1-axis tracking, 19-21% capacity factor, CapEx of ~USD 0.6 k / kW, OpEx of ~2% of CapEx per year, WACC of 8%
[45] Assuming Vestas 136 4000 MW turbines at 120 m hub height, 35-42% capacity factor, CapEx of ~USD 1.3 k / kW, OpEx of ~1.3% of CapEx per year, WACC of 8%
[46] Assuming 85% capacity utilisation, CapEx required to prolong block lifetime of ~USD 0.3 k / kW, variable OpEx of USD 17 / MWh electricity, decommissioning cost of USD 350-1,100 / kW, WACC of 5-10%
[47] Assuming large Alkaline electrolyzer technology, 50-61% onshore wind and 39-50% solar PV in the energy mix, 2.4-2.8 renewable energy to electrolyzer capacity oversizing, 67-74% capacity utilisation, CapEx of ~USD 1.3 k / kW, OpEx of ~3% of CapEx per year, WACC of 8%

SIDEBAR: Key projects on repurposing of natural gas pipelines for hydrogen transport

Parmelia Gas Pipeline conversion project. Australian project conducted by APA Group, aimed at converting a 43 km section of the Parmelia Gas Pipeline to carry 100% hydrogen. Testing results indicate it is technically feasible, safe and efficient to run the section of pipeline at current operating pressure using hydrogen. The project is progressing to phase three, which will consider preparing the section of pipeline for hydrogen service, and will include detailed safety studies and conversion plans, while continuing to investigate potential supply and offtake opportunities.

Snam gas pipeline network. Italian gas transmission system operator Snam announces that ~99% of their network (~33 k km) is ready for 100% hydrogen transport. Up to 70% hydrogen blended with natural gas could be transported with no or limited reductions on max operating pressure. Snam conducted field tests with hydrogen and natural gas blending mix of up to 10% hydrogen on key gas turbines.

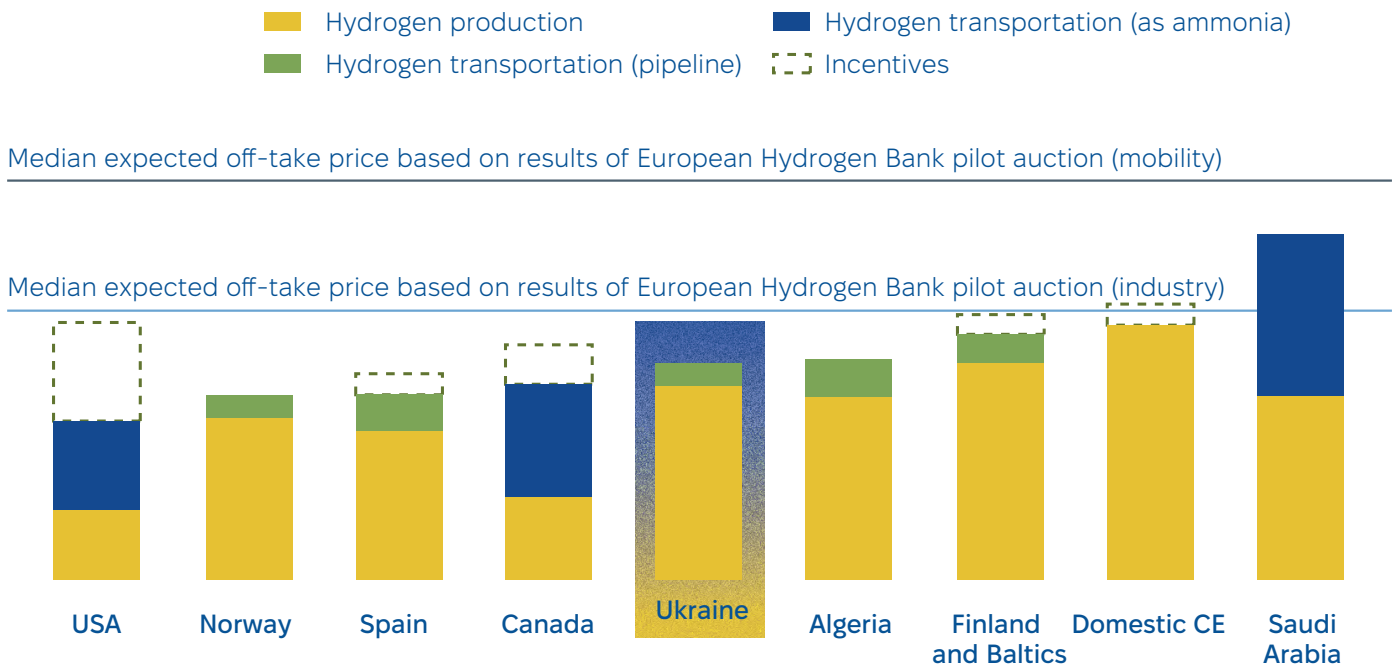
Hydrogen Network Netherlands. Dutch transmission system operator Nederlandse Gasunie has taken FID on the project to develop a national hydrogen network in the Netherlands. Over 1,000 km of pipelines are planned to be repurposed for hydrogen transport (~85% of the total pipeline network planned under project).

Emsburen-Bad Bentheim-Legden pipeline section retrofit (part of GET H2 Nucleus project). German gas grid operator Open Grid Europe (OGE) and Nowega have launched the first conversion of natural gas pipeline to transport hydrogen. The 46 km pipeline sections were detached from the natural gas network in October 2023, paving the way for hydrogen transport upgrading. First renewable hydrogen flow through the pipeline is expected in 2025.

Damao-Industrial Zone Hydrogen Pipeline Project. Chinese project by PetroChina China Petroleum and Natural Gas Pipeline Engineering Co., Ltd. to retrofit ~159 km of gas pipeline for pure hydrogen transport. The project was completed in March 2022, with potential to transport ~0.4 million tonnes of hydrogen per year.

Figure 5: Landed cost of renewable hydrogen, EUR / kg H_2

(preliminary, more detailed analysis will be part of activities of Platform for Ukraine Hydrogen Export Corridor Project Development)



STRATEGIC ROLE OF UKRAINE AS HYDROGEN SUPPLIER TO EUROPE

The European Union recognizes the potential for hydrogen production in Ukraine. EU's Hydrogen Strategy adopted on July 8th, 2020, designates Ukraine as a priority partner. European industry association Hydrogen Europe announced its 2x40 GW Green Hydrogen Initiative in 2020, which includes plans for 10 GW of hydrogen production capacity in Ukraine for export to the EU. Memorandum of understanding between EU and Ukraine on a Strategic Partnership on Biomethane, Hydrogen and other Synthetic Gases, signed at the beginning of 2023, sets out the common goal of Ukraine and EU to accelerate deployment and use of renewable energy sources and increase energy security of the region.

GTSOU is part of European Hydrogen Backbone – an initiative of infrastructure operators, which aims to enable the development of a competitive, liquid, pan-European renewable and low-carbon hydrogen market by building-out pipeline and storage system for hydrogen transport.

HYDROGEN STRATEGY OF UKRAINE

Hydrogen Strategy of Ukraine developed in consultation with European experts sets out a goal to produce

0.4-0.6 /Mtpa hydrogen by 2035

and

1.65-2.5 /Mtpa hydrogen by 2050

Targets for domestic consumption of hydrogen are 0.1-0.2 Mtpa by 2035 and 1.0-1.5 Mtpa by 2050, depending on internal demand. Meanwhile, targets for hydrogen export are 0.3-0.4 Mtpa by 2035 and 1.5-2.0 Mtpa by 2050, depending on importers' demand. Key target market stated in the Strategy – the EU.

To enable this level of hydrogen production, targets for capacity build out have been set:

- Electrolyzer capacity: no less than 3 GW by 2035 and no less than 10 GW by 2050
- Wind capacity: no less than 5 GW by 2035 and no less than 20 GW by 2050
- Solar capacity: no less than 2 GW by 2035 and no less than 5 GW by 2050

Realisation of the Strategy is planned in 3 Phases:

- Phase 1 (2024-2026): Creation of pre-requisite conditions for build-out of hydrogen economy in Ukraine, including development of necessary regulatory base
- Phase 2 (2027-2035): Establishment of hydrogen industry, including realisation of pilot projects for hydrogen production and export
- Phase 3 (2036-2050): Sustainable development of hydrogen industry, including at-scale hydrogen production and export

4.4.3. Opportunity overview

Ukraine's favourable positioning as well as the ongoing momentum in the market present an attractive opportunity for investment into renewable hydrogen production and infrastructure development in the country. Following is the description of what a potential investment project could look like.

PRODUCTION CAPACITIES SITING AND DELIVERY ROUTE

Renewable electricity and hydrogen production could be located in southern and central parts of Ukraine (e.g., Odesa, Mykolaiv, Kherson, Kirovograd, Dnipro and Zaporizhzhia regions), which combine relatively favourable renewable energy resources and access to natural gas transportation network. Multiple large-scale renewable hydrogen projects may be required to produce sufficient volumes of hydrogen export to ensure optimal pipeline utilisation. Delivery of produced hydrogen to the central export pipeline could be accomplished by repurposing regional pipelines or building new pipelines for hydrogen transport.

A part of a single line **(1,400 mm diameter)** of the Urengoy–Pomary–Uzhhorod pipeline **(~750 km)** could be repurposed for pure hydrogen transport. This pipeline further connects to Uzhgorod–Velke Kapusany pipeline **(1,400 mm diameter, 14.5 km)**, with further transport on Slovakia's territory going to either Lanzhot exit point on the border between Slovakia and Czech Republic or Baumgarten exit point on the border between Slovakia and Austria **(1,400 mm or 1,200 mm diameter, 400-450 km pipeline length for either route).**

PRODUCTION CAPACITIES AND VOLUMES

Total renewable hydrogen production volume could be **~ 1.5 /mln tonns**

This would close the gap between expected hydrogen demand and local production in Central Europe and ensure sufficient utilisation (~50%) for a large-diameter pipeline. This scale of production would require 10-15 GW electrolyzer capacity and 20-40 GW onshore wind and solar capacity build-out.

PROJECT ECONOMICS

The project could deliver ~1.5 million tonnes per year of renewable hydrogen to Central Europe by 2030 at the landed cost of

~EUR 5 /per kg H_2

At an expected market price of renewable hydrogen in Central Europe (set by regulation-driven willingness-to-pay), the project could achieve an IRR of 10-20%, which makes it a highly attractive investment opportunity.

4.4.4. Required unlocks to realise the opportunities

Technical feasibility assessment

A major consideration for potential investors is the technical feasibility of at-scale renewable hydrogen production in Ukraine and its delivery to Central Europe. Feasibility studies are required to evaluate project viability.

Renewable energy and hydrogen production
Renewable electricity generation and production of hydrogen through water electrolysis are proven technologies with known efficiency parameters. Technical feasibility analysis for renewable hydrogen production in Ukraine should focus on investigation of renewable energy generation potential at various locations in Ukraine (wind and solar capacity factors, potential electrolyzer capacity utilisation, etc.). Potential costs of production of renewable hydrogen need to be estimated to analyse the economic viability of the project.

Repurposing natural gas pipeline for hydrogen transport
Technical feasibility of natural gas pipeline retrofit to transport hydrogen needs to be extensively studied. While several projects on repurposing of natural gas pipelines for hydrogen transport have been successfully implemented, applicability of such cases to Ukrainian pipelines is not certain. Technical feasibility study should focus on defining key infrastructure requirements and target operating parameters for blended or pure hydrogen transport. Such parameters could include identification of required coating of pipelines (to avoid hydrogen embrittlement effect), required operating pressure and implied compression parameters, evaluation of leakage and combustion risks as well as estimation of gas losses in transport.

Hydrogen storage
Technical and economic feasibility studies are required to assess possibility of at-scale hydrogen storage on Ukrainian territory at reasonable cost (e.g., hydrogen storage in depleted natural gas fields and / or salt caverns, repurposing of underground natural gas storage to store blended or pure hydrogen, pipeline packing, etc.).

Economic feasibility and financing requirements

Economic feasibility study
Economic feasibility study is needed to assess potential demand for hydrogen in Central Europe and competitiveness of Ukrainian hydrogen in the European market. Further investigation is required to determine potential off-takers' requirements to the product (e.g., blended vs. pure hydrogen, renewable vs. zero-carbon hydrogen, documentation required to prove hydrogen origin, etc.)

Financing need

Investment requirements of the project could be separated into two main stages:

- Project preparation finance (pre-FID);
- Capital investment (post-FID).

Project preparation costs vary for different parts of the value chain. For renewable energy projects, pre-FID financing could be in the range of USD 2-4 million per GW installed capacity. For electrolyzer build-out, project preparation costs could be in the range of USD 6-10 million per GW electrolyzer capacity. Financing needed for preparation of gas pipeline conversion for hydrogen transport is yet to be determined. Feasibility study costs were estimated at USD 3-4 million. Total pre-FID financing needed for a project to deliver 1.5 million tonnes of renewable hydrogen produced in Ukraine to Central Europe could amount to USD 103-315 million.

Post-FID capital investment need for such project could be in the range of USD 32-66 billion, including:

- USD 17-44 billion for renewable energy capacity build-out;
- USD 13-19 billion for electrolyzer capacity build-out;
- USD 2-3 billion for pipeline retrofit for pure hydrogen transport (including ~USD 1 billion for pipeline retrofit on Ukrainian territory).

Potential sources of finance

The proposed project will likely require financing from both commercial and international financial institutions (IFIs). The participation of public organisations will be vital for securing capital at non-prohibitive interest rates and crowding-in private capital. IFIs will have a vital role to play in providing risk mitigation and blended finance instruments, as well as technical assistance. National development financial institutions (DFIs) and export credit agencies (ECAs) can also play an important role in providing additional capital. A syndicate of private banks will be required to provide commercial financing, led by a major international project finance specialist organisation.

A range of financial support mechanisms from public organisations can be used to reduce project risks. Grant funding is available across multiple IFIs during the ongoing war for the project preparation stage.

Various IFIs have proposed equity, debt, guarantees and insurance mechanisms available specifically for Ukraine that could be applied to the proposed project and help to de-risk investment. The EU Ukraine Facility Pillar II is set to unlock a further EUR 7 billion for the provision of guarantees to mobilise investment into reconstruction efforts, substantially increasing availability of financing, including for the renewable energy sector.

The following conditions must be met to secure post-FID financing:

- Stable geo-political situation (however, some investments could be considered even before the end of the war);
- Reputable project sponsor(s) with a strong balance sheet and proven track record, able to cover substantial equity tickets and provide completion guarantees;
- Firm commitments for long-term off-take from multiple potential customers, accounting for a substantial part of planned hydrogen production (>70%).

Potential sources of finance

To implement a large-scale hydrogen production and export project in Ukraine, coordinated effort of industrial and infrastructure companies across the entire value chain is required. Alignment between up-stream (renewable energy and hydrogen production), mid-stream (hydrogen transportation) and down-stream (potential hydrogen off-takers in Central Europe) players could help resolve the "chicken-and-egg» dilemma typical for such projects.

The cooperation between players across the renewable hydrogen value chain could take the form of a platform for project preparation and development, leading up to creation of a consortium of industrial and infrastructure companies. Cooperation agreements with increasing degree of commitment (e.g., Letters-of-Intent, Memoranda-of-Understanding, etc.) could be concluded between platform participants at each stage of project development.

The financial structure of the proposed green hydrogen project in Ukraine could take several forms depending on the prevailing conditions at the time of FID and will necessarily be a tailor-made arrangement between the parties involved. The leading project sponsor(s) or a consortium across the value chain will need to establish a local special purpose vehicle to raise equity and debt for the capital investment requirements of the project. Financing will require sequential tranches of debt and / or grace periods until revenues are generated.

Regulatory alignment and reforms

To support the build-out and operation of hydrogen production and transportation projects in Ukraine, a number of regulatory changes are required.

Renewable energy generation

Key required reforms to support renewable energy build-out in Ukraine include:

- Ensuring functioning of PPA system;
- Implementation of certificates of green origin for renewable electricity;
- Streamlining of process to obtain land rights, permits and grid connection for renewables projects.

On 24 July 2023, President of Ukraine signed Law No.3220-IX "On Amendments to Some Laws of Ukraine Regarding the Restoration and Green Transformation of the Energy System of Ukraine". This law has potential to address a substantial part of required regulatory reforms to facilitate renewable energy build-out in Ukraine. The law's effective implementation is key to enabling future renewable energy projects.

This law establishes a possibility for renewable energy producers to conclude an agreement with a counterparty on ensuring stability of the price of electricity produced from renewable energy sources (so called "Contract for Difference" or CFD). The parties may fix reference price in CFD and possible fluctuations thereof.

The law is expected to achieve substantial progress towards eliminating regulatory barriers for PPAs (Power Purchase Agreements) implementation for renewable electricity.

The law also establishes a notion of Guarantee of Origin (GoO) for electricity produced from renewable energy sources. Ownership title to GoO can be transferred separately from that of the underlying electricity. According to the law, GoO will be provided by virtue of the registry.

On 10 June 2023, Ukrainian Parliament adopted the Law of Ukraine «On Amendments to Certain Laws of Ukraine on Prevention of Abuse in Wholesale Energy Markets». The Law implements EU Regulation on Wholesale Energy Market Integrity and Transparency (REMIT), a set of European rules and practices aimed at preventing abuse in the energy market, into national legislation.

Hydrogen production, transportation and use

Dedicated regulation governing hydrogen production, transmission and distribution, and use in Ukraine is required, including alignment with the EU standards and regulations.

To enable pipeline transport of hydrogen, Ukrainian regulatory framework for gas transportation has to be adapted for hydrogen transportation. In particular, regulation on injection of hydrogen into natural gas transmission system (in pure or blended form) is needed. Process for obtaining gas grid connection should be established for hydrogen production projects. Moreover, synchronisation of regulation of transit (Slovakia, Czech Republic, Poland, Moldova) and destination (Austria, Germany, Romania) countries is needed. Operations of transmission system operators in these countries also need to be aligned.

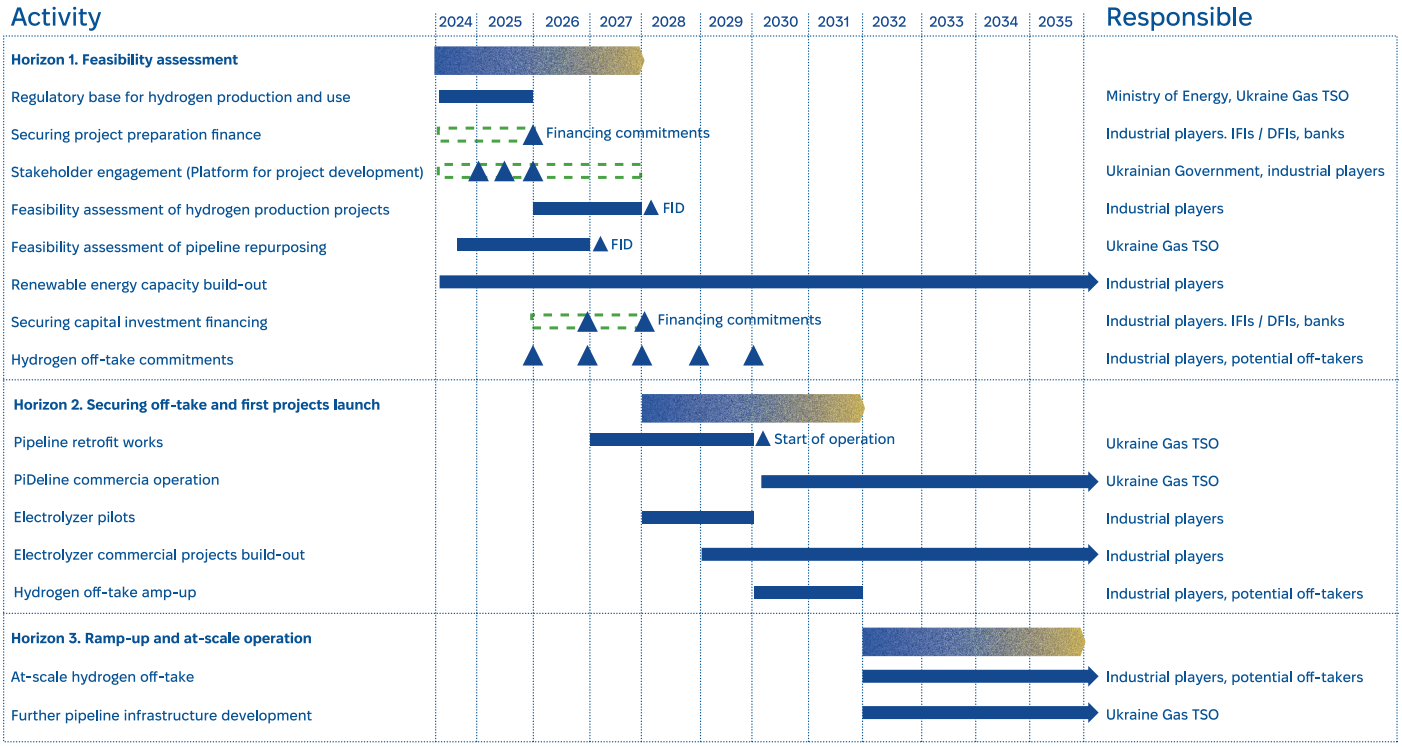
Ukrainian government is currently working on the development of new legislation under guidance of European advisors. At the end of 2019, the department responsible for the implementation of low carbon hydrogen technologies in Ukraine was established within the Ministry of Energy and Environmental Protection.

In June 2020, a working group was created within the National Security and Defense Council of Ukraine to discuss the possibility of a hydrogen economy. Furthermore, at the end of July 2020 a scientific-technical council, "Hydrogen Energy", was created within the Ministry of Energy. In 2018, the first industry association aimed at the promotion of low carbon hydrogen energy, the Ukrainian Hydrogen Council, was established in Ukraine.

ROADMAP FOR DEVELOPMENT

Build-out of renewable hydrogen production in Ukraine and export to Europe can be accomplished in stages. While gradual ramp-up of volumes is complicated due to the need to ensure sufficient gas pipeline utilisation, some strategies are available for transition period before renewable energy capacity and off-take reaches the necessary scale, including hydrogen blending with natural gas or production and export of clean hydrogen produced from nuclear power.

Preliminary high-level timeline for Ukraine Hydrogen Export Corridor project implementation



At-scale production of renewable hydrogen in Ukraine will create new jobs and economic opportunities in the country, while also reducing dependence on imported fossil fuels. At the same time, Central Europe will benefit from a reliable and sustainable source of energy, which will help to reduce greenhouse gas emissions and improve air quality. This shift towards renewable hydrogen will also help to strengthen economic ties between Ukraine and Central Europe, creating a more stable and prosperous region overall.

HYDROGEN

Highlighted investment projects

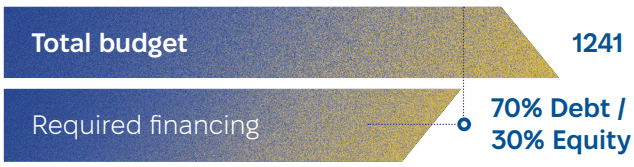
UDPR LLC

WEST UKRAINE GREEN HYDROGEN / AMMONIA VALLEY

VOLYN REGION

- **Brief Description:** providing a combination of infrastructure and resources for renewable H2 / NH3 and derivatives production in the western part of Ukraine, adjacent to existing gas pipeline networks, railways and the Western Bug River.
- **Target Market:** local market, European Union countries.
- **Products/Services:** Renewable hydrogen / ammonia production.
- **Technologies and Innovations:** Renewable hydrogen / ammonia production infrastructure.
- **Unique Selling Proposition**: Ukraine's leading investment and development company with running portfolio in photovoltaic energy (150 MW) in a partnership with E-Group, Acciona Energia and Nebras Power and vast development pipeline in wind energy (0.5 GW)
- **Project Status:** Feasibility study/pre-feasibility study.

Projects Highlights[1] ($ mln)



Type of financing – Private.

Financing structure: CAPEX – 98% / OPEX – 2%

Expected Financial Indicators:

- NPV – 875
- DPP (months) – 132
- Revenue – 238 (annually)
- IRR – 14% (up to 20%)
- Project launch period – 2026
- EBITDA – 198 (annually)

BUSINESS MODEL

Production of renewable hydrogen and ammonia for local consumption and export to European countries.

Key partners

International donors: financing, procurement of equipment and delivery to Ukraine

Key Points of Project Implementation:

Q1 2024	Q4 2024	2025
Pre-Feasibility study ready	Business Plan and Business Case ready	Fund attraction and partnership structuring

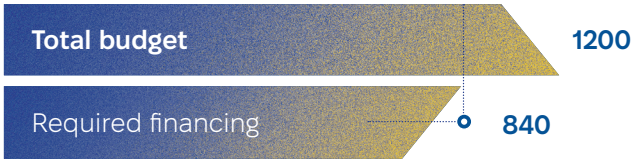
UDPR LLC

WEST UKRAINE RENEWABLE HYDROGEN VALLEY

VOLYN REGION

- **Brief Description:** Construction of a complex plant to produce ecologically clean hydrogen in Western Ukraine, which will annually produce 35,000 tonnes of hydrogen or 250,000 tonnes of "green" ammonia.
- **Target Market:** EU countries, including Germany, Poland, Slovakia and the Czech Republic.
- **Products/Services:** 35 thousand tons of hydrogen or 250 thousand tonnes of "green" ammonia.
- **Technologies and Innovations:** Complex plant to produce ecologically clean hydrogen.
- **Unique Selling Proposition**: Strong developer company track record / advantageous location on the border with the EU. Powerful solar and wind potential. Exit to the West Bug River and Baltic Sea through the Visla River.

Projects Highlights[1] ($ mln)



Type of financing – Equity financing.

Expected Financial Indicators:

- DPP (months) – 60-108
- IRR – 12-20%
- Project launch period – 2025-2026

- **Project Status:** Feasibility study / pre-feasibility study.

BUSINESS MODEL

Production of renewable hydrogen for export to Central European countries.

1 - The project information and financial indicators are provided by company-initiator of the project.

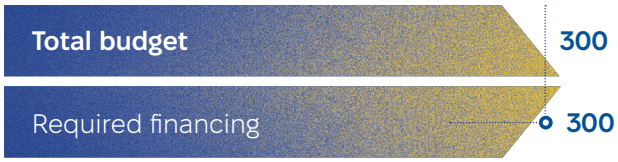
HYDROGEN UKRAINE, LLC

H_2U HYDROGEN VALLEY ZAKARPATTIA

ZAKARPATTIA REGION

- **Brief Description:** Creation of a small-scale local hydrogen value chain, with further stages including large-scale production of renewable hydrogen with a capacity from 100 MW to 1.5 GW, aiming for hydrogen supply to European consumers.
- **Target Market:** Ukrainian and Central European industry. USS Kosice steel plant is a potential off-taker.
- **Products/Services:** Renewable hydrogen production.
- **Technologies and Innovations:** Renewable hydrogen production infrastructure.
- **Unique Selling Proposition**: Hydrogen production to be built-out in proximity to electricity transmission and gas transmission infrastructure with access to water resource. This project is part of Slovak-Ukrainian hydrogen valley.

Projects Highlights[1] ($ mln)



Type of financing – Private.

Expected Financial Indicators:

- Project launch period – 2028

- **Project Status:** pre-feasibility study. The project is awaiting approval for funding, and a development schedule for the feasibility study will be established in September 2024.

BUSINESS MODEL

Production of renewable hydrogen for export to Central European countries.

Key partners

USS Kosice

Key Points of Project Implementation:

2022	2028
start of project development	project finalization

1 - The project information and financial indicators are provided by company-initiator of the project.

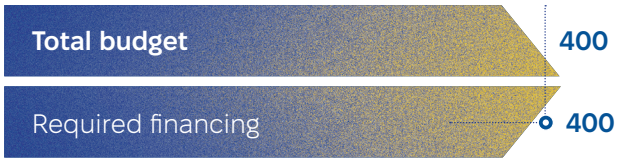
HYDROGEN UKRAINE, LLC

H_2U HYDROGEN VALLEY RENI

VOLYN REGION

- **Brief Description:** Project is dedicated to producing renewable hydrogen. Potentially three Phases are planned with 100 MW, 200 MW, and 3,000 MW installed electrolyzer capacity.
- **Target Market:** Ukrainian and Central European industry. Export plan involves hydrogen pipeline transport, or compressed gaseous hydrogen transported through barges up the Danube River.
- **Products/Services:** Renewable hydrogen production.
- **Technologies and Innovations:** Renewable hydrogen production infrastructure.
- **Unique Selling Proposition**: A land plot for the 200 MW electrolysis plant is registered and prepared following the Pre-FEED Design. Project received grant funding from the InnovateUkraine competition funded by UK International Development and hosted by the British Embassy Kyiv.

Projects Highlights[1] ($ mln)



Type of financing – Equity financing.

Expected Financial Indicators:

- Project launch period – 2027

- **Project Status:** Feasibility study. Financial indicators will be available after the completion of the feasibility study in February 2025.

BUSINESS MODEL

Production of renewable hydrogen for export to Central European countries.

Key Points of Project Implementation:

2024	2025 - 2026	2027
feasibility study and design & engineering work	permitting, delivery of equipment, construction and installation	commissioning of the facility and scaling-up of production

1 - The project information and financial indicators are provided by company-initiator of the project.

HYDROGEN

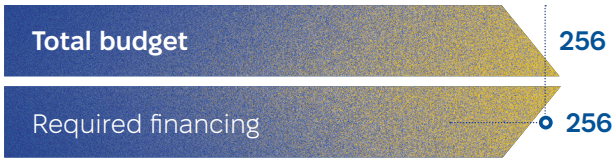
ZAKHIDNADRASERVIS, LLC

YAVORIV GREEN HYDROGEN PROJECT

LVIV REGION

- **Brief Description:** The project is aimed at construction of a 100 MW electrolysis facility in Western Ukraine that would produce ~12 ktpa of clean hydrogen. The facility would be powered by adjacent RES capacities, with possibility for grid power supply. To be transported by repurposed Uzhgorod-Dolyna gas pipeline and ~40.
- **Target Market:** Ukrainian and Central European industry. Supplied in a mix with natural gas (~5% hydrogen) to the EU through the pipeline network.
- **Products/Services:** Renewable hydrogen production.
- **Technologies and Innovations:** RRenewable hydrogen production infrastructure (electrolysis), hydrogen pipelines (repurposing existing and 40 km new pipeline).
- **Unique Selling Proposition**: Immediate proximity to the strategic Urengoy-Uzhgorod-Bratislava gas pipeline and Western border, strong logistical cost advantage. Sponsor might contribute the project land plot and its operational ~72 MW Yavoriv-1 solar plant.

Projects Highlights[1] ($ mln)



Type of financing – Private.

Expected Financial Indicators:

- IRR – 6-14%
- DPP (months) – 144
- Project launch period – 2027
- Revenue – 89 (year 4 after FID)
- EBITDA – 36 (year 4 after FID)

- **Project Status:** Feasibility study / pre-feasibility study.

BUSINESS MODEL

Production of renewable hydrogen for export to Central European countries.

Sponsor financial highlights[1].

$131 mln	$21 mln	16%
Revenues (2024)	EBITDA (2025)	EBITDA Margin (2026)

Key Points of Project Implementation:

- Land use and grid connection permits received.
- Pre-feasibility Q1 24
- Feasibility Q3 24
- Construction start Q1 25
- Launch Q3 26

1. Data is from readily available Ukrainian financial information.