Energy Dialogue
Germany – Central Asia

H2-diplo
DECARBONIZATION DIPLOMACY

Case Study:

Kazakhstan on the Way to Green H_2 Ramp-Up

dena

Published by

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH
Registered offices
Bonn and Eschborn
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Publication date
July 2025

This study has been made possible through the collaboration of H_2-diplo and the German Energy Agency (dena). H_2-diplo is implemented by GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH) on behalf of the German Federal Foreign Office and is financed by the International Climate Initiative (Internationale Klimaschutzinitiative, IKI).
dena is implementing the Energy Dialogue between Germany and Kazakhstan on behalf of the Federal Ministry for Economic Affairs and Energy (BMWE). The opinions and recommendations expressed do not necessarily reflect the positions of the commissioning institutions or the implementing agency.

Executive summary

Kazakhstan's energy system presents significant potential for renewable energy development and green hydrogen production. The country boasts substantial wind energy capacity of 1,820 billion kWh per year and solar potential of 2.5 billion kWh per year. Vast territories and favourable natural conditions, particularly in regions like Zhetisu, Almaty, Atyrau and Mangistau, create optimal conditions for large-scale renewable energy projects. This abundance of resources positions Kazakhstan as a potentially competitive green hydrogen producer, with estimated costs of $3.94–$5.52/kg by 2030. Despite this potential, Kazakhstan currently has very limited hydrogen production, primarily consisting of 'unabated' or grey hydrogen used in the country's three refineries (Atyrau, Pavlodar and Shymkent) and as feedstock for ammonia production in the fertiliser industry.

This study primarily focuses on green hydrogen (produced through electrolysis powered by renewable energy) as the centrepiece of Kazakhstan's hydrogen strategy. Unless otherwise specified, all references to 'hydrogen' throughout this document refer to green hydrogen. When other hydrogen types are discussed (such as blue hydrogen produced from natural gas with carbon capture), they are explicitly labelled as such.

The study analyses Kazakhstan's potential as a green hydrogen producer and exporter to European markets while addressing legal, financial and infrastructure barriers. It examines how local financing instruments can be complemented by German and EU mechanisms to implement recommendations for regulatory reform, infrastructure development and the institutional coordination needed to build sustainable hydrogen export capabilities.

While Kazakhstan's renewable energy resources provide a strong foundation for green hydrogen development, the country remains in the early stages of implementation. Kazakhstan's early adoption of renewable energy initiatives and its commitment to hydrogen development create a strategic advantage in the global market. However, current green hydrogen capabilities are minimal, with only one experimental alkaline electrolyser unit in the entire country. The most significant green hydrogen initiative currently underway is the Hyrasia One project (by Svevind), which aims to produce up to 3,465 kilotonnes of hydrogen annually by leveraging Kazakhstan's renewable resources. This ambitious project remains in the pre-FEED (Front End Engineering Design) phase with production not expected to begin until 2030.

The country's proactive approach, exemplified by the 2060 Net-Zero Carbon Strategy and the 2030 Concept for the Development of Hydrogen Energy, sets ambitious targets to increase the renewable energy share to 15% by 2030 and 50% by 2050, while positioning hydrogen as a crucial element in achieving carbon emission reduction targets. Recent progress includes the adoption of international hydrogen standards (CT PK ISO 14687-2023, CT PK ISO/TR 15916-2023, CT PK IEC 62282-3-100-2023) in July 2024, demonstrating alignment with global frameworks.

Decarbonisation opportunities and partnerships

Hydrogen integration in mining/metallurgy could reduce emissions by 30–90%, while green ammonia fertilisers in agriculture may cut GHG outputs by 20–25%. Domestic industrial opportunities extend to steel production and chemical manufacturing, where hydrogen could drive economic diversification.

Regional synergies, such as Uzbekistan's target of 40% renewables by 2030 and Tajikistan's 1-million-tonne green hydrogen goal by 2040, highlight Central Asia's collective potential. Globally, demand for PtX products like green ammonia and methanol is surging, and Kazakhstan can complement EU-funded projects while navigating falling green hydrogen costs in other markets. The German-Kazakh Energy Dialogue, active since 2020, plays a crucial role in supporting Kazakhstan's hydrogen ambitions by providing technical assistance for the development of the National Hydrogen Strategy. This partnership has produced several key studies addressing hydrogen market mechanisms, potential sales markets and water supply solutions for green hydrogen production. The Energy Dialogue, implemented by the German Energy Agency (dena), and the German Chambers of Commerce Abroad (AHK), have established a Hydrogen Initiative Group for business cooperation. Together with strategic German partnerships like H_2-diplo Decarbonization Diplomacy, they promote the Kazakh-German hydrogen cooperation and contribute expert recommendations to Kazakhstan's hydrogen strategy[1]. International mechanisms like Germany's

H_2Global and the EU's Innovation Fund are important tools to support the hydrogen market ramp-up and will be pivotal to de-risk investments and scale production.

Infrastructure challenges

Kazakhstan's existing energy infrastructure (70% coal-dependent) and grid instability (66% depreciation rate) make large-scale pipeline investments risky.

Pipelines require stable, high-volume demand and upfront capital for electrolysers (€800–€1,500/kW). Repurposing natural gas pipelines could reduce costs by ~50%, but limited hydrogen demand complicates domestic pipeline viability. A survey among key stakeholders revealed that 94% identified technology costs as a primary barrier to hydrogen solution adoption, underscoring the need for government support and incentives.

Hydrogen transport options

- **Ammonia**: Leverages existing global shipping infrastructure, avoids cryogenic costs and suits long-distance export markets (e.g., Europe/Asia). However, cracking requires energy and purification, and ammonia's toxicity requires sound safety measures.
- **LOHCs**: It is safer to store and transport hydrogen in liquid form under atmospheric conditions. Unlike compressed or cryogenic hydrogen, LOHCs do not ignite and do not require high pressure. They are suitable for the climate of Kazakhstan when using thermal insulation, heating and special frost-resistant media.
- **Liquefied H_2 (LH_2)**: Higher energy density than gaseous hydrogen but energy-intensive liquefaction (-253°C) and boil-off risks make it less practical for Kazakhstan's climate and infrastructure.
- **Pipeline transport**: Transporting hydrogen via pipelines – whether through repurposed natural gas infrastructure or newly built hydrogen pipelines – is technically feasible. However, due to Kazakhstan's geographic distance from key import markets and the absence of a transnational hydrogen corridor, such solutions would require massive, coordinated infrastructure development over the long term. In the near to medium term, alternative carriers such as ammonia or LOHCs may offer more viable export pathways.

Economic opportunities

With 94% of stakeholders citing technology costs as a barrier, ammonia and LOHCs offer lower upfront costs and scalability for international markets. Pipelines become cost-effective only for stable, long-term and large-scale demand, which remains uncertain.

For exports exceeding 3,000 km, ammonia shipping is optimal due to synergies with existing infrastructure and competitive costs. LOHCs provide a safer, flexible alternative for regional markets. Pipelines should be secondary, prioritised only if repurposing existing infrastructure or domestic demand stabilises.

German development cooperation organisations (GIZ, KfW) are actively supporting grid modernisation through technical assistance programmes, creating opportunities for mutual knowledge transfer.

Regulatory framework and investment needs

The legal and regulatory framework for hydrogen development in Kazakhstan remains in its early stages, though foundational elements exist through key legislation such as the Environmental Code (2021), the Water Code (2025) and the Law on Supporting Renewable Energy Sources (2009). Recent initiatives, including the Strategy for Achieving Carbon Neutrality by 2060 and the Concept for Development of Hydrogen Energy until 2030, demonstrate Kazakhstan's commitment to the clean energy transition. Proposed amendments to the Entrepreneurial Code and Tax Code aim to introduce hydrogen-specific incentives, including tax holidays for green hydrogen producers and accelerated depreciation for electrolysis equipment. These regulatory changes not only align Kazakhstan with international best practices but also enhance its eligibility for international funding mechanisms. The country is actively positioning itself to access funding from EU programmes, multilateral development banks and climate finance initiatives supporting green hydrogen projects.

Critical gaps persist in aligning Kazakhstan's regulatory environment with international standards, which directly impacts its potential as a hydrogen exporter. Existing energy laws, formulated between 2009 and 2014, fail to address hydrogen production, transport or certification, risking misalignment with EU directives like the Renewable Energy Directive (RED III). This misalignment could hinder Kazakhstan's ability to meet stringent EU sustainability criteria, such as greenhouse gas (GHG) reduction targets and certification requirements for low-carbon hydrogen exports.

Environmental and geopolitical considerations

Environmental and safety regulations for hydrogen infrastructure – pipelines, storage and refuelling – remain underdeveloped, creating investment uncertainty while presenting environmental challenges. Management of water as a scarce resource poses a critical challenge due to the total water impact of green hydrogen production (15–30 l water/kg H_2 produced) depending on various circumstances. Smart solutions are needed to avoid straining Kazakhstan's arid regions and prevent competing use with agricultural priorities. Environmental considerations include habitat disruption from infrastructure expansion and operational safety risks.

Strategic partnerships with water-rich neighbours offer an efficient solution by potentially relocating electrolysis operations closer to EU markets, optimising resource utilisation while reducing transportation costs and environmental impact through integrated renewable electricity transmission corridors.

Kazakhstan is currently producing hydrogen at pilot scale (e.g., Green Spark's operational project since 2021) but has not yet launched large-scale commercial production, with targets to reach 25,000 tonnes by 2030 and ambitious plans like the Hyrasia One project aiming for 2 million tonnes annually by 2032. It is a country that is looking to diversify its hydrogen trade partners beyond Russia and China to mitigate geopolitical risks and avoid over-dependence on these markets, which currently account for 19.2% (Russia) and 27.4% (China) of its trade share. This reliance threatens energy autonomy and exposes Kazakhstan to shifting regional alliances and trade route vulnerabilities. Currently, 94% of Kazakhstan's oil exports transit through Russia via the Caspian Pipeline Consortium (CPC), creating significant export vulnerabilities – as evidenced by four pipeline disruptions in 2022 alone, with the first suspension occurring just two days after Kazakhstan promised to increase oil exports to the EU. While Kazakhstan is developing hydrogen production capacity, with current pilot projects and an interim target of 10,000 tonnes by 2027, these same geopolitical issues could affect future hydrogen exports. The Middle Corridor to Europe faces bottlenecks, including limited Caspian Sea ferry capacity and competition from Azerbaijan-Turkey hydrogen initiatives. Meanwhile, adapting existing oil/gas infrastructure – such as the Caspian Pipeline Consortium – for hydrogen transport would offer a cost-effective solution but require regional cooperation. Safety risks associated with the scaling of hydrogen exports may furthermore arise from hydrogen leakage or ammonia toxicity during transport. Here, technical assistance from Germany, the EU or other partner countries can make a difference, for example through the PtX Hub, to facilitate infrastructure retrofitting studies, combining European engineering expertise with local operational knowledge. Strategic partnerships with water-rich neighbours such as Azerbaijan or Turkey could mitigate water constraints by relocating electrolysis closer to EU markets.

Navigating EU regulatory frameworks

Compliance with EU sustainability criteria demands rigorous certification and alignment with mass-balance tracking systems. Domestically, modernising legislation to address hydrogen-specific safety, production and export standards is critical to attract investment and avoid market exclusion. Kazakhstan's eligibility for EU funding mechanisms like the European Hydrogen Bank and Connecting Europe Facility requires accelerated regulatory reforms.

Kazakhstan's potential as a hydrogen exporter to the EU hinges on aligning with the body of EU regulation, particularly the Renewable Energy Directive (RED III) and Carbon Border Adjustment Mechanism (CBAM). The EU mandates that renewable hydrogen (classified as Renewable Fuel of Non-Biological Origin, RFNBO) must meet strict criteria, including production via electrolysis powered exclusively by new renewable energy installations (post-2028) and adherence to a 70% greenhouse gas (GHG) savings threshold compared to fossil fuels. Compliance requires dedicated infrastructure to prevent gas mixing, rigorous GHG lifecycle accounting and certification through EU-recognised schemes like ISCC or REDcert. For low-carbon fuels (LCFs) such as blue hydrogen, alignment with the EU Methane Regulation and the Delegated Act for low-carbon hydrogen and fuels is critical. Kazakhstan currently lacks a dedicated hydrogen legal framework, creating investor uncertainty and hindering infrastructure development.

The EU market presents substantial export potential, with REPowerEU envisaging 20 million tonnes of hydrogen by 2030 (10 million tonnes from imports) and Germany alone requiring 50-70% of its projected 95-130 TWh annual hydrogen demand to be imported by 2030, growing to 360-500 TWh for pure molecular hydrogen by 2045. Key challenges include navigating the EU's additionality requirements for producing RFNBOs, addressing CBAM reporting obligations for embedded emissions and establishing certification processes via the EU's Union Database. The EU's mass-balancing tracking system and Germany's 37th

BImSchV regulation exemplify the need for robust national registries to ensure traceability. To access EU markets, Kazakhstan must prioritise regulatory reforms, invest in dedicated hydrogen transport infrastructure and engage with voluntary certification schemes which are deemed viable by the European Commission. Strategic partnerships with EU institutions and adherence to methane leakage standards will be essential to mitigating trade barriers and leverage opportunities under initiatives like the European Hydrogen Bank.

Financing and partnership

The financing landscape for Kazakhstan's green hydrogen development comprises a complex interplay of domestic and international funding mechanisms, with significant opportunities for strategic partnerships and investment. Local financing instruments, including public-private partnerships, investment agreements and green bonds, have shown promising potential. The Damu Entrepreneurship Development Fund and AIFC Green Finance Centre have emerged as key facilitators, providing crucial support through interest rate subsidies and external reviews for green financial instruments. These mechanisms align with international standards, such as the Green Bond Principles, and address critical needs identified by local industries: 80% of surveyed companies seek enhanced financing for hydrogen production, while 70% emphasise renewable energy investments.

Germany and the EU have put in place various support mechanisms. It should be noted however that not all instruments described in this study are currently available for projects in Kazakhstan. Two of Germany's defining mechanisms function in distinct ways: One is H_2Global which bridges the price gap between the cost of renewable hydrogen and its market price to enable imports, while H_2Uppp fosters capacity building and technology transfer. KfW's financing frameworks enable infrastructure upgrades, such as retrofitting pipelines for hydrogen compatibility. The PtX Development Fund, which currently does not support projects in Kazakhstan, provides funding for green hydrogen initiatives in other regions. EU mechanisms, including the European Hydrogen Bank and Innovation Fund, prioritise cross-border infrastructure and first-of-a-kind projects, though alignment with EU standards is critical for eligibility.

Policy recommendations

To unlock Kazakhstan's export opportunities, policymakers should prioritise regulatory reforms, incentivise private-sector participation and strengthen partnerships with German and EU institutions. Critically, Kazakhstan should align its hydrogen regulatory framework with the EU's rules to ensure market access, as the EU represents both a key trading partner and potential hydrogen importer. This alignment should include adopting certification schemes that meet the EU's 70% greenhouse gas emission reduction requirement (maximum 3.38 kg CO_2eq per kg of hydrogen to qualify as RFNBO) and establishing an independent regulatory authority similar to EU models. The Strategic Partnership MoU signed with the EU in November 2022 provides a foundation for this regulatory harmonisation across raw materials, batteries and renewable hydrogen value chains[2]. Kazakhstan must establish a comprehensive investment framework to de-risk hydrogen projects and attract private sector participation. While green bonds and loans have raised KZT 150.2 billion, there is no centralised financing mechanism for large-scale hydrogen projects. A dedicated hydrogen investment plan should combine Kazakh public funds, international development finance (e.g., KfW, EBRD) and private capital. Kazakhstan should also explore contract-for-difference (CfD) models, similar to Germany's H_2Global programme, to provide price certainty and long-term market stability for hydrogen producers. Additionally, leveraging tools such as the EU Hydrogen Regulatory Navigator and information provided by the Energy Dialogue with Germany would help Kazakh producers understand and comply with the complex EU regulatory landscape governing hydrogen imports, ensuring their products qualify for the European market under frameworks like the Hydrogen and Decarbonised Gas package adopted in May 2024.

Key steps include enacting hydrogen-specific laws in line with EU regulatory requirements, piloting export routes via the Caspian Sea and retrofitting pipelines for hydrogen compatibility. Infrastructure upgrades, such as developing Caspian ammonia routes, are critical to accessing EU markets.

1. Institutional coordination: Establish a dedicated Hydrogen Department to centralise expertise and a Unified Hydrogen Purchaser to streamline market development.
2. Legislative reforms: Enact hydrogen-specific laws with clear definitions, EU-aligned certification systems (e.g., RED III) and amendments to codes

(Environmental, Tax) to incentivise production through tax breaks and carbon credits.

3. Financial mechanisms: Phase out fossil fuel subsidies while scaling blended financing models – combining PPPs, international funding (e.g., Horizon Europe's €1 billion Clean Hydrogen Partnership for R&D) and CfD schemes.

Implementation roadmap

The implementation roadmap presented below represents the authors' recommendations to Kazakhstan for hydrogen development, not an official government strategy. This proposed phased approach could leverage existing international cooperation frameworks to accelerate implementation:

Phase 1 (2025–2030): Regulatory/institutional reforms, pilot projects to retrofit pipelines and develop Caspian ammonia routes.

Phase 2 (2030–2045): Scale production and establish hydrogen hubs in partnership with Uzbekistan (targeting 40% renewables by 2030) and Tajikistan (aiming for 1 million tonnes of H_2 production by 2040).

Phase 3 (2045–2060): Full EU market integration, export leadership.

Kazakhstan's hydrogen future hinges on accelerating reforms, strategic partnerships, cross-sector collaboration and blended financing. Prioritising EU alignment, infrastructure upgrades, harmonising industrial decarbonisation efforts (e.g., steel, chemicals), regional collaboration and leveraging multilateral platforms have the potential to secure Kazakhstan's role as a global hydrogen exporter, driving sustainable development and energy independence.

The existing Kazakh-German Energy Dialogue can play a crucial role in implementing these recommendations, starting from Phase 1. Since 2021, this cooperation format has already supported Kazakhstan's hydrogen strategy development through technical expertise, policy advice and business engagement. The Energy Dialogue has prepared specific studies on hydrogen market support mechanisms, potential sales markets and water supply issues for green hydrogen production in Kazakhstan. Additionally, the Hydrogen Initiative Group for Business, established by the German Energy Agency (dena) and the German Chambers of Commerce Abroad (AHK), provides a platform for engaging Kazakh and international companies in policy discussions. With dena already serving on the steering committee finalising Kazakhstan's National Hydrogen Strategy in 2024, this established cooperation framework could be leveraged to support the regulatory reforms, pilot projects and infrastructure development envisioned in Phase 1.

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List of abbreviations

ADB	Asian Development Bank
AFID	Alternative Fuels Infrastructure Directive
AIFC	Astana International Financial Centre
API	American Petroleum Institute
BMWE	German Ministry for Economic Affairs and Energy
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CO_2	Carbon dioxide
DBK	Development Bank of Kazakhstan
dena	Deutsche Energie-Agentur (German Energy Agency)
DRI	Direct Reduced Iron
EBRD	European Bank for Reconstruction and Development
EIA	Environmental Impact Assessment
ESG	Environmental, Social and Governance
ETS	Emission Trading System
EU	European Union
EUR	Euro
FuelEU	EU Maritime Fuel Regulation
GCF	Green Climate Fund
GEFF	Green Economy Financing Facility
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Agency for International Cooperation)
HPP	Hydroelectric power plant
H_2	Hydrogen
ISO	International Organization for Standardization
kW·h	Kilowatt per hour
LH_2	Liquid hydrogen
LCF	Low Carbon Fuel
LOHC	Liquid Organic Hydrogen Carrier
MDBs	Multilateral Development Banks

Mt	Million tonnes
$MtCO_2e$	Metric tonnes of CO_2 Equivalent
Mtpa	Million tonnes per annum
NDC	Nationally Determined Contribution
NH_3	Ammonia
N_2O	Nitrous oxide
PPAs	Power Purchase Agreements
PPP	Public-private partnerships
PtX	Power-to-X
R&D	Research and development
RCF	Renewable Carbon Fuel
RED	Renewable Energy Directive
RES	Renewable energy sources
RFNBO	Renewable Fuels of Non-Biological Origin
SMR	Steam Methane Reforming
SPP	Solar power plant
TITR	Trans-Caspian International Transport Route
UN	United Nations
USD	United States Dollar
WPP	Wind power plant

1 Introduction: Hydrogen in Central Asia as a key region

Introduction

The European Hydrogen Strategy, published by the European Commission in 2020, identifies clean hydrogen as critical for decarbonising industrial processes and hard-to-abate sectors. Under the European Green Deal framework, the EU has committed to achieving climate neutrality by 2050.

To operationalise this ambition, the European Commission introduced the REPowerEU plan in 2022, as a direct response to the hardships and severe global energy market disruptions caused by Russia's illegal war of aggression against Ukraine. This urgent initiative primarily aimed to secure Europe's energy independence from Russian fossil fuels through accelerated green energy adoption and diversification of supplies. This strategy mandates annual production and import of 20 million tonnes of renewable hydrogen by 2030, equally split between domestic output and international procurement. Concurrently, the Fit for 55 legislative package establishes binding requirements for Renewable Fuels of Non-Biological Origin (RFNBOs), aiming for 55% greenhouse gas reduction by 2030 through sector-specific emissions regulations.

EU hydrogen demand substantially exceeds projected domestic production capacity, necessitating imports to meet both interim targets and long-term decarbonisation objectives. Imported hydrogen serves three strategic purposes: to ensure energy security, maintain cost competitiveness and provide scalable solutions for emission-intensive industries.

Germany's National Hydrogen Strategy mirrors this import dependency, forecasting 95–130 TW h annual hydrogen demand by 2030, with 50-70% sourced internationally. Projections indicate escalating requirements until 2045, reaching 360-500 TW h for pure hydrogen and 200 TW h for derivatives. Primary demand drivers include steel production (accounting for 35–40% of total), chemical manufacturing (25-30%), maritime/aviation fuels (15–20%) and flexible power generation (10–15%). Germany's Hydrogen Import Strategy, adopted in July 2024, establishes diversified supply pathways: pipelines from European neighbours (primarily Denmark, Norway, UK) for direct hydrogen and maritime shipping for derivatives from distant partners[1]. While prioritising green hydrogen in the long term, the strategy pragmatically permits low-carbon alternatives during market development. Implementation leverages the €900 million H_2Global foundation, creating long-term purchase contracts with international producers across fifty-plus non-EU countries, all subject to strict sustainability criteria including social standards and ecological safeguards.

Kazakhstan can emerge as a strategic partner in this energy reconfiguration, leveraging 280+ annual sunny days and wind potential exceeding 1,820 billion kWh/year. The Hyrasia One project – a 40-GW renewable complex targeting 11 million tonnes of green ammonia annually made from electrolytic hydrogen – exemplifies Kazakhstan's potential to become a hydrogen export hub. Infrastructure modernisation at Caspian ports (Aktau, Kuryk) and pipeline development enhances cost-competitive transport options critical for EU market access.

This report is grounded in meticulous analysis that combines desk research, in-depth stakeholder interviews and a survey of 17 key organisations spanning Kazakhstan's vital economic sectors, including oil & gas, power generation, mining and transportation. These efforts have uncovered crucial insights into the nation's current energy landscape and its capacity to integrate hydrogen technologies.

Survey findings reveal that only 24% of respondents generate over 10% of electricity from renewables, 65% lack energy storage systems and 71% are exploring low-carbon technologies. Oil & gas companies and industrial complexes are identified as the most prepared early adopters.

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1 https://www.publikationen-bundesregierung.de/pp-de/publikationssuche/importstrategie-wasserstoff-und-wasserstoffderivate-2300640

The survey assessed organisational readiness through questions about energy profiles, infrastructure and planning horizons. Results show 53% of organisations have systems to integrate new technologies. Sector analysis identified specific companies like Atyrau Oil Refinery LLP, JSC NC KazMunayGaz and Pavlodar Petrochemical Plant LLP as priority candidates for initial hydrogen projects due to existing infrastructure and interest in emission reduction, enabling a phased implementation approach toward Kazakhstan's hydrogen export ambitions. This granular understanding of the industrial landscape enables a strategically phased implementation approach, beginning with pilot projects in receptive entities and gradually expanding toward Kazakhstan's broader hydrogen export ambitions.

Personal interviews were conducted with three strategic stakeholders, offering complementary perspectives on Kazakhstan's hydrogen ecosystem: Hyrasia One, as developer of Kazakhstan's flagship $40–50 billion hydrogen megaproject (targeting 11 million tonnes of green ammonia annually), provides invaluable insights on project implementation challenges, financing requirements and regulatory needs from a producer's viewpoint; meanwhile, Kazakhmys Corporation and Eurasian Resources Group (ERG) represent potential major industrial consumers in hard-to-abate mining and metallurgical sectors, with ERG already announcing plans to incorporate green hydrogen in calcination processes as part of their decarbonisation strategy. Together, these stakeholders' perspectives form a bridge between theoretical potential and market realities across the hydrogen value chain, offering practical insights that inform policy recommendations to accelerate Kazakhstan's hydrogen sector development and strengthen its position in European supply chains.

While these findings illustrate a sector in flux, they reveal urgent need to square ambition with execution.

Central to this transition is the role of hydrogen – a versatile energy vector capable of addressing challenges in hard-to-abate sectors such as heavy industry, long-haul transportation and power generation. However, understanding the nuances of hydrogen production and its environmental impact is critical for charting an effective path forward.

Hydrogen is classified based on its production method and environmental footprint:

Hydrogen type	**Production method**	**GHG emissions**
Green	Renewable-powered electrolysis	Low lifecycle emissions
Grey	Fossil fuels without CCS	High
Blue	Natural gas with CCS	Reduced
Turquoise	Methane pyrolysis	Solid carbon byproduct
Pink	Nuclear-powered electrolysis	Low lifecycle emissions[2]
Brown/Black	Coal gasification	Highest

Table 1: Hydrogen classification by colour code

This study focuses exclusively on green hydrogen's transformative potential, aligning with EU sustainability criteria and Kazakhstan's renewable ambitions. The study also evaluates Kazakhstan's hydrogen economy potential while addressing legal, financial and infrastructure barriers. It analyses the EU's/Germany's role as a strategic partner in technology transfer and market integration, offering actionable recommendations to harness bilateral support mechanisms for building hydrogen export capabilities to Europe.

[2] The average carbon intensity of pink hydrogen is approximately 0.41 kg CO_2eq/kg H_2 (Source: MDPI Environmental Sciences). Direct emissions range between 0.3 and 0.6 kg CO_2eq/kg H_2, reflecting lifecycle emissions including construction, operation, and decommissioning of nuclear power plants (Source: Minenergia Colombia).

2 Navigating the energy transition in Kazakhstan

2.1 Status quo of the energy system

Kazakhstan has rich natural resources, which create significant potential for the development of renewable energy. The country is at the forefront of Central Asia in terms of wind, solar, hydropower and geothermal resources. It can become a hub for green hydrogen production, contributing to economic diversification and reducing the carbon footprint.

- **Risks**: It should be taken into account that the basis of Kazakhstan's energy system is made up of coal-fired plants (about 70%), manouverable plants (gas and hydro power plants) do not provide sufficient flexibility of the energy system, so significant investment is required to upgrade outdated infrastructure to connect new renewable energy sources to the existing power grid.
- **Opportunities**: Steady growth in global demand for clean energy opens the door to attract foreign investment and new technologies. Large consumers of electricity within Kazakhstan, such as oil and gas companies, mining and metallurgical companies are developing low-carbon development strategies in order to reduce their carbon footprint and improve their ESG rating to increase their competitiveness in global markets in the medium and long term. One of the effective areas they consider is the consumption of green energy in their own production facilities.

Wind energy

Kazakhstan's wind energy potential is about 1,820 billion kWh per year. This makes it the most promising resource for green hydrogen production. The Wind Atlas of Kazakhstan shows that there are good wind resources (7–8 m/s) over an area of more than 50,000 square km, and that in some areas of the Zhetisu, Almaty, Atyrau and Mangistau regions, the wind speed is very good (8–9 m/s) and exceptional (>9 m/s).[3]

- **Risks**: Risks associated with the integration of wind power plants (WPP) into the energy system, especially in regional networks, require additional efforts to upgrade the infrastructure. Also, difficulties with the logistics of large-tonnage WPP equipment require additional costs for equipment insurance.
- **Opportunities**: The vast territories of Kazakhstan allow for the placement of large wind farm projects on separate sites, while wind farms can balance each other, with the correct placement of stations in the regions of Kazakhstan.

Solar energy

Kazakhstan's solar radiation provides ample opportunities for energy generation. The solar energy potential is estimated at 2.5 billion kWh per year, and the number of sunny days in the southern regions exceeds 280. This creates excellent conditions for the installation of solar power plants (SPP), especially in the energy-deficient southern regions of the country.[4]

- **Risks**: SPPs are dependent on weather conditions, which can lead to instability in energy supplies.
- **Opportunities**: Investments in storage technologies and integration of solar power with other energy sources such as wind power can significantly improve the overall efficiency of the energy system and reduce dependence on fossil fuels.

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3 https://www.undp.org/ru/kazakhstan/publications/uroki-proekta-proon-gef-kazakhstan-iniciativa-razvitiya-rynka-vetroenergii-zaklyuchitelnaya-publikaciya

4 Renewable Energy as a Potential Driver of Kazakhstan's Growth* – ERI

Hydropower

Hydropower portrays one of the most important energy sources in Kazakhstan. In 2023, large hydroelectric power plants produced about 10% of the country's total electricity, and the hydropower potential is 62 billion kWh per year. This makes it an important component of the energy balance, especially in the southeastern and eastern regions. The hydro potential of medium and large rivers is 55 billion kWh, and of small rivers is 7.6 billion kWh per year.[5]

Hydropower resources are distributed throughout the country, but among them, three particularly large areas are worth noting: the Irtysh River basin with its main tributaries (Bukhtarma, Uba, Ulba, Kurchum, Kardzhil), the South-Eastern zone with the Ili River basin and the Southern zone - the Syr Darya, Talas and Chu river basins.

In the current legislation, small hydroelectric power plants (HPPs) are considered to be HPPs with an installed capacity of no more than 10 MW, and over 10 MW are considered large HPPs. At the same time, large HPPs are used by the National Energy System as manouverable sources of generation, while small HPPs can be used, among other things, for the production of green hydrogen.

Currently, the Asian Development Bank is implementing a programme to support hydropower in Kazakhstan, with the aim of attracting investment in projects to build cascades of hydroelectric power plants on individual rivers in Kazakhstan.[6]

- **Risks**: Hydropower is vulnerable to climate change, such as reduced river flows due to drought, which can negatively impact electricity production. In addition, the creation of new hydropower plants, especially those with reservoirs, can be sensitive to local communities, require their displacement and have impacts on ecosystems.
- **Opportunities**: Small hydropower is a relatively stable source of generation. Large hydroelectric power plants with reservoirs can provide not only stable generation but are also manouverable sources that can provide balancing of variable energy sources from the wind and sun. This in turn will allow integrating wind and SPPs into the energy system of Kazakhstan.

In 2013, specific goals for the development of the renewable energy sector were formulated and, as a result, the foundations for a renewable energy market were established and the potential for reducing greenhouse gases from renewable energy was determined. In the context of Kazakhstan's transition to a 'green' economy, within the framework of the Kazakhstan 2050 Strategy, the Strategy of the Republic of Kazakhstan on Achieving Carbon Neutrality by 2060[7] and the Hydrogen Energy Development Concept, the key goals include increasing the share of alternative and renewable energy in the country's energy balance to 15% by 2030 and to 50% by 2050.

It is important to note that the Carbon Neutrality Strategy emphasises the need for decarbonisation policies, while the Hydrogen Energy Development Concept focuses on hydrogen as a crucial element of Kazakhstan's sustainable energy strategy, which can play a key role in achieving the country's carbon emission reduction targets.

5 Resolution of the Government of the Republic of Kazakhstan No. 724 On approval of the Concept for the development of the fuel and energy complex of the Republic of Kazakhstan for 2023–2029, dated 28 June 2014.

6 https://www.adb.org/news/adb-kazakhstan-sign-transaction-advisory-agreement-hydropower-development-program

7 https://unfccc.int/sites/default/files/resource/Carbon_Neutrlaity_Strategy_Kazakhstan_Eng_Oct2024.pdf

Currently, there are 148 renewable energy facilities operating in Kazakhstan (over 100 kW and taking into account the exclusion of failed facilities), with an installed capacity of 2,903.7 MW:

Indicator	Unit of measurement	For 9 months of 2024
Installed capacity including:	MW	**2,903.7**
59 WPPs	MW	1,409.55
40 small hydroelectric power plants	MW	269.79
46 SPPs	MW	1,222.61
3 bioelectric power plants	MW	1.77
Electricity generation including:	million kWh	**5,782.6**
WPPs	million kWh	3,224.7
small hydroelectric power plants	million kWh	944.4
SPPs	million kWh	1,612.62
bioelectric power plants	million kWh	0.56
The share of electricity generated by renewable energy sources in the total volume of electricity production	%	**6.67**
The increase in electricity generation by renewable energy facilities for the first 9 months of 2024 compared to the first 9 months of 2023 is 18%		

Table 2: Production of electricity by renewable energy facilities for nine months of 2024

Overall, Kazakhstan has significant potential for integrating renewable energy sources[8] into green hydrogen production. The practical experience of implementing renewable energy projects accumulated in Kazakhstan and the high interest of investors speak in favour of further large-scale development of renewable energy sources in the country. However, to successfully realise this potential, it is necessary to take into account existing risks and use available opportunities. Sustainable development of the hydrogen sector will require an integrated approach, including investment in infrastructure, legislative reforms and the development of coordination between public and private participants.

Although Kazakhstan has significant natural resources for renewable energy sources, such as wind and solar energy, as well as a large territory, the real potential requires further exploration. The geographical distribution and seasonal variations of wind and solar radiation may greatly limit the actual availability of these sources for continuous and stable energy production. For example, wind energy is concentrated in some parts of the country, and the issue of transportation from remote areas to industrial centres needs to be addressed. In addition, the availability of individual land plots also requires further exploration.

2.2 Energy and climate policy conditions for the emerging hydrogen industry in Kazakhstan (incl. hydrogen concept/strategy)

2.2.1 Legal framework for hydrogen production and transport

The legal and regulatory framework for hydrogen production and transport in Kazakhstan is still in its formative stages, reflecting the country's increasing commitment to a clean energy transition and hydrogen as part of its low-carbon development strategies. Kazakhstan is actively working on developing policies, standards and regulations in alignment with international frameworks to foster hydrogen technologies and infrastructure.

[8] https://rfc.kz/ru/res-sector/map/

1. **Environmental Code of Kazakhstan (2021):** Sets standards for environmental protection, pollution control and sustainable resource use, and mandates Environmental Impact Assessments (EIAs). Emphasises the 'polluter pays' principle and encourages public involvement in environmental decisions.
2. **Water Code of Kazakhstan (2025):** Governs water resource management with provisions for climate adaptation. Important for hydrogen production which requires significant water resources.
3. **Strategy for Achieving Carbon Neutrality by 2060 (2023):** Plans to reduce greenhouse gas emissions through renewable energy, energy efficiency and carbon capture technologies. Hydrogen is highlighted as a key energy source for hard-to-abate sectors.
4. **Concept for the Development of the Water Resources Management System (2024-2030):** Focuses on water use efficiency and integrating climate considerations into water management policies, supporting sustainable hydrogen production.
5. **Law on Supporting the Use of Renewable Energy Sources (2009):** Promotes renewable energy generation, reducing environmental impacts and increasing renewable energy share. Includes incentives for renewable energy facility development.
6. **Concept for the Development of Hydrogen Energy in Kazakhstan until 2030:** Sets out a vision for hydrogen as a cornerstone of a low-carbon economy, with plans for infrastructure development, pilot projects and national standards for hydrogen.
7. **Standards development for hydrogen:** Establishes hydrogen standards aligned with international benchmarks, ensuring high-quality and safe hydrogen production and use. Key standards include Hydrogen Fuel Quality (CT PK ISO 14687-2023), Basic Safety Requirements for Hydrogen Systems (CT PK ISO/TR 15916-2023) and Safety for Stationary Fuel Cell Power Systems (CT PK IEC 62282-3-100-2023).

Kazakhstan is currently drafting a draft **Law on the Use of Alternative Energy Sources,** aimed at accelerating the development of renewable and non-renewable alternative energy sources, including green hydrogen production.[9] This law expands the definition of 'alternative energy' to encompass nuclear energy, industrial gases (e.g., landfill gases), low-potential heat and hydrogen. It is expected to provide a framework for integrating hydrogen technologies into the energy sector, offer incentives for investment and establish guidelines for hydrogen infrastructure.

The law's hydrogen provisions align with the Hydrogen Energy Development Concept until 2030, approved in September 2024, which prioritises pilot projects, export-oriented infrastructure and cross-border partnerships. However, the draft law's emphasis on market-driven mechanisms (e.g., ESCOs and private investment) suggests a shift away from state-led renewable projects, raising questions about how hydrogen incentives will balance public and private interests.

The new law explicitly positions hydrogen as a 'critical component' of Kazakhstan's energy transition, complementing the 2009 RES Law by addressing gaps in hydrogen-specific regulations. For instance, it introduces tax exemptions for hydrogen infrastructure and mandates grid operators to allocate capacity for hydrogen production facilities. Additionally, the law proposes a certification system to distinguish green hydrogen from grey/blue variants, ensuring alignment with EU sustainability standards under the 2024 EU-Kazakhstan Green Partnership.

[9] https://legalacts.egov.kz/npa/view?id=15077769

Additional relevant laws:

- **Law on Subsoil and Subsoil Use (2010, updated 2017)**: This law sets the legal framework for the exploration and extraction of mineral resources. It is vital for hydrogen projects that rely on subsoil resources, such as methane or minerals for hydrogen storage, ensuring compliance with regulations on environmental safety and sustainable development.
- **Law on the Electric Power Industry (2004)**: This law establishes the objectives of state regulation in the power industry, defining the roles of the government, state authorities and the Kazakhstan Electricity Grid Operating Company (KEGOC). This law can support the integration of hydrogen production facilities with the existing power grid, facilitating the use of renewable energy sources for hydrogen production. It also aids in the development of hydrogen storage and distribution infrastructure as part of Kazakhstan's broader energy sector.
- **Law on Natural Monopolies (2018)**: This law regulates the activities of natural monopolies in electricity and thermal energy transmission and distribution. As hydrogen production and distribution grow, this law will help regulate monopolistic tendencies in the energy sector. It provides the basis for tariff regulation and ensures fair competition among hydrogen producers and distributors, especially in terms of integrating hydrogen into energy networks.
- **Law on Energy Saving and Energy Efficiency (2012)**: This law encourages energy conservation and the adoption of energy-efficient technologies. It can support hydrogen production by promoting optimal resource use, energy management systems and technologies that improve the efficiency of hydrogen production processes, contributing to Kazakhstan's low-carbon economy goals.
- **Law on Public-Private Partnership (2015) and Law on Concessions (2006)**: These laws create a framework for public and private entities to collaborate on capital-intensive projects. They can facilitate private investments in hydrogen infrastructure, including production plants and storage facilities, and enable pilot projects to test new technologies and business models, attracting both local and foreign investment.

2.2.2 Legislative and regulatory frameworks for integrating RES in green hydrogen production

Kazakhstan has made progress in developing renewable energy sources (RES) legislation, providing a foundation for green hydrogen production. Current RES investment regulations can be adapted for hydrogen, leveraging the experience gained in RES development to create a solid support system for green hydrogen projects.

Main conditions	Current status	Applicability for green hydrogen
Single purchase electricity	In 2013, the Renewable Financial Center (RFC) was established under the JSC Kazakhstan Electricity Grid Operating Company (KEGOC) to facilitate the centralised purchase and sale of electricity generated from renewable energy sources (RES). In 2022, the RFC came under the control of the Ministry of Energy of the Republic of Kazakhstan. As the sole purchaser of electricity from RES, the RFC is responsible for financial settlements related to imbalances in renewable energy supply. All generated renewable energy is allocated to wholesale consumers.	The RFC's role as a single purchaser is crucial for ensuring returns on investment in the renewable energy sector. This mechanism will also provide a guaranteed offtake for green hydrogen. To minimise conflicts of interest, the RFC should not own any assets beyond processing support.
Tariffs	From 2014 to 2017, fixed tariffs for electricity from RES were implemented until the introduction of an auction mechanism. Currently, tariffs established through auctions from 2018 to 2023 are in effect.	The competitive auction mechanism for determining tariffs promotes transparency in selecting investors for green hydrogen projects and helps reduce hydrogen costs. This approach should be applied once initial projects are operational and a maximum price for hydrogen

Main conditions	Current status	Applicability for green hydrogen
		is established, which will then serve as the benchmark for future auctions.
Indexing tariffs	Fixed tariffs are subject to annual indexation: 70% based on the consumer price index (CPI) and 30% on fluctuations in foreign currency exchange rates. Auction tariffs are also subject to annual indexation. According to the amendments and additions made to the Resolution of the Government of the Republic of Kazakhstan dated 27 March 2014 No. 271 On approval of the rules for determining fixed tariffs and maximum auction prices in 2023, the new amendments allow for: • one-time indexation of auction prices during construction based on currency exchange rate changes; • annual indexation of auction prices with a chosen formula upon finalising purchase agreements; • annual indexation based entirely on currency exchange rate changes.	Indexing tariffs according to currency exchange rates protects investments, particularly when financing is in foreign currency. Additionally, inflation-indexed tariffs safeguard long-term contracts and provide stability during project construction phases. For hydrogen supplied domestically, similar tariff indexation approaches can be considered, while exports should fix hydrogen prices in stable currencies with inflation-adjusted formulas to protect long-term contracts.
Term of the power purchase agreement (PPA)	The standard term for a Renewable Power Agreement (RPA) is 15 years from the commencement of comprehensive testing or from the deadline for facility acceptance, whichever occurs first. Sellers must provide financial security amounting to 10,000 tenge per kW of installed capacity. For auction winners post-1 January 2021, the PPA extends to 20 years.	A longer term for green hydrogen purchase agreements supports project recoupment and investor profitability, necessitating discussions with banks and major investors.
Construction deadlines	The RRA stipulates commissioning deadlines: 24 months for solar plants; 36 months for wind and bioelectric plants; and 60 months for hydroelectric plants. Extensions of up to one year are possible if at least 70% readiness is achieved by the original deadline. In response to COVID-19 challenges, energy producers with valid purchase agreements were granted extensions until 1 November 2020, allowing additional time for construction notifications and operational acceptance.	To ensure timely project implementation while allowing flexibility in commissioning schedules, such approaches should be adopted after initial pilot projects are completed.
Dispute resolution	Disputes are generally resolved in courts at the buyer's location (RFC), but parties may also opt for international arbitration at the Astana International Financial Center (AIFC), which allows flexibility in choosing arbitration rules. The AIFC rules allow you to choose *IAC Rules*, *UNCITRAL Model Rules* or *ad hoc rules.*	This dispute resolution framework should apply to hydrogen projects to safeguard investor interests.
Network connection	Access to electric grids is guaranteed, including priority dispatching and mandatory transmission of electricity from RES. Energy transmission organisations cannot refuse connections if grid readiness is confirmed.	This standard should extend beyond electrical networks to include hydrogen transmission infrastructure via pipelines and gas networks. Regulatory measures must address connection refusals and dispatching issues within both electrical and pipeline systems.
Auction mechanism for renewable energy projects	Introduced in 2017, the auction format operates as a one-way online auction where land plots and network connection points are reserved beforehand. The primary criterion for selecting winners is the lowest price, with successful bidders receiving a PPA lasting 15 years; those	The auction mechanism may be beneficial in more developed hydrogen markets; however, initial stages should prioritise a 'first come, first served' approach.

Main conditions	Current status	Applicability for green hydrogen
	winning post-1 January 2021 receive a PPA lasting 20 years. This auction process has increased transparency in selecting renewable energy investors while lowering electricity costs.	
Investment preferences	The Entrepreneurial Code of Kazakhstan provides investment incentives under specific conditions, including exemptions from customs duties and VAT on imported equipment and state grants.	Applying similar investment preferences to green hydrogen projects will encourage investor participation and optimise project costs.

Table 3: Legislative and regulatory frameworks for integrating RES in green hydrogen production

Based on the existing regulations, a system of incentives can be developed to attract investment into the green hydrogen sector. However, there is a need to refine mechanisms for distributing hydrogen within the domestic market among consumers and to optimise costs in order to reduce the price of green hydrogen.

It is important to note that a significant portion of green hydrogen will be directed to external markets, where more market-driven approaches are utilised for project selection, offtake agreements and hydrogen suppliers.

2.3 Key gaps and inconsistencies in the legal framework

No. 1: Absence of a direct legal framework and comprehensive hydrogen strategy

Kazakhstan's existing energy laws do not specifically address hydrogen production, transport, storage or export, creating ambiguity for investors and stakeholders. Although hydrogen is mentioned within broader energy initiatives, there is no comprehensive strategy setting clear goals, timelines or frameworks for hydrogen's role in the national energy mix. This absence of a dedicated legislative and strategic framework hinders long-term planning and confidence in large-scale hydrogen projects, and without a comprehensive roadmap, Kazakhstan risks losing out on global green hydrogen market opportunities, particularly in domestic deployment.

No. 2: Outdated legislative framework and limited integration with renewables

Kazakhstan's energy regulations, largely formulated between 2009 and 2014, have not kept pace with hydrogen, resulting in a legislative framework misaligned with current industry demands.

Additionally, current renewable energy laws do not explicitly incorporate hydrogen production, leading to inconsistent or incomplete guidance – particularly when renewable sources are used to produce green hydrogen. As a result, new hydrogen systems may lack the regulatory support necessary for effective deployment, potentially slowing progress toward decarbonisation by underutilising the country's renewable energy potential.

No. 3: Environmental and infrastructure regulatory gaps

Kazakhstan's existing legislation does not specifically address hydrogen-related environmental factors such as water usage and emissions management, even though Environmental Impact Assessments are required for large-scale initiatives. Moreover, there is a lack of clear safety standards and operational protocols for hydrogen pipelines, storage facilities and refueling stations. This regulatory vacuum could lead to unsustainable practices that undermine the country's environmental goals, while also creating significant safety and operational uncertainties that impede the smooth development of hydrogen infrastructure.

No. 4: Incomplete coverage of hydrogen technologies and international standards

Kazakhstan has made progress in implementing standards for hydrogen fuel quality and stationary fuel cell systems, but coverage across the production, distribution and usage stages remains fragmented. Although some ISO guidelines are in place, there is no comprehensive, regularly updated framework to align with evolving international and EU norms – particularly critical since the EU tightened renewable hydrogen requirements under its Renewable Energy Directive and Delegated Acts. This patchwork of standards risks inconsistent technology adoption and may limit Kazakhstan's ability to certify hydrogen as renewable for export to the European market.

No. 5: Hydrogen certification and classification system

A robust hydrogen certification and classification system, modelled on international frameworks, is pivotal for Kazakhstan's sustainable hydrogen development. Such a system would classify hydrogen by production source (e.g., green, blue), thereby enhancing market transparency, investor confidence and export potential. The EU's mass balancing system provides a useful blueprint, featuring certification bodies, private voluntary schemes (e.g., ISCC or REDcert) and the EU Union Database to ensure transparency and traceability. By partnering with these voluntary schemes, documenting certified hydrogen in the EU database, managing methane emissions and maintaining dedicated transport infrastructure, Kazakhstan can position itself as a key player in the global hydrogen economy.

3 Hydrogen potential in Kazakhstan and challenge

3.1 Economic, technological, political and environmental challenges

Kazakhstan's strategic geopolitical location and rich natural resources position it favourably in the global energy market. However, navigating the geopolitical landscape – marked by regional instability, economic dependencies and infrastructure challenges – will be crucial for successful hydrogen exportation. Additionally, the environmental implications of hydrogen production must be carefully considered, particularly regarding water resource management and local ecosystem impacts. This section explores the intricate balance between harnessing Kazakhstan's hydrogen potential and addressing the environmental challenges that accompany this transition. The analysis aims to lay the groundwork for a sustainable hydrogen strategy that enhances Kazakhstan's economic prospects while contributing positively to global efforts in combating climate change.

3.1.1 Economic factors

Discussions surrounding the investment climate and economic factors reveal a complex landscape for Kazakhstan's hydrogen sector. The results gained from the interviews which were conducted for the purpose of this study strongly support this assessment, with 94% of respondents (16 out of 17) citing the cost and availability of technologies as a primary concern for adopting new technologies, including hydrogen. This unanimous response underscores the critical importance of making these technologies more accessible and affordable.

While institutional support exists, key challenges remain regarding regulatory efficiency, consumer incentives and market readiness. The desk research and discussions with Kazakhmys, Hyrasia One and ERG consistently highlighted the critical role of government support, regulatory stability and an attractive (both domestic and foreign) investment climate in the development of Kazakhstan's hydrogen economy.

11 out of 17 respondents (65%) in the survey highlighted the need for government support and incentives as being crucial for implementing new technologies.

In addition to emphasising the need for support and stability, the companies cited significant challenges that hinder the viability of hydrogen initiatives. High capital costs associated with hydrogen production, the imperative to achieve cost competitiveness with fossil fuels and the bureaucratic obstacles in implementing supportive legislation were all identified as prominent barriers that must be navigated to advance the hydrogen sector effectively.

Investment climate

The transition to a hydrogen economy requires significant investment in technology and infrastructure. The survey results reinforce this, with 53% of respondents indicating they have systems to integrate new technologies into existing infrastructure, while 47% do not.

The discussions with Kazakhmys, Hyrasia One and ERG collectively underscore the critical importance of government support, subsidies and a stable regulatory environment to make hydrogen projects economically viable. The importance of creating an attractive investment climate through long-term policies, incentives, and regulatory frameworks to enhance investor confidence was a recurring theme across all discussions.

In stakeholder interviews, representatives from **Hyrasia One** emphasised their view that long-term offtake agreements spanning 15 to 20 years are essential for providing stable revenue forecasts for hydrogen derivatives.

Project representatives also expressed concerns regarding what they perceive as bureaucratic obstacles hindering the implementation of supportive legislation for hydrogen projects. They advocated for what they described as a more agile regulatory environment to address the emerging market needs.

At the same time Kazakhstan needs to manage corruption risks and domestic economic challenges such as inflation and currency fluctuations to enhance investment and legal certainty:

- Institutions are perceived as being corrupt and weak, despite some improvements in recent years. Investors often seek assurance that their investments will be protected from arbitrary government actions.
- Investment security and legal certainty remain a significant concern for international investors. While Kazakhstan has signed numerous bilateral investment treaties (BITs) and is a member of the Energy Charter Treaty, offering formal protections against expropriation and guaranteeing fair and equitable treatment, practical implementation has been inconsistent. The country's judicial system faces challenges related to independence and enforcement capabilities, creating uncertainty for complex hydrogen infrastructure projects. Recent legal reforms aim to strengthen investment protection through specialised investment courts and international arbitration recognition, but investors continue to report concerns about regulatory unpredictability, selective law enforcement and contract sanctity – particularly for long-term projects spanning multiple political cycles that are typical in the hydrogen sector.
- The benchmark interest rate in Kazakhstan is currently set at 15.25%, which is relatively high compared to global averages. This rate increases the cost of borrowing for hydrogen projects, which are inherently capital-intensive. High financing costs can deter both domestic and foreign investors from committing to large-scale hydrogen infrastructure projects, as the return on investment may not justify the initial capital outlay.
- The volatility of the Kazakh tenge (KZT) poses a significant risk to financing hydrogen projects, as fluctuations in the exchange rate can drastically alter the cost structure of projects reliant on imported equipment. If project financing is largely in foreign currencies, even minor changes in the tenge's value can lead to increased costs and financial instability. In response, the government is working to stabilise the currency and promote economic diversification. Measures such as indexing tariffs for electricity generated from renewable sources to exchange rate fluctuations aim to buffer against currency volatility, thereby enhancing investment attractiveness in renewable energy and hydrogen production.

According to representatives from **Eurasian Resource Group (ERG),** hydrogen technologies would need to deliver returns on investment comparable to existing fossil fuel sources, such as coal and gas, to be considered financially viable by the company. In interviews, ERG's leadership expressed their belief that without significant government backing, hydrogen production might struggle to achieve sustainability due to what they perceive as high operational costs, particularly in sectors such as freight transport.

ERG executives suggested that the profitability of hydrogen initiatives, from their perspective, depends heavily on establishing regulatory frameworks that would help achieve cost parity with traditional fuels. In their assessment, such supportive policies would be necessary to make hydrogen investments attractive both to their company and to potential external investors.

Cost competitiveness and economic viability

Developing large-scale hydrogen production facilities in Kazakhstan necessitates substantial investment in advanced technologies and infrastructure, along with access to adequate water resources. The survey highlights that only 24% of respondents produce more than 10% of their electricity from renewable sources, indicating a significant gap in the renewable energy infrastructure necessary for green hydrogen production.

According to **Hyrasia One** representatives, who expressed their opinion on the competitive landscape of the hydrogen market, they believe the Neom Green Hydrogen project in Saudi Arabia[10] is making significant strides in hydrogen production. In their view, this project exemplifies the intense competitive pressure that Kazakhstan faces in establishing its hydrogen market. Hyrasia One suggested that without immediate buyers and long-term contracts, new hydrogen projects in Kazakhstan could potentially struggle to gain a foothold in the global market. The stakeholders asserted their belief that the viability of these investments largely depends on securing reliable offtakers who are willing to commit to long-term agreements, which they identified as a challenge they envisage for prospective hydrogen initiatives in the region.

Key technical and economic parameters for hydrogen production from solar, wind and a combination of both sources are summarised in **Annex 1,** Tables 18–20. These tables highlight critical inputs such as electricity costs, capacity factors and full-load hours for each energy source, which directly influence the levelised cost of hydrogen (LCOH).

Electricity costs and capacity factors

As of 2024, electricity costs for hydrogen production vary significantly depending on the energy source:

- Solar power: €46.46/MWh (constant over 2024–2027) due to lower capacity factors (16–18%) and limited full-load hours (1401.6–1600 hours annually).
- Wind power: While electricity costs were not explicitly provided in the wind dataset, capacity factors range from 30% in 2024 to 39% in 2027, with full-load hours increasing from 2,628 to 3,416.4 annually.
- Combined solar and wind power: Electricity costs are lower (€36.81/MWh in 2024, decreasing to €36.38/MWh by 2027), reflecting higher capacity factors (46% in 2024, improving to 57% by 2027) and extended full-load hours (4029.6 to 5016.4 annually).

These differences highlight that combining solar and wind power offers a more favourable economic profile due to higher utilisation rates and reduced electricity costs.

Projected hydrogen production costs (2024–2027)

Based on these inputs, the estimated production costs for hydrogen in Kazakhstan range from $3.94 to $5.52 per kilogram when generated from a combination of solar and wind power. According to the modelled assumptions, electrolyser utilisation for combined solar and wind power would have reached 4,029.6 full-load hours in the baseline year 2024 and would subsequently increase to 5,016.4 hours by 2027. These figures do not represent actual historical data. These costs are projected to decline annually due to:

- reductions in electricity prices, as shown by the decreasing trend for combined energy sources;
- improvements in capacity factors, particularly for wind energy (from 30% in 2024 to 39% in 2027) and combined sources (from 46% in 2024 to 57% in 2027).
- declining capital expenditures (CAPEX): CAPEX for electrolyser systems ranges between €800/kW (low estimate) and €1500/kW (high estimate), with additional system costs such as stack replacement (€30% of CAPEX) and building expenses (€150/kW). A sensitivity analysis indicates that reducing CAPEX by approximately 30% could lower hydrogen production costs to $2–$3 per kilogram.

These cost projections are based on an optimistic scenario and expert assumptions regarding technology advancements, energy prices and capacity factor improvements. Actual costs may vary depending on market dynamics, regulatory changes and unforeseen challenges.

Sensitivity analysis

Sensitivity analysis is crucial for understanding how variations in key parameters impact the technical performance and economic feasibility of hydrogen infrastructure:

- Electricity costs: The analysis shows that lower electricity costs for combined solar and wind power contribute significantly to achieving competitive LCOH values.

[10] https://www.neom.com/en-us/newsroom/neom-green-hydrogen-investment

- Capacity factors: Higher capacity factors directly reduce LCOH by increasing system utilisation rates. For example, wind power's increasing capacity factor from 30% to 39% over four years demonstrates its growing potential as a cost-effective energy source.
- Electrolyser full-load hours: The electrolyser utilisation rates directly correspond to the renewable energy availability, operating at 4029.6 full-load hours annually in the baseline year 2024 when powered by combined solar and wind sources, and increasing to 5016.4 hours by 2027. This improved utilisation of electrolyser capacity significantly optimises hydrogen production efficiency and reduces the capital cost impact on the LCOH. By comparison, electrolysers powered solely by solar energy operate at only 1401.6–1600 full-load hours annually, while those powered by wind energy operate at 2628–3416.4 full-load hours annually, demonstrating why combined sources offer superior economics.

The findings of **Eurasian Resource Group (ERG), which** conducted a comparative economic analysis of hydrogen technologies versus renewable electrification pathways for its operations, suggest that, particularly in the realm of heavy transport, such as trucks, electric vehicles powered by renewable energy are, in their assessment, more cost-effective than hydrogen trucks. This preference expressed by ERG is rooted in a comparative assessment of hydrogen fuel, which is, in their view, too expensive despite its potential contributions to decarbonisation and energy transition efforts.

ERG representatives believe that while hydrogen remains a viable option for certain applications, its current economic positioning may hinder its adoption in comparison to more established alternatives like electric transport.

Challenges of single energy sources

When hydrogen is produced solely from photovoltaic (PV) or wind power. The LCOH remains above $3 per kilogram due to lower capacity factors for PV (16–18%) or limited cost reductions for standalone wind systems.

This reflects Kazakhstan's unique geographical characteristics, such as seasonal variability in solar radiation and wind speeds, which constrain single-source reliability.

Stakeholders emphasise that achieving cost parity with conventional fuels like mazut requires robust government support through subsidies, regulatory frameworks and guaranteed offtake agreements for green hydrogen projects.

According to **Kazakhmys** representatives, transitioning from mazut to cleaner energy sources, such as hydrogen, is viewed by the company as a crucial part of their stated strategy to reduce carbon emissions and achieve carbon neutrality. The company representatives claimed that this shift aligns with both government requirements and international environmental standards. During the interview, they reported that the company had begun researching the implementation of hydrogen technologies and other alternative energy sources in order to decrease its reliance on mazut. The Kazakhmys team mentioned that their internal discussions included the establishment of electric and hydrogen refueling stations, as well as their interest in potentially utilising renewable energy sources to produce green hydrogen.

Locating small-scale green hydrogen production centres near consumption hubs could be considered as a potential option, since this offers the advantage of reducing transportation costs and improving operational efficiency, as was discussed with ERG.

According to one **ERG** representative, they believe locating electrolysers close to consumption centres is significant to minimise hydrogen transportation costs and enhance its availability. The interviewed person expressed their opinion that in the regions where ERG's facilities are located, there are no issues with access to water, which they consider a positive factor for the development of hydrogen projects. In the view of ERG, proximity to consumers is crucial for the economic viability of hydrogen projects, potentially enabling more efficient operations and reducing what they perceive as potential barriers related to transport infrastructure. Moreover, the speaker shared their perspective on the importance of understanding consumer demand – including the water needed for hydrogen production and the prices consumers are willing to pay – which they believe are essential for establishing a successful hydrogen supply chain.

However, the economic viability of these centres depends on key factors such as electricity costs, capacity factors and capital expenditures (CAPEX). Electricity costs are a significant driver of hydrogen production economics, with combined renewable energy sources like solar and wind generally offering more cost-effective solutions compared to standalone systems. The use of hybrid systems ensures better utilisation of electrolysers due to higher capacity factors and longer operational hours.

Reducing CAPEX is another critical factor in improving economic feasibility. Investments in more efficient electrolyser systems and reductions in associated costs, such as stack replacement and building expenses, can significantly lower the levelised cost of hydrogen (LCOH). Additionally, locating production centres near renewable energy sources with high-capacity factors optimises system performance, while proximity to consumption hubs minimises transportation costs and energy losses associated with hydrogen distribution. However, challenges such as limited economies of scale and variability in renewable energy availability near urban areas must be addressed to ensure the sustainability and cost-effectiveness of these small-scale production centres.

Market development

There is consensus among interviewed stakeholders regarding the necessity for a well-developed market for hydrogen and green products, emphasising the importance of long-term offtake agreements to provide financial security for investors. Such agreements are crucial in fostering investor confidence and ensuring the stability needed for large-scale hydrogen projects.

While there is an acknowledged market for green metals and hydrogen, **ERG** leadership perceives unpredictability in pricing and demand. According to company executives interviewed, several factors are believed to influence the viability of the green market, including the need for long-term contracts with buyers and what they describe as an ambiguous premium associated with green products compared to traditional materials. In their opinion the challenge of establishing stable demand for products like green aluminium underscores the importance of bilateral negotiations to secure favourable terms between producers and consumers.

To facilitate the transition from fossil fuels to green hydrogen, additional consumer incentives are essential. Without clear incentives for end-users, the market may struggle to shift towards hydrogen solutions, potentially undermining investment attractiveness. Effective incentive structures could include subsidies, tax breaks or grants that encourage consumers to adopt green hydrogen technologies.

According to stakeholders from **Hyrasia One**, the readiness of European markets to engage in long-term commitments for hydrogen is another critical economic factor affecting Kazakhstan's hydrogen ambitions. These interviewees expressed the view that, at present, they believe the market is not sufficiently prepared to enter into the long-term contracts that they consider essential for financing and executing hydrogen projects. In their assessment, this potential misalignment between Kazakhstan's production capabilities and European market readiness could delay the country's ability to capitalise on its abundant hydrogen resources.

Resource dependency and knowledge gap

Kazakhstan's economy remains heavily dependent on natural resource exports, which poses risks for hydrogen development, related with impacts on investment and technological base development:

- The volatility of global energy prices can lead to uncertainty in revenue generation from traditional energy sources, which may reduce available capital for investment in hydrogen infrastructure. For instance, during periods of low oil prices, the government may prioritise immediate economic recovery over long-term investments in alternative energy sources like hydrogen.
- Global decarbonisation efforts in Kazakhstan's major export markets will likely decrease demand for traditional fossil fuel exports over time, creating additional economic insecurity and revenue volatility. As importing countries implement climate policies and transition to cleaner energy sources, Kazakhstan faces diminishing markets for its hydrocarbon exports, further threatening the stability of government revenues needed for hydrogen infrastructure investments.
- The focus on traditional resource extraction has resulted in a limited technological base for advanced hydrogen production methods (e.g., electrolysis, carbon capture).
- To develop this base, Kazakhstan needs to invest in education and training programs that enhance local expertise in hydrogen technologies. The survey identified a significant knowledge gap, with 40% of respondents expressing a need for more data on the benefits and costs of hydrogen technologies.

3.1.2 Technological and infrastructure challenges

Kazakhstan's ambition to establish a competitive hydrogen export sector faces significant technological and infrastructure-related hurdles. These challenges span across production, storage, integration and transportation aspects of the hydrogen value chain.

Production and storage limitations

The survey results paint a stark picture of the current state of hydrogen infrastructure in Kazakhstan. A staggering 65% of respondents report a lack of energy storage systems, which are crucial for effective hydrogen implementation. This deficiency in storage infrastructure is identified by 90% of respondents as a major technical barrier, highlighting the urgent need for investment in this area.

ERG is keen on exploring hydrogen technologies and acknowledges the necessity of advancing electrolyser technology and establishing infrastructure that supports hydrogen production and usage. The lack of existing infrastructure poses significant challenges for transitioning to hydrogen as a viable energy source. The company is also exploring hybrid solutions, such as using hydrogen in conjunction with electric vehicles, particularly in heavy industries where specific operational needs persist.

Integration challenges

The integration of new hydrogen technologies into existing infrastructure presents another significant obstacle. Only 53% of organisations report having systems capable of integrating new technologies, underscoring the need for substantial upgrades to support hydrogen technologies. This limitation not only hampers the adoption of hydrogen solutions but also impedes the overall progress and investment in this emerging energy market.

Transportation infrastructure

Kazakhstan's geographical distance from European markets contributes to high transport costs, estimated between €1.50 and €6.00 per kilogram of hydrogen. The country must consider various transport methods, each with its own set of challenges:

- Pipeline transport: While cost-effective for gas, substantial upfront investment in hydrogen-specific infrastructure is required.
- Hydrogen carriers: Using carriers like ammonia for long-distance transport is gaining traction due to advantageous storage and handling characteristics.
- Liquefied hydrogen: Suitable for long distances but incurs high energy costs due to the extreme cooling requirements (-253°C).

Representatives from **Kazakhmys** expressed their opinion that developing robust logistics and energy supply chains is essential for the successful execution of new projects, especially given the existing infrastructure challenges that they perceive could hinder timely and cost-effective implementation. Stakeholders interviewed believe investing in infrastructure development is crucial not only for supporting the energy transition but also for fostering broader economic growth and improving trade routes.

The company representatives shared their perspective on the need for a stable regulatory environment to drive R&D and innovations, particularly in the context of what they described as increasing global demand for sustainable technologies like green hydrogen. According to Kazakhmys, they view this shift as a significant growth opportunity for Kazakhstan's energy sector, emphasising in their assessment the need to enhance infrastructure to facilitate the transportation and production of green energy.

Grid infrastructure

Kazakhstan's aging power infrastructure poses additional challenges. With an average depreciation level of 66% in the grids, ensuring stable operation of renewable energy facilities and energy supplies becomes problematic. This is particularly challenging in remote areas with high wind or solar potential, where grid reliability is crucial for hydrogen production from renewable sources.

3.1.3 Key geopolitical factors and trade route vulnerabilities

Geopolitical risks play a crucial role in the green hydrogen sector in Kazakhstan for several interconnected reasons. Political stability is fundamental for attracting foreign investment, which is essential for developing the necessary hydrogen infrastructure for large-scale production and export. Interviewed stakeholders from industrial sectors, including representatives from Hyrasia One, Kazakhmys and ERG, have emphasised that external geopolitical instability – particularly following Russia's illegal war of aggression against Ukraine – could jeopardise project stability and erode confidence in long-term investments. Without a stable political environment, the risks associated with hydrogen infrastructure and technology investments could deter both domestic and foreign investors.

Kazakhstan's geopolitical position also exposes it to external influences that can affect trade routes and energy partnerships. As the country endeavours to establish itself as a significant player in the hydrogen market, these influences could complicate its export ambitions and impact the viability of hydrogen projects. The interplay of political, economic and security aspects suggests that any escalation in regional tensions could have immediate repercussions for Kazakhstan's hydrogen sector.

- The broader **Central Asian region** faces potential instability that could disrupt export plans. Border disputes or conflicts in neighbouring countries could affect transit routes. Moreover, other countries may vie for the same export markets, potentially leading to price competition or strategic alliances.
- **Russia's** influence in the Central Asian region, intensified since the outbreak of its war against Ukraine, presents challenges for hydrogen production in Kazakhstan. As a major energy supplier, Russia significantly impacts Kazakhstan's energy independence and its strategy for developing alternative energy sources like hydrogen. The geopolitical landscape has been fundamentally altered by Russia's illegal invasion of Ukraine, further complicating Kazakhstan's ambition to build a hydrogen economy.

Kazakhstan faces a delicate balancing act in maintaining amicable relations with Russia while diversifying its economic and political ties. Russia remains a crucial player in Kazakhstan's economic landscape, representing 10.7% of exports and 26.1% of imports.

Kazakhmys also addressed the complexities of Russian influence in Kazakhstan. According to company representatives interviewed, the company acknowledged the deep-rooted historical and economic ties between Kazakhstan and Russia, particularly in the energy and mineral sectors. However, there is a clear recognition within Kazakhmys of the need to diversify economic partnerships beyond Russia. These interviewees suggested that this diversification is seen as a strategy to mitigate risks associated with over-dependence on any single country and to enhance Kazakhstan's own national interests in the broader geopolitical context.

In early 2024, Kazakhstan's exports to Russia rose by 5.7%, amounting to around $2.8 billion. The share of Russia in Kazakhstan's total trade volume is 19.2%, placing it second after China, which leads in trade relations. These dynamics influence hydrogen export plans in several ways. Russia may seek to control Kazakhstan's energy export routes, potentially limiting market access. Additionally, sanctions imposed on Russia because of its war against Ukraine could indirectly affect Kazakhstan's export capabilities, particularly if Russian territory or infrastructure is involved in transport routes.

China's increasing influence in Central Asia, particularly through its Belt and Road Initiative (BRI), presents both opportunities and risks for Kazakhstan's hydrogen export potential. The BRI offers significant infrastructure development prospects that could enhance Kazakhstan's renewable energy production and hydrogen export capabilities, with Chinese investments in projects like wind and solar farms aligning with the country's goals to diversify its energy portfolio and reduce fossil fuel reliance. Kazakhstan has established itself as China's leading trading partner, accounting for 22.5% of its exports and 27.4% of its imports. In the first nine months of 2024, trade turnover between Kazakhstan and China reached approximately $33 billion, reflecting robust economic ties fostered through initiatives like the BRI. Exports to China increased by 19.4%, reaching about $6.8 billion from January to May 2024.

However, this growing partnership raises concerns about economic dependence on China, as deeper engagement could lead to reliance on Beijing for technological and financial support, limiting Kazakhstan's autonomy in energy policy and export strategies. Additionally, with China setting ambitious domestic hydrogen production goals – projecting a demand increase to 35 million tonnes by 2030 – its own consumption needs may diminish its import requirements from Kazakhstan, potentially impacting the latter's export potential as it competes with a major market player that is also a key partner.

The strategic hydrogen initiatives in Kazakhstan face an intricate balance of geopolitical considerations, as they rely heavily on German and European financial backing. Representatives of the **Hyrasia One Project** have stated their view that the German government's support comes with contingency plans – specifically, financial compensation mechanisms designed to protect investors should Kazakhstan experience political instability comparable to recent Russian scenarios. According to interviewees, this investor protection framework, while offering security to international stakeholders, may indicate Kazakhstan's vulnerability: They suggest that any significant geopolitical disruption could trigger capital flight or investment reductions.

According to Hyrasia One, questions regarding Kazakh-German governmental collaboration underscore the necessity for Kazakhstan to cultivate and maintain robust diplomatic relations with Germany to secure continued support for its hydrogen projects. Any significant deterioration in these bilateral ties could jeopardise not only current funding arrangements but also project viability.

Trade route vulnerabilities

1. Middle Corridor (Trans-Caspian International Transport Route)

The Middle Corridor provides Kazakhstan with a key route to Europe through the Caspian Sea, Azerbaijan, Georgia and Turkey, bypassing Russian transit routes. Supported by China's Belt and Road Initiative and EU investments, it faces logistical challenges, including limited ferry capacity and outdated rail infrastructure. Transport costs range from $2000 to $6000 per container, and uncertainty around EU-China traffic remains due to high costs. The corridor's success requires regional cooperation and significant infrastructure investments.

- **Azerbaijan, Georgia and Turkey** are developing hydrogen strategies centred on green hydrogen, leveraging renewable resources like wind, solar and hydropower. Azerbaijan is targeting both blue and green hydrogen, Turkey is planning to scale electrolyser capacity and Georgia is focusing on hydropower. Hydrogen production costs are projected to decrease by 2050, with plans to integrate hydrogen domestically and export via existing energy corridors (**Annex 2**, Table 21).
- **Political complexities** pose risks to regional trade stability, including the Armenia-Azerbaijan conflict, Russia's aggressive posture in the region – a direct extension of its illegal war against Ukraine – and competition among powers like Turkey, Russia and Iran. While cargo volumes along the corridor have surged, infrastructure bottlenecks and border issues persist.
- For **Kazakhstan**, which lacks direct infrastructure to the EU, partnerships with Middle Corridor countries and further investments in infrastructure are essential for successful hydrogen and energy exports.

2. Caspian Sea and Trans-Caspian Corridor

Energy security in the Caspian region is crucial for Europe due to the region's substantial hydrocarbon reserves, estimated at total proven reserves exceeding 100 billion barrels of oil and 12 trillion cubic metres of gas[11]. The region, which includes Russia, Azerbaijan, Kazakhstan, Turkmenistan, Uzbekistan and Iran, is one of the oldest oil-producing areas in the world and an increasingly important source of global energy production.

The Caspian basin offers Europe vital diversification away from Russian energy dependency, with Azerbaijan delivering 11.4 bcm of natural gas to the EU in 2022 (up from 8.1 bcm in 2021), followed by 11.8 bcm in 2023[12]. This supply flows through the Southern Gas Corridor, which includes the South Caucasus Pipeline, Trans-Anatolian Pipeline and Trans-Adriatic Pipeline. The European Commission has recognised this strategic importance by designating the Southern Gas Corridor as one of its six priority areas for energy infrastructure[13].

Beyond fossil fuels, the region is increasingly contributing to Europe's green energy transition. In

[11] https://www.eia.gov/todayinenergy/detail.php?id=12911
[12] https://www.boell.de/en/2024/11/05/eu-and-azerbaijan-energy-partners-short-term-benefits-uncertain-future
[13] https://www.osw.waw.pl/en/publikacje/analyses/2023-12-07/eus-new-priorities-developing-energy-infrastructure

May 2024, Azerbaijan, Kazakhstan and Uzbekistan signed a Memorandum of Understanding on linking their power grids through a high-voltage transmission line on the Caspian seabed for renewable electricity exports to Europe[14]. This initiative culminated in a formal green energy corridor agreement signed on 27 December 2024, with Uzbekistan alone estimating an annual export potential of 10–15 billion kW·h . The project includes an underwater cable connecting through Azerbaijan and Georgia and extending under the Black Sea to Romania, with projected costs exceeding $2 billion[15].

The REED index highlights higher risks from Iran, Russia and Turkmenistan, with the war against Ukraine significantly elevating regional instability and creating unprecedented geopolitical risks. Azerbaijan and Kazakhstan face moderate challenges but must navigate the spillover effects of Russia's aggressive foreign policy and its illegal war. Strengthening partnership with the European countries and exploring routes like the Trans-Caspian Pipeline can enhance stability but require cooperation due to geopolitical tensions and environmental risks.

- **Political complexities** include territorial disputes among the five littoral states (Kazakhstan, Russia, Azerbaijan, Turkmenistan and Iran), with Russia and Iran exerting significant influence. Regional tensions, such as military build-ups and oil extraction disputes, add to instability.

Annex 2 (Table 22) highlights key international and regional treaties shaping legal, environmental and resource extraction frameworks around the Caspian Sea, detailing their implementation status and ongoing challenges. These agreements play a foundational role in establishing regional governance for the Caspian Sea, yet face persistent challenges in enforcement, political complexities and economic interests that impact their practical effectiveness. Additionally, they must be adapted to address the emerging needs of hydrogen production and resource management, ensuring that regional cooperation supports sustainable energy development.

3. Black Sea

The **Black Sea** is a strategic body of water bordered by Ukraine, Russia, Georgia, Turkey, Bulgaria and Romania. Following Russia's illegal full-scale invasion of Ukraine in 2022, the blockade of Ukrainian ports by Russian forces has disrupted key shipping lanes, especially for grain exports, constituting a violation of international law that has severely impacted global food security and global commodity markets. This illegal blockade has led to higher operational costs, logistical challenges and disrupted maritime traffic, representing one of many destabilising consequences of Russia's unprovoked aggression.

- **Strategic responses** include the increased use of Romanian and Bulgarian ports, along with the expansion of European rail and road networks. Nations are seeking alternative energy sources and investing in infrastructure.
- The **Black Sea** lacks specialised infrastructure for hydrogen transport, complicating logistics. Political instability in the region affects the viability of hydrogen transport routes, requiring careful planning and investment to ensure successful implementation.

[14] https://www.boell.de/en/2024/11/05/eu-and-azerbaijan-energy-partners-short-term-benefits-uncertain-future

[15] https://kun.uz/en/news/2024/12/30/uzbekistan-azerbaijan-kazakhstan-sign-pact-on-green-energy-corridor

Country	Port	Challenges
Turkey	Istanbul	Major hub influenced by regional and international tensions, particularly Russia's illegal war of aggression against Ukraine
	Zonguldak	Near conflict zones, heightened geopolitical risks
	Samsun	Sensitive to regional policies due to role in exports
Bulgaria	Varna	Relatively stable as EU member but susceptible to regional politics
	Burgas	Vital for the oil industry, must adhere to EU regulations
Romania	Constanta	EU's largest port, navigating EU and regional complexities
Ukraine	Odessa	Impacted by Russia's war, critical energy transit point
	Chornomorsk	Strategic location for military and trade, impacted by Russia's illegal war of aggression against Ukraine
Russia	Novorossiysk	Main port facing international sanctions and regional tensions due to Russia's war against Ukraine
	Sochi	Tourist port affected less by politics, but influenced by regional policies
Georgia	Batumi	Strategic for energy corridors, operations hinge on geopolitical stability
	Poti	Major trade gateway, operations influenced by Georgian politics
Abkhazia	Sukhumi	The disputed region faces continuous tensions affecting operations

Table 4: Key challenges and geopolitical dynamics for major ports in the Black Sea region

Key stakeholders and their influence on trade route management

Key stakeholders in hydrogen development play a crucial role in ensuring the growth of hydrogen infrastructure:

- **Governments**: Ensure energy security, oversee infrastructure and maintain trade relations to support hydrogen markets.
- **Regulatory bodies**: Set safety, emissions and trade standards to ensure safe, sustainable hydrogen infrastructure.
- **International organisations**: Promote global standards and cooperation, helping manage trade disputes and support regional alignment.
- **Environmental agencies and NGOs**: Monitor ecological impacts, advocate for biodiversity and shape public opinion for sustainable hydrogen projects.
- **Logistics providers and private sector**: Manage infrastructure, transport and supply chains to enable efficient hydrogen transit and support its commercialisation.

These stakeholders collaborate to create a stable, efficient and sustainable hydrogen infrastructure. The list of **main stakeholders** involved in shaping hydrogen initiatives is detailed in **Annex 2** (Table 23), highlighting the role of key public and private organisations, government ministries and international entities across the Caspian region.

Regional synergies for sustainable hydrogen exports

Existing oil and gas infrastructure in the region can be adapted to support hydrogen transport, utilising pipelines, storage, ports and rail networks for cost-effective distribution. **Annex 2** (Table 24) outlines various transportation methods for oil, natural gas and potentially hydrogen from Kazakhstan, including pipelines, rail and maritime routes, and highlights how infrastructure can be adapted for hydrogen transport.

- **Oil:** The Caspian Pipeline Consortium (CPC) is the primary route for transporting oil from Kazakhstan to Azerbaijan and Europe, with rail used for smaller volumes. Oil is processed at the Sangachal Terminal and exported via the Baku-Tbilisi-Ceyhan (BTC) pipeline to Turkey and Europe.
- **Gas:** The CPC pipeline is also a key route for natural gas, along with the Kazakhstan-China Gas Pipeline for direct exports to China. Gas is integrated into regional networks for export, with LNG export being an emerging method.
- **Hydrogen:** Pipeline construction and the adaptation of existing gas pipelines are possibilities for hydrogen transport, including the Trans-Caspian International Transport Route.
- ***Compressed hydrogen*** is transported in high-pressure cylinders for smaller-scale distribution.
  - Liquid hydrogen can be shipped from Aktau Port to Baku, Azerbaijan, then to European markets via maritime routes.
- Hydrogen carriers, such as ammonia and methanol, can transport hydrogen in chemical forms.
- Rail and maritime transport also offer potential options for hydrogen distribution to nearby regions and Europe.

However, challenges remain, including the need for infrastructure upgrades and Kazakhstan's limited water resources for electrolysis. An alternative is exporting Kazakhstan's renewable electricity to water-rich areas in Azerbaijan, Turkey or Georgia, where hydrogen can be produced closer to European markets. **Annex 2** (Table 25) outlines major cross-border initiatives aimed at exporting green energy from the Caspian region to Europe, detailing capacities, routes, investment costs and geopolitical considerations for submarine cable and electricity grid interconnections.

Key advantages include:

1. **Renewable energy base:** Kazakhstan has strong wind and solar potential, providing a cost-effective base for green hydrogen production.
2. **Proximity to water resources:** Azerbaijan, Turkey and Georgia offer access to water resources and coastal locations for efficient electrolysis and transportation.
3. **Logistics and market access:** Producing hydrogen near Turkey or Georgia offers easier access to Europe, lowering transport costs and risks.
4. **Lowering production costs:** Combining Kazakhstan's renewable energy with production hubs in Turkey and Georgia can significantly reduce hydrogen production costs.
5. **Geopolitical and trade alliances:** A strategic partnership between Kazakhstan, Azerbaijan, Turkey and Georgia can support stable hydrogen exports to Europe, strengthening trade ties and boosting investment.

ESCAP and UNECE are working on a plan to enhance energy connectivity within the Economic Cooperation Organization (ECO) region. Azerbaijan, Kazakhstan and Uzbekistan are also collaborating to integrate power grids and export green energy to the EU, with Uzbekistan targeting 27 GW of renewable energy by 2030.

3.1.4 Environmental implications of increased hydrogen exports and transportation

Kazakhstan's ambition to expand hydrogen exports can yield considerable economic and environmental benefits, yet it also entails challenges related to production, transportation and broader ecological impacts. Careful planning, robust regulations and sustainable practices are essential to balance economic growth with environmental stewardship.

Production impacts

Producing green hydrogen via electrolysis offers significant potential to reduce greenhouse gas emissions by relying on renewable energy. However, high-pressure systems and hazardous chemicals involved in hydrogen production introduce risks to ecosystems if equipment fails or is mishandled. Implementing strict safety protocols and conducting environmental risk assessments are critical to mitigate these hazards.

Water resource management

Green hydrogen production through electrolysis requires significant water resources, with approximately 15 to 30 litres of water needed in total per kg of hydrogen produced[16]. This demand poses a challenge for Kazakhstan, given its limited water resources, particularly in arid and semi-arid regions.

The increased water extraction for hydrogen production may adversely affect local ecosystems and compete with other sectors, such as agriculture.

According to **Hyrasia One**, while Kazakhstan possesses substantial water resources essential for hydrogen production, effective management of these resources is critical due to competing demands from other sectors, particularly agriculture. In their opinion, it is vital for the hydrogen sector to ensure that its water consumption does not negatively impact other economic activities, making sustainable water management what they consider a key concern for the successful implementation of hydrogen projects in Kazakhstan.

Land use and ecosystem impact

Infrastructure development for hydrogen production may necessitate significant changes in land use. Construction activities could lead to soil contamination from spills or leaks, impacting soil health and agricultural productivity.

Transportation implications

Infrastructure vulnerabilities

Temperature sensitivity and extreme weather conditions pose significant challenges to hydrogen transportation infrastructure:

Rising temperatures and extreme weather events like floods and earthquakes can damage transportation infrastructure and increase the risk of hydrogen leaks.

Kazakhstan's extreme winters and hot summers can affect the performance of hydrogen storage and transport infrastructure, potentially causing stress fractures, leaks or failures.

Spells of hot and cold weather generate higher energy demand, potentially disrupting the power required for hydrogen compression or liquefaction during transportation.

Biodiversity risks

The construction of new pipelines, roads or storage facilities for hydrogen export can disturb natural habitats and biodiversity along trade routes. While pipelines are cost-effective for transporting large volumes of hydrogen over land, they involve complex permitting and can lead to habitat disruption and increased land use.

Safety and environmental risks

Transporting hydrogen presents several safety and environmental risks:

- Liquefied hydrogen (LH_2) transportation by sea requires specialised ships with cryogenic tanks, posing risks to marine ecosystems and coastal communities in case of malfunctions.
- Transporting hydrogen as ammonia (NH_3) involves risks associated with its toxicity and potential to form nitrous oxide (N_2O), a potent greenhouse gas.
- High-pressure containers and pipelines pose explosion and fire risks, threatening nearby communities and potentially causing severe environmental damage.

Regulatory considerations

The push for increased hydrogen exports may prompt Kazakhstan to strengthen its environmental regulations to align with international standards. This could lead to improved domestic environmental practices, although it may also pose challenges for local industries that must adapt to new regulations. Additionally, environmental groups and communities in neighbouring countries may oppose trade routes passing through ecologically sensitive areas, potentially imposing restrictions and increasing costs and logistical hurdles.

In conclusion, while hydrogen exports from Kazakhstan offer significant potential for economic growth and international cooperation in energy transition efforts, careful planning and sustainable practices are essential to address the environmental challenges associated with production and transportation.

[16] Deutsche Energie-Agentur (Publisher) (dena, 2023). The Role of Water for Sustainable Hydrogen Production in Kazakhstan – Part I: Water management for the production of sustainable hydrogen. Berlin: Deutsche Energie-Agentur GmbH.

3.2 Decarbonisation potential of exported goods

The integration of green hydrogen into the economies of Central Asia presents a transformative opportunity for sustainable development and economic diversification. This strategic shift aligns with global efforts to transition towards cleaner energy sources and positions Central Asian countries as potential leaders in the burgeoning green hydrogen market.

Under the International Renewable Energy Agency's (IRENA's) 1.5°C scenario, green hydrogen accounts for approximately 12% of global greenhouse gas (GHG) emissions abatement by 2050. This is achieved by decarbonising hard-to-abate sectors and through its use as a sustainable feedstock for industrial applications. Beyond its role in reducing emissions, the sustainable deployment of green hydrogen offers broader benefits, including enabling green industrialisation, fostering energy independence, expanding participation in global trade and markets, and driving substantial job creation. For the Central Asia region, the adoption of green hydrogen could catalyse industrial innovation, enhance energy security and set the foundation for a diversified economic future.

Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan each possess unique resources and industrial capabilities that can benefit from the adoption of green hydrogen technologies (Table 5).

Country	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Industry	Mining	Mining	Mining	Natural gas	Metallurgy
	Metallurgy	Metallurgy	Metallurgy	Petroleum industry	Chemical
	Agriculture	Agriculture	Agriculture	Agriculture	Agriculture
	Chemical	Textile	Electricity generation	Textiles	Textiles

Table 5: Harnessing green hydrogen

Kazakhstan's export portfolio, dominated by mineral products and hydrocarbons, harbours significant potential for integrating hydrogen across key sectors such as mining, metallurgy and agriculture. The country's commitment to reducing its carbon footprint is evident in its Strategy for Achieving Carbon Neutrality by 2060, which emphasises hydrogen as a critical component in decarbonising various industries.

Kyrgyzstan's agricultural sector not only plays a vital role in food security but also has the potential to leverage green hydrogen for sustainable practices. With significant contributions to GDP and employment, the integration of hydrogen technologies can enhance productivity while reducing emissions. The textile industry in Kyrgyzstan also stands to benefit from hydrogen integration, particularly in energy-intensive processes like fabric dyeing and finishing.

Tajikistan aims to produce up to 1 million tonnes of green hydrogen by 2040, utilising its abundant hydropower resources to support this initiative. This ambitious target underscores the country's commitment to diversifying its energy sources and fostering economic growth through sustainable practices. The integration of green hydrogen into Tajikistan's export industries – such as gold, aluminium and cotton – can significantly reduce greenhouse gas emissions while enhancing competitiveness.

In **Turkmenistan**, despite heavy reliance on hydrocarbons, there is an increasing recognition of the need to transition towards renewable energy solutions. The government is exploring pathways for both blue and green hydrogen production, aiming to reduce emissions while capitalising on its extensive natural gas resources. The integration of green hydrogen into the agriculture sector can further enhance sustainability by reducing methane emissions associated with traditional farming practices.

Uzbekistan's export structure has been characterized by significant dynamics in recent years, with key sectors such as precious metals, textiles, chemicals and agriculture showing strong growth potential. The country has set ambitious climate goals and recognises that integrating green hydrogen technologies can help achieve these targets while enhancing economic competitiveness.

- The integration of green hydrogen in the mining sector could potentially reduce GHG emissions by approximately 30% to 80%, particularly by replacing diesel fuel in heavy transport vehicles and optimising processing operations. This aligns with findings that suggest significant reductions in emissions when transitioning to hydrogen-powered equipment.
- The use of green hydrogen in metallurgy could achieve GHG reductions of approximately 60%

to 90%, particularly in steel production processes where traditional methods rely heavily on carbon-intensive fuels.
- The deployment of green hydrogen in electricity generation could potentially reduce GHG emissions by 30% to 50% compared to traditional fossil fuel-based generation methods.
- The textile industry could see potential GHG reductions of about 25% to 30%, primarily from adopting clean heating systems and transitioning to hydrogen-powered machinery.
- The agricultural sector could achieve GHG reductions of approximately 20% to 25%, especially through the modernisation of machinery and sustainable practices like green fertiliser production.
- The transition to green hydrogen in the petroleum sector could result in GHG reductions of approximately 40% to 70%, particularly through the decarbonisation of refining processes and the adoption of hydrogen fuel cells in transportation.

3.2.1 Republic of Kazakhstan

Kazakhstan's export portfolio has shown a modest increase, rising from $51.82 billion in January-August 2023 to $53.55 billion in the same period of 2024, reflecting growth of 3.3%. Despite the continued dominance of mineral products, this data indicates strategic diversification efforts and shifts in export composition.

Export composition breakdown

1. Mineral products. In 2023, mineral products constituted 65.9% of total exports, valued at $34.16 billion, and slightly increased to 66.0% ($35.35 billion) in 2024. The fuel and energy subcategory remained stable at 58.9% of total exports, with a slight value increase from $30.55 billion to $31.55 billion.
2. Metals and metal products. This sector grew from 12.7% to 13.4% of total exports, with values increasing from $6.58 billion to $7.12 billion.
3. Chemical industries. Significant expansion was observed, rising from 6.2% to 7.5% of exports, with values increasing from $3.22 billion to $4.02 billion.
4. Agricultural products. Experienced a decline from 7.1% to 5.6% of exports, with values dropping from $3.66 billion to $3.01 billion.

Kazakhstan is actively pursuing non-oil export targets, which have grown significantly – from $26.5 billion in 2022 to $35.1 billion (44.7% of total exports) in 2023 – with a goal of reaching $41 billion by 2025. Key focus areas for this diversification include food and light industry products, metallurgical and chemical products, equipment and electronics, and automotive components. Leading non-raw material exports contribute significantly to the economy, with top contributors including uranium, copper products, ferrochrome and distillates – collectively accounting for approximately 40% of total exports.

Green hydrogen integration potential in key export industries

Kazakhstan has developed industries in steel, ammonia and cement production – sectors where green hydrogen is typically seen as a crucial decarbonisation pathway. In particular, the mining industry of Kazakhstan is responsible for approximately 30% to 80% of emissions, while the remaining 20% to 70% stem from other industrial processes such as ore processing, transportation and energy consumption in mining operations[17]. The government plans to increase mineral production by 40% by 2029, which aligns well with the integration of hydrogen technologies to enhance sustainability.

Kazakhstan's current export portfolio presents multiple opportunities for integrating green hydrogen across key industries and harbours substantial carbon reduction potential.

[17] https://unfccc.int/documents/271261

Mining sector

Kazakhmys reflected on the adaptability of hydrogen technologies in the mining sector, emphasising, "We are exploring the use of hydrogen-powered vehicles, which could significantly reduce diesel consumption and emissions." They expressed interest in "establishing pilot projects that incorporate hydrogen as an energy source for mining operations, especially given the high fuel costs associated with traditional energy sources in remote locations".

- Partner with manufacturers of mining equipment to develop and test hydrogen-powered machinery, focusing on transitioning heavy mining vehicles from diesel to hydrogen fuel. Set up hydrogen production facilities near mining sites to ensure a reliable supply for heavy transport vehicles and mineral processing operations. The government plans to increase mineral production by 40% by 2029, which aligns well with the integration of hydrogen technologies.
- Systematically integrate hydrogen technologies into mineral processing operations, utilising hydrogen in reduction processes instead of traditional fossil fuels.
- Improve logistics for transporting green hydrogen from production facilities to mining sites, ensuring an efficient and reliable supply chain.

ERG also contributed insights, stating that "while hydrogen-powered trucks were considered, they were found to be less economically viable compared to electrified options, especially when using green electricity". They suggested that collaboration with equipment manufacturers is essential, noting the need to partner with them to "develop and test hydrogen-powered machinery, focusing on transitioning heavy mining vehicles from diesel to hydrogen fuel".

Metallurgy

Hyrasia One representatives highlighted that "hydrogen could play a transformative role in the metallurgy sector by serving as a cleaner energy source and a reducing agent in metal production". They stated, "The shift towards green hydrogen aligns with global trends aiming to reduce carbon emissions in heavy industries", adding that the implementation of hydrogen could enhance the sustainability of Kazakhstan's metallurgical output

- Launch pilot projects that utilise hydrogen in Direct Reduced Iron processes, which convert iron ore into sponge iron without the use of coke. This approach is vital as Kazakhstan's metallurgical industry represents 56.5% of all non-raw material goods exports.
- Set up facilities that produce green hydrogen through electrolysis powered by renewable energy sources.

Kazakhmys discussed hydrogen's potential in metallurgy, specifically noting, "Hydrogen could replace fossil fuels in high-temperature processes, such as those used in steelmaking." They acknowledged the necessity of understanding the "economic viability and technical requirements of such a transition, including the infrastructure needed for hydrogen production and supply".

- Retrofit existing blast furnaces to accommodate hydrogen injection alongside traditional processes, thereby reducing carbon emissions from steel production.
- Collaborate with global leaders in hydrogen technology to share knowledge, best practices and technological innovations that can optimise hydrogen use in metallurgical processes.
- Focus on research and development aimed at optimising hydrogen use in metallurgical processes, including exploring alternative methods such as direct electrolysis of iron ore.

ERG mentioned ongoing efforts, revealing that they initiated research on “replacing current fuels with hydrogen in operations, particularly in industrial heating and technological processes where coal and fuel oil are currently used”. While recognising the technical feasibility, they highlighted that “hydrogen applications in these sectors were found to be quite expensive and not economically viable without significant government support”.

The speaker specifically highlighted a hot briquetted iron (HBI) project in the Kostanay region, stating, “This project is currently in the design phase and could be realised within 10 years if favourable conditions emerge.” This structure provides clarity on the contributions from different speakers regarding the potential applications of hydrogen in the mining and metallurgy sectors in Kazakhstan.

Chemical industry

- Traditional ammonia production emits about 1.8 tonnes of CO_2 per tonne produced. By substituting conventional hydrogen with green hydrogen, this process could become nearly carbon neutral. Kazakhstan has substantial experience with grey hydrogen production for domestic industrial use, having produced around 12 PJ of grey hydrogen in 2020.
- Beyond ammonia, green hydrogen can be utilised in producing various chemicals and synthetic fuels, further enhancing sustainability across the chemical industry. The potential for green ammonia production aligns well with Kazakhstan’s existing ammonia production capabilities.

Hyrasia One representatives highlighted hydrogen’s significant potential in Kazakhstan’s chemical industry, particularly for synthesizing methanol and ammonia, aligning with the country’s strategic goals to enhance chemical manufacturing capabilities and reduce emissions.

Kazakhmys is actively exploring the feasibility of integrating hydrogen into its processes, including capturing CO_2 emissions for methanol production. Developing a sustainable hydrogen supply chain is essential for Kazakhstan to tap into global chemical markets, capitalising on the growing demand for green chemicals while creating opportunities for producing value-added chemicals sustainably.

Agriculture

The discussion highlighted hydrogen’s potential in agriculture, particularly for producing green ammonia, a crucial fertiliser component.

Kazakhmys emphasized that green ammonia production from hydrogen could fulfil the agricultural sector’s demand for sustainable fertilisers while mitigating nitrogen-related emissions. They noted the significant water and energy requirements for hydrogen production, underscoring the need for reliable resources to support agricultural needs. Additionally, hydrogen is seen as a potential energy source for farming inputs, and transitioning to green hydrogen could significantly reduce the environmental impact of traditional fertilisers reliant on fossil fuels.

Hyrasia One representatives stressed that agricultural stakeholders would need incentives to adopt hydrogen-based solutions, requiring supportive policies and technology investments. This transition could position Kazakhstan as a leader in sustainable agriculture and boost the hydrogen market.

- Green hydrogen can be used in ammonia production for fertilisers, significantly reducing emissions associated with traditional methods. This transition is essential given that ammonia is a key input for fertilisers used extensively in agriculture.
- Explore the use of green hydrogen in tractors and irrigation systems to improve efficiency and reduce fossil fuel dependency in agricultural operations.
- Investigate innovative applications of green hydrogen in irrigation systems, which can enhance water efficiency and sustainability in agriculture.

KMG Engineering's research details a hydrogen supply strategy in Kazakhstan, highlighting immediate opportunities for domestic market development for hydrogen use in the chemical and refinery sectors due to existing infrastructure. It identifies mid-term prospects in steel production and heavy transport, with long-term potential in industrial heating and aviation, pending significant technological advances (Fig.1).[18]

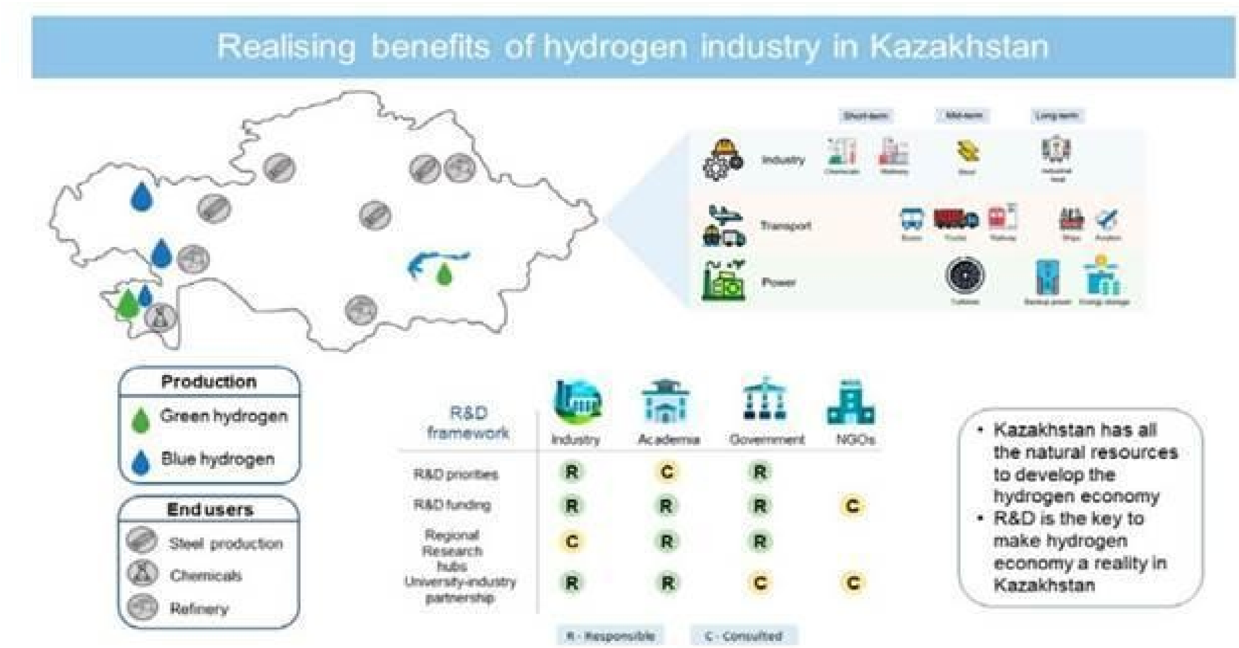

Figure 1: Potential hydrogen supply and end-users in Kazakhstan (Abuov, Yerdaulet, et al. "Realizing the Benefits of a Hydrogen Industry in Kazakhstan." International Journal of Hydrogen Energy, 2024. Web.)

[18] https://www.sciencedirect.com/science/article/abs/pii/S0360319923026496

3.2.2 Kyrgyz Republic

The Kyrgyz Republic's trade performance for January-August 2024 showed positive momentum with total exports reaching $2,154.2 million (13.1% year-on-year growth), though maintaining a substantial trade deficit of $6,305.5 million, reflecting ongoing structural challenges in achieving trade balance despite export growth.[19]

Export composition breakdown

Primary export sectors reached $2,154.2 million in January–August 2024[20]

- Gold and precious metals: 34% of total exports
- Mineral products: 15% of total exports
- Textiles: 12% of total exports
- Agricultural products: 9% of total exports.

Green hydrogen integration potential in key export industries

This emissions profile makes Kyrgyzstan one of the lowest emitters in the region, with its CO_2 intensity of GDP approximately 12% higher than the global average.[21] The agricultural sector of Kyrgyzstan contributes 14.68% to GDP and employs 40% of the labour force. It has already achieved a reduction in GHG emissions by 21.18% compared to 1990 levels.

The Kyrgyz government aims to decarbonise its energy sector to meet its commitments under the Paris Agreement. This includes a target of a 16% reduction in GHG emissions by 2025–2030 without international support and up to 44% with international assistance. Moreover, the National Development Strategy (2018–2040) outlines plans to increase renewable energy production (excluding large-scale hydropower) to 10% of the total energy supply by 2040.

The Kyrgyz Republic's export structure presents significant opportunities for green hydrogen integration to reduce carbon emissions while maintaining economic competitiveness.

Mining

- Establish hydrogen production facilities near mining sites to ensure a reliable supply for heavy transport vehicles and mineral processing operations. This localised production can reduce transportation costs and enhance operational efficiency.
- Collaborate with manufacturers of mining equipment to develop and test hydrogen-powered machinery. This partnership should focus on transitioning heavy mining vehicles from diesel to hydrogen fuel, which can significantly lower emissions.
- Enhance logistics for transporting green hydrogen from production facilities to mining sites. Given the mountainous terrain and underdeveloped transport infrastructure, optimising logistics may require significant investment.
- Systematically integrate hydrogen technologies into mineral processing operations, utilising hydrogen in reduction processes instead of traditional fossil fuels.

Metallurgy

- Initiate pilot projects that utilise hydrogen in DRI processes, converting iron ore into sponge iron without the use of coke. This method can drastically reduce carbon emissions associated with traditional steelmaking.
- Establish facilities that produce green hydrogen through electrolysis powered by renewable energy sources. This ensures a sustainable supply of hydrogen for metallurgical processes.
- Retrofit existing blast furnaces to accommodate hydrogen injection alongside traditional processes, which can lower carbon emissions significantly.
- Partner with global leaders in hydrogen technology to share knowledge, best practices and technological innovations, facilitating a smoother transition to greener practices.
- Invest in R&D focused on optimising hydrogen use in metallurgical processes, including

[19] https://www.ceicdata.com/en/indicator/kyrgyzstan/total-exports
[20] https://stat.gov.kg/media/publicationarchive/e48671aa-a0ae-49ce-a1e7-148a4db68efa.zip
[21] https://unece.org/sites/default/files/2024-09/kyrgyzstans%20(7).pdf

exploring alternative methods such as direct electrolysis of iron ore.

Textile industry

- Invest in clean heating systems powered by green hydrogen.
- Transition to hydrogen-powered industrial equipment throughout the manufacturing chain, which can significantly lower operational emissions while enhancing productivity.
- Ensure that the transition aligns with international sustainability standards to improve market competitiveness and meet growing global demand for sustainably produced textiles.

Agricultural processing

- Invest in hydrogen-fuelled machinery for farming and processing operations.
- Develop facilities that utilise green hydrogen for ammonia production, transforming agricultural practices towards more sustainable methods.
- Implement hydrogen-powered refrigeration systems in cold chain logistics to enhance energy efficiency and reduce emissions associated with food storage and transportation.

3.2.3 Republic of Tajikistan

In 2023, Tajikistan's export portfolio showcased a diverse range of products, primarily dominated by precious metals, agricultural goods and aluminium. In 2022, Tajikistan exported goods worth approximately $2.41 billion, marking a significant increase from $1.41 billion in 2017. The latest quarterly data for 2024 showed exports at $384.29 million in Q2, down from $613.56 million in Q1 of 2024.

Export composition breakdown

Tajikistan's export portfolio is characterised by heavy reliance on a few key sectors, primarily gold, aluminium and cotton, which together account for over 75% of total exports.

The importance of aluminium is underscored by its status as a primary industrial product, while cotton remains a staple agricultural export. Generated mainly from hydroelectric power, electricity ranks as the third most significant export product, reflecting Tajikistan's abundant water resources. Notable export commodities are:

- Gold: $644 million
- Precious metal ores: approximately $249 million. This category includes various ores containing precious metals, contributing to the overall mining output.
- Raw cotton: about $212 million
- Copper ore: $203 million
- Raw aluminium: around $174 million

Green hydrogen integration potential in key export industries

Tajikistan's energy policy emphasises diversifying its energy sources beyond hydropower to include solar and wind energy. The government has set a target for non-hydropower renewables to account for 10% of the energy mix by 2030. This diversification is essential for mitigating the risks associated with climate variability that can affect hydropower generation.

Tajikistan aims to produce 500,000 tonnes of green hydrogen by 2030, with plans to double this output by 2040. This ambitious target is part of a broader strategy to leverage the country's hydropower resources, which currently generate nearly all of its electricity. Tajikistan's Green Economy Development Strategy emphasises the importance of integrating green technologies, including hydrogen, into the national energy mix to reduce greenhouse gas emissions and reliance on fossil fuels.

Mining sector (gold and precious metal ores)

- Transitioning from diesel-powered machinery to hydrogen fuel cell vehicles can significantly reduce greenhouse gas emissions in mining operations.
- Utilising green hydrogen in the refining processes of gold and precious metals can replace fossil fuels used for heating.
- Partnering with international firms specialising in hydrogen technology can help develop tailored solutions for the mining sector.
- Given Tajikistan's mountainous terrain and underdeveloped transport infrastructure, optimising logistics for transporting green hydrogen from production facilities to mining sites is crucial.

Metallurgy (aluminium production)

- Establish facilities that utilise renewable energy (primarily hydropower) to produce green hydrogen through water electrolysis. This can be done by retrofitting existing power plants or building new ones specifically for hydrogen production.
- Develop infrastructure for safe storage and transportation of hydrogen within the aluminium production facilities and to other industrial users.
- Retrofit existing aluminium smelters to accommodate hydrogen use without significant downtime.
- Initiate pilot projects to demonstrate the feasibility of hydrogen use in aluminium smelting. Collaborate with international partners to share knowledge and technology.

Agriculture (raw cotton production)

- Provide financial incentives for farmers to adopt hydrogen-powered machinery, such as tractors and irrigation systems.
- Establish demonstration farms that utilise hydrogen technology to showcase its benefits in reducing fossil fuel dependency.
- Use green hydrogen to produce ammonia fertilisers through the Haber-Bosch process, reducing reliance on traditional fossil fuel-based ammonia production.
- Set up small-scale ammonia production units powered by green hydrogen near agricultural zones.
- Powering advanced irrigation systems that require energy-intensive operations. Utilising hydrogen as an energy source can improve water management practices in agriculture.

Electricity generation

- Expand electrolyser capacity at hydropower plants to produce sufficient quantities of green hydrogen, particularly during peak generation periods when electricity supply exceeds demand.
- Invest in infrastructure for transporting green hydrogen, including pipelines or specialised transport vehicles, targeting regional markets.
- Engage with neighbouring countries (e.g., Kazakhstan, Uzbekistan) to establish trade agreements for exporting green hydrogen.

3.2.4 Turkmenistan

In 2022, Turkmenistan's total exports amounted to approximately $2.506 billion. Turkmenistan's export structure is heavily skewed towards hydrocarbons, particularly natural gas and petroleum products, which dominate its export revenues. While there is some diversification with agricultural products like cotton, the overall reliance on fossil fuels poses risks related to market volatility and global energy transitions. The country exports a total of 418 different products to 58 trading partners, indicating a moderate level of diversification in its export portfolio.

Export composition breakdown

- Turkmenistan exports a total of 418 different products, although the export portfolio is heavily skewed towards a few key commodities.
- Natural gas ($1,244.4 million) is the leading export product, accounting for nearly 50% of total exports.
- Petroleum products (petroleum oils $513.1 million and other products $241.9 million)
- Cotton ($223.5 million) and uncombed cotton ($25.1 million)

Recent trends

The government has reported a steady increase in gas production, with exports to China facilitated by an extensive pipeline network. In July 2024, a new contract was signed with Iran to export an additional ten billion cubic metres of natural gas annually, indicating efforts to diversify gas markets beyond China.

In addition to hydrocarbons, Turkmenistan has seen substantial growth in agricultural exports, particularly melons and watermelons. In the first seven months of 2024, watermelon exports increased tenfold compared to the entire volume exported in 2022.

The country has invested in chemical production facilities, including those for urea and polypropylene, which are increasingly part of its export portfolio.

Green hydrogen integration potential in key export industries

Turkmenistan's greenhouse gas (GHG) emissions are primarily driven by its energy sector, which is heavily reliant on fossil fuels, particularly natural gas. As of the latest data, Turkmenistan contributes approximately 0.43% of global GHG emissions, ranking as the 37th largest emitter worldwide. In 2020, the country emitted around 194 million metric tonnes of CO_2 equivalent ($MtCO_2e$), reflecting a decrease of 10.2% from the previous year. The energy sector is responsible for over 85% of total GHG emissions, with electricity and heat generation alone contributing approximately 27%. The agriculture sector, while significant, contributes a smaller share at 12.4%, primarily through methane emissions from livestock and agricultural practices. The industrial processes sector accounts for about 1.9%, indicating a relatively lower impact compared to energy and agriculture.

In its revised Nationally Determined Contribution (NDC) submitted in January 2023, Turkmenistan committed to an unconditional target of reducing emissions by 20% by 2030 compared to 2010 levels under a business-as-usual scenario. Turkmenistan's energy strategy is increasingly focused on diversifying its energy sources and integrating renewable energy technologies, particularly green hydrogen. The government recognises the need to reduce reliance on fossil fuels and mitigate environmental impacts, aiming to position itself as a leader in sustainable energy production.

Turkmenistan has set ambitious targets for green hydrogen production, with plans to develop infrastructure that can facilitate the generation of hydrogen from renewable sources like solar and wind energy. By leveraging its extensive natural gas resources, the country aims to explore both blue and green hydrogen production pathways, potentially producing 1.82 to 5.76 million tonnes of hydrogen annually by 2040. This initiative aligns with the global push towards cleaner energy solutions and supports the country's economic diversification efforts.

Mining and natural gas industry

The mining sector, which includes the extraction of minerals like gold, copper and lead, can transition to hydrogen-powered equipment to reduce reliance on diesel fuels.

- Integrate into the direct reduction process of iron ore for steel production, replacing carbon-intensive methods that rely on coking coal.
- Implement technologies such as steam methane reforming (SMR) combined with carbon capture and storage (CCS) to produce blue hydrogen from natural gas. This can serve as a transitional step towards fully green hydrogen production.
- Develop electrolyser facilities powered by renewable energy sources (e.g., solar or wind) to produce green hydrogen. This can diversify the energy portfolio and reduce reliance on fossil fuels.

Petroleum industry

- Explore the use of green hydrogen as a feedstock in refining processes to produce cleaner petroleum products. This could involve retrofitting existing refineries to accommodate hydrogen use.
- Promote the development of hydrogen fuel cell vehicles for transportation within the petroleum sector, reducing reliance on diesel and petrol.

Agricultural sector (cotton production)

- Encourage the adoption of hydrogen-powered tractors and irrigation systems in cotton farming.
- Utilise green hydrogen in the production of ammonia fertilisers for cotton cultivation, decreasing reliance on carbon-intensive production methods.
- Introduce hydrogen-powered machinery for farming operations, including tractors and irrigation systems.

3.2.5 Uzbekistan

Uzbekistan's export portfolio has been characterized by significant dynamics in recent years, reflecting the country's economic reforms and strategic trade relationships. As of the first half of 2024, Uzbekistan's foreign trade turnover reached approximately $31.8 billion, with exports totaling $12.99 billion, marking a 5.5% increase compared to the same period in 2023.

Export composition breakdown

- Precious stones and metals: Gold remains Uzbekistan's largest export, accounting for approximately $5.18 billion in 2022, representing about 21% of total exports.
- Textiles and cotton products: As one of the world's largest cotton producers, Uzbekistan exported non-retail pure cotton yarn valued at $1.39 billion in 2022.
- Natural gas and petroleum products reached around $934 million, with significant volumes also exported as part of the energy sector.
- Agriculture, particularly fruits and vegetables, contributed around $851.5 million, with significant growth observed in these sectors.
- Chemicals and fertilisers accounted for approximately $764 million in exports

Recent trends

In the first half of 2024, Uzbekistan's agricultural exports surged by 21%, driven primarily by a significant increase in fruit and vegetable exports, which totaled approximately 1,000.6 thousand tonnes valued at around $607.3 million.

The textile sector remains crucial, with textile product exports reaching $1.53 billion, despite a slight decline from previous years. The primary components were yarn (46.2%) and finished products (38.1%)

Green hydrogen integration potential in key export industries

Uzbekistan's total GHG emissions were approximately 206 million tonnes CO_2 equivalent in 2021. The energy sector in Uzbekistan is a major contributor to greenhouse gas (GHG) emissions, accounting for approximately 76% to 89% of total emissions, with total emissions reaching around 116.1 million tonnes of CO_2 equivalent ($MtCO_2e$) in 2021. Key sources of these emissions include fugitive emissions from oil and gas extraction, which comprise nearly half of the sector's total emissions, and electricity generation, where natural gas dominates the energy mix, constituting about 88% of electricity production, while renewable sources contribute only about 0.9%. Agriculture is the second-largest emitter of GHGs in Uzbekistan, contributing about 15.6% of total emissions. In 2021, the sector's emissions were approximately 32.25 million tonnes of CO_2 equivalent, reflecting a substantial increase of 172.7% since 1990.

Uzbekistan has set ambitious climate goals, including a commitment to reduce specific GHG emissions per unit of GDP by 35% by 2030 compared to 2010 levels. Uzbekistan aims for 25% renewable energy by 2026 and 40% by 2030, which aligns with hydrogen production needs. The country's main export industries – agriculture, energy production, chemicals, metals and electronics – are well-positioned to benefit from the integration of green hydrogen technologies.

Metallurgy, particularly steel production

- To adopt hydrogen-based direct reduction processes to significantly reduce its carbon footprint.
- Establishing partnerships with technology providers and investing in pilot projects will be crucial for scaling up these hydrogen applications.

Agriculture and food production

- Sustainable agricultural practices, such as producing ammonia-based fertilisers through decarbonised processes.
- Invest in research and development to explore the use of green hydrogen in irrigation systems, farm machinery and other agricultural processes.
- Develop training programmes for farmers and agricultural stakeholders on the benefits and applications of green hydrogen technologies to encourage adoption

Chemical industry

- Replacing grey hydrogen (produced from natural gas) with green hydrogen in ammonia synthesis.
- Expand pilot projects similar to the one with the JSC Uzkimyosanoat to demonstrate the feasibility of using green hydrogen in chemical processes, particularly ammonia synthesis.
- Collaborate with international partners experienced in hydrogen technology to facilitate knowledge transfer and investment.

Textile industry

- Invest in clean heating systems powered by green hydrogen to replace conventional fossil fuel-based heating methods in textile manufacturing.
- Transition to hydrogen-powered industrial equipment throughout the manufacturing chain, which can significantly lower operational emissions while enhancing productivity.
- Ensure that the transition aligns with international sustainability standards to improve market competitiveness and meet growing global demand for sustainably produced textiles.

3.3 Global competitive pressure

3.3.1 Global trends in hydrogen and PtX exports

The key global trends in the hydrogen and PtX (Power-to-X) product export market are significantly influenced by the global transition to low-carbon energy and the increasing demand for sustainable fuels. The main trends that have been identified are outlined below:

1. **Growing demand for low-carbon products**: The push toward decarbonisation is driving up demand for low-carbon products, particularly hydrogen, across various sectors. Hydrogen is becoming a critical energy carrier that can help reduce greenhouse gas emissions, especially in heavy industries, transportation and the power sector. Hydrogen demand reached 97 Mt in 2023 and is projected to exceed 100 Mt in 202422 with global production expected to reach 180 Mt by 2030, in line with net-zero emissions goals23.
2. **Power-to-X (PtX) technologies**: PtX technologies, which convert renewable energy into alternative fuels and materials, are gaining traction for their potential to decarbonise hard-to-abate sectors and solve energy storage challenges. PtX products like green ammonia, methanol and sustainable aviation fuels (SAF) are receiving attention for their role in sectors such as agriculture, chemicals and aviation. Europe is leading the way in PtX projects, with countries like Germany and France investing heavily in infrastructure. Germany is the leading country in PtX projects, accounting for 44% of all identified projects[24].
3. **Hydrogen derivatives**: Renewable hydrogen derivatives like green ammonia and methanol are gaining traction as essential inputs for fertilisers, chemicals and sustainable fuels. This presents a significant opportunity for suppliers with competitive production capabilities. Table 6 represents the most important products.

Product	Demand	Cost
Green hydrogen	Around 150 million tonnes per year (Mtpa) by 2050 under the Net Zero Emissions (NZE) Scenario	Below $2/kg
Green ammonia	350 million tonnes/year by 2050	$250–300/tonne by 2040–2050
Renewable methanol	250 million Mt of e-methanol and 135 million Mt of biomethanol by 2050	€/370–600/tonne by 2030
Sustainable aviation fuel	About 200 billion litres per year by 2050 (NZE scenario)	$5.50 and $8.00 per gallon currently

Table 6: Power-to-X products. https://www.iea.org/reports/global-hydrogen-review-2024

[22] https://www.iea.org/reports/global-hydrogen-review-2024/hydrogen-demand
[23] https://doi.org/10.3390/asec2023-15497
[24] https://doi.org/10.1016/j.ijhydene.2024.05.273

4. **Technological advancements**: Technological improvements in hydrogen production, storage and fuel cell technologies are progressing rapidly. High efficiency electrolysers and fuel cells, along with energy storage solutions like hydrogen storage material and underground storage, are advancing to improve production efficiency and reduce costs.
5. **Infrastructure and supply chain challenges**: The development of a robust hydrogen export infrastructure is key to unlocking the global hydrogen market. This includes pipelines, storage facilities and transportation options for hydrogen carriers like ammonia. While several countries have made progress, delays due to high costs and regulatory challenges are common. Notable projects, such as the Store&Go project in Germany and the HyBalance project in Denmark, are demonstrating large-scale hydrogen storage and integration with renewable energy sources.
6. **Global policy and regulatory support**: Government policies and regulatory frameworks play a critical role in driving the hydrogen market. Financial incentives, carbon pricing and emission reduction targets are being implemented by countries around the world. In particular, the EU's Green Deal financial incentives are encouraging investment in clean hydrogen production. Notably, the EU's renewable energy and carbon reduction initiatives, such as the Renewable Energy Directive (RED), are fostering the growth of PtX technologies.
7. **Environmental, social and financial challenges**: Environmental, social and governance (ESG) criteria are reshaping global investments, with financial institutions increasingly favouring projects that align with sustainability goals. As the demand for low-carbon hydrogen grows, the production of clean hydrogen could help reduce greenhouse gas emissions by up to 48% in the transportation sector by 2050. ESG performance is correlated with financial outcomes, as companies with strong ESG practices tend to outperform financially, attracting investment and reducing risks.

3.3.2 Trends shaping Kazakhstan's market position

Evaluating how global hydrogen and PtX (Power-to-X) technology trends might influence Kazakhstan's market position and export prospects highlights both opportunities and strategic challenges. Kazakhstan's market position can be strengthened if it capitalises on its renewable resources and geographic advantages. However, this will require alignment with global trends and significant investments in technology, infrastructure and policy frameworks.

Increased demand for low-carbon products and hydrogen

Rising global demand for low-carbon products, like green ammonia and methanol, is favourable for Kazakhstan. The country's abundant solar and wind resources give it a competitive advantage in producing green hydrogen at scale, a key factor as global markets shift toward sustainable products.

Kazakhstan's proximity to high-demand regions in Europe and Asia offers a strategic advantage. As the EU and Asian nations implement policies for decarbonisation, Kazakhstan can position itself as a preferred supplier of green hydrogen and hydrogen derivatives, if it can establish reliable production and export channels. The number of petrochemical plants operating is currently shown in Table 7. Moreover, there are several projects for future plants producing hydrogen-containing products (Table 8).

Plant	Feedstock	Product	Capacity, t/year	Location	Commissioning year
KPI Inc.	Propane	Polypropylene	500,000	Atyrau	2022
Neftekhim LTD	Refinery fluxes	MTBE, Polypropylene	48,000	Pavlodar	2009
Atyrau Refinery (KMG)	Refinery fluxes	Aromatics	630,000	Atyrau	2016
SAT Operating Aktau	Ethane	Polystyrene	200,000	Aktau	1980-1981
KazAzot	Natural gas	Ammonium nitrate	400,000	Mangystau	1978
Kazphosphate	Natural gas	Phosphoric acid	405,000	Zhambyl	2016
Shymkent chemical company	Refinery fluxes	MTBE	57,000	Shymkent	2021

Table 7: Petrochemical plants in operation in Kazakhstan25

Plant	Feedstock	Product	Capacity, t/year	Location	Commissioning year
KMG PetroChem	Ethane	Ethylene/polyethylene	1.25MMt/y	Atyrau	2028
Butadien	Butane	Butadiene rubber	187,000	Atyrau	2026
KazAzot	Natural gas	Ammonia and urea	660,000 ammonia / 395,000 nitric acid/ 500,000 ammonium nitrate	Mangystau	2022–2026
Kazphosphate	Phosphate rock and ammonia	Ammophos	500,000	Zhambyl	2023
Zhaik petroleum	Natural gas and carbon dioxide	Methanol	130,000	West-Kazakhstan	2024
Zhaik petroleum	Natural gas	Ammonia and urea	40,000 ammonia/ 100,000 urea	West-Kazakhstan	2029
Westgasoil Pte	Natural gas	Olefins	800,000	Atyrau	2027
Almex polymer	Refinery fluxes	Polypropylene	80,000	Shymkent	2025
Almex Petrochemical	Paraxylene	Terephthalic acid/ polyethylene terephthalate	600,000 Terephthalic acid/ 430,000 polyethylene terephthalate	Atyrau	2026

Table 8: Future petrochemical plants in Kazakhstan[26]

[25] https://www.giz.de/en/downloads/giz2025-en-kazakhstan-green-hydrogen-c-and-i-sector.pdf
[26] https://www.giz.de/en/downloads/giz2025-en-kazakhstan-green-hydrogen-c-and-i-sector.pdf

Growth in Power-to-X (PtX) technologies

Kazakhstan can diversify its economy through PtX technologies, producing green hydrogen, ammonia and synthetic fuels. Competing countries like Germany, Japan and Australia are investing heavily, and Kazakhstan must keep pace to remain competitive. The H_2Global programme in Germany uses a subsidy mechanism to support Power-to-X products such as ammonia and methanol. 'Green' hydrogen is becoming cheaper than 'grey' hydrogen in some regions, with BNEF estimates indicating that green ammonia could become cost-competitive with grey ammonia. Kazakhstan has the potential to produce cost-competitive green hydrogen from onshore wind, with interregional exports possible by 2035, according to World Bank CCDRs. Projects like Hyrasia One and Semurg Invest aim to establish ammonia export routes to the EU via the Caspian Sea. By investing in PtX, Kazakhstan can expand its exports to sectors like agriculture, chemicals and international transport.

Environmental, social and financial pressures

Global ESG criteria are driving investment flows, and Kazakhstan's compliance with environmental standards will impact its ability to attract green finance. Ensuring that hydrogen and PtX production align with low-emission goals will strengthen Kazakhstan's reputation as a sustainable energy producer.

Kazakhstan stands at a pivotal juncture in its journey toward establishing a robust green hydrogen economy. Section 3 has outlined the legislative, regulatory and infrastructure-related strides the country has made while emphasising the critical gaps that need to be addressed. The integration of renewable energy sources (RES) into hydrogen production is not merely a technical or economic endeavour – it requires careful alignment with international standards, robust support mechanisms and a commitment to sustainability.

Key challenges, such as economic, technological, geopolitical and environmental risks, as well as the effective implementation of Kazakhstan's hydrogen strategy, remain central to the country's path forward. Addressing these hurdles will require coordinated efforts between the government, private sector and international partners, fostering innovation and investment to ensure Kazakhstan's competitiveness in global hydrogen markets.

To realise these ambitions, securing sustainable and diversified financing mechanisms is paramount. Section 4 will explain the EU regulatory and certification requirements. Section 5 will look into the financial framework needed to support Kazakhstan's green hydrogen aspirations, exploring local conditions and opportunities for leveraging international funding programmes, particularly from the EU and Germany, to catalyse progress in this emerging sector.

4 Importability and regulatory requirements for hydrogen exports

4.1 EU legislative and regulatory frameworks for hydrogen imports

Kazakhstan, with its unique geographical location and abundant energy resources, has the potential to play a central role as an exporter of green hydrogen to the European Union (EU). However, establishing an efficient hydrogen economy requires not only technological and infrastructural advancements but also targeted regulatory adjustments.

This section outlines the EU legislative and regulatory frameworks for importing hydrogen. It outlines the production rules for hydrogen, together with the various definitions of RFNBOs, RCFs, LCFs, including the most important legislative tools such as the Renewable Energy Directive and the CBAM. Furthermore, the certification process for hydrogen traded in the EU is outlined, examples of the German certification system are given and implications for Kazakh producers are drawn.

For Kazakhstan, the lack of specific legal regulation represents a major challenge for the hydrogen sector. There is currently no specific legal framework (please consult section 2.2. for further details) or incentives for hydrogen production and export. This is hampering the development of the hydrogen economy in the country and causing uncertainty among investors.

Potential

Due to its geographical location and energy sources, Kazakhstan harbours significant potential to emerge as a key supplier of hydrogen to both the European Union (EU) and China. Estimates suggest that the production costs for green hydrogen could be $3.94 to $5.52 per kilogram when generated from a combination of solar and wind power, with a further decline to $2–$3 per kilogram.

Existing infrastructure projects such as the expansion of port facilities on the Caspian Sea could also efficiently support the export of hydrogen. Export via pipelines or the rail network is crucial here.

Challenges

Kazakhstan also faces significant challenges that could affect the country's potential for exporting green hydrogen. For the expansion of renewable energy capacities and infrastructure for production, transport and storage, the production costs for green hydrogen are associated with high capital expenditure. In order to make technologies such as electrolysis more cost-efficient, investment in research and development (R&D) is needed to reduce costs by up to $50/MWh by 2050.

The lack of infrastructure for transporting hydrogen and Kazakhstan's role as a landlocked country represent a further bottleneck. In addition, the development of suitable infrastructure requires enormous investment, which is necessary for the conversion of existing gas infrastructures.

A further risk for Kazakhstan in establishing a new export industry for hydrogen is the possible one-sided dependence on this raw material. As with crude oil and natural gas, the development of the hydrogen market could result in long-term economic instability for Kazakhstan.

4.1.1 Production rules for RFNBOs

Meeting EU requirements will be key for renewable hydrogen to become a tradable good in the European Union. That implies legislative and regulatory alignment. In the following, key pieces of EU legislation and regulation are explained. Particular attention is paid to hydrogen certification that is introduced in detail. Possible imports of hydrogen and hydrogen derivatives from Kazakhstan will have to adhere to these standards.

General rules for hydrogen production

a. Context

As part of the EU's Fit for 55 package[27] aimed at achieving a 55% reduction in greenhouse gas emissions by 2030, the Renewable Energy Directive[28] (RED) was updated. In 2018, RED II set out systematic criteria for electricity sourcing in the production of renewable hydrogen and its derivatives, termed Renewable Fuels of Non-Biological Origin (RFNBOs). In 2023, RED III introduced stricter sustainability and greenhouse gas (GHG) reduction requirements that align with more ambitious RFNBO integration goals. These regulations aim to ensure the sustainability of hydrogen production, promote additional renewable energy capacity and align with the EU's climate neutrality goals. The EU co-legislators formally adopted the RED III on 19 September 2023, increasing the EU's renewable energy target to 42.5% of gross final energy consumption by 2030, with an indicative target of reaching 45%.

Within the framework of RED II/III, the European Union has established regulations and criteria that must be met for hydrogen to be classified as an RFNBO. The usual colour-based classification from public hydrogen discourse that refers to green, blue or grey hydrogen is not used in the EU regulatory language. Instead, hydrogen and its derivatives are classified as 'renewable' if it meets the RFNBO criteria.

To be defined as RFNBO, hydrogen and its derivatives must be produced exclusively from renewable energy sources without relying on fossil or biological feedstocks. Thus, green hydrogen meets the RFNBO definition because it is produced through electrolysis of water powered entirely by renewable energy sources like wind and solar. Other forms of hydrogen, like blue hydrogen, produced via steam methane reforming (SMR) or auto-thermal reforming (ATR) of natural gas with carbon capture and storage (CCS), do not meet this definition[29] (Article 2 of Commission Delegated Regulation 2023/1184). These can be classified as Low Carbon Fuels (for definition see below) which are regulated under the EU Gas Market Regulation (Directive (EU) 2024/1788)[30] (see subsection 4.1.2).

In addition to RFNBOs, the EU has introduced other classifications for fuels, as defined in RED II and related regulations:

- Renewable Carbon Fuels (RCF): Renewable carbon-based fuels derived from biological or recycled CO_2 sources, such as biogenic residues or industrial CO_2 emissions
- Low Carbon Fuels (LCF): Low-emission fuels produced using fossil resources but with reduced greenhouse gas (GHG) emissions compared to conventional fossil fuels, achieved through measures like CCS or energy efficiency

While RFNBOs and, in some cases RCFs, are relevant within the context of the EU's targets, it is important to note that LCFs such as 'blue hydrogen' are not covered under the RED II quota regulations.

The EU's established quota targets for the use of renewable energy, particularly in the industrial and transport sectors explicitly apply to RFNBOs. This means only green hydrogen and its derivatives (or other RFNBOs) can be credited towards these targets, creating a strong demand push. Whether or not this ultimately benefits hydrogen imports from non-EU-countries such as Kazakhstan will depend on the progress being made at developing economically viable multi-modal transportation routes. At the same time, the implementation gap of intra-EU hydrogen production projects may increase the need for extra-EU import sources.

- Industry quota: Under RED III, the target is to have at least 42% of hydrogen used for final energy and non-energy purposes in the industrial sector covered by RFNBOs by 2030, and 60% by 2035.
- In the transportation sector, a combined quota of 5.5% renewable fuels, including RCFs and RFNBOs, must be achieved. The sub-quota for RFNBOs is at least 2.6% in 2030.

Through its clear focus on RFNBOs, the EU aims to significantly reduce GHG emissions, accelerate the expansion of renewable energy and avoid promoting technologies based on fossil resources (such as LCFs) within the scope of these regulatory frameworks.

[27] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en

[28] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en

[29] https://eur-lex.europa.eu/eli/reg_del/2023/1184/oj/eng

[30] https://eur-lex.europa.eu/eli/dir/2024/1788/oj/eng

b. Production rules for RFNBO

RED II provides a foundational framework for the production of RFNBOs. The European Commission has further specified these basic rules through two key Delegated Acts adopted in 2023:

- Regulation (EU) 2023/1184[31] defines electricity sourcing criteria for RFNBO production
- Regulation (EU) 2023/1185[32] outlines greenhouse gas (GHG) accounting rules for RFNBOs

These regulations apply equally to hydrogen produced within the EU and to imported hydrogen, ensuring consistency in how RFNBOs are regulated across borders. Thus, also hydrogen imported from Kazakhstan would have to meet these standards.

- To maintain RFNBO classification, green hydrogen produced outside the EU must adhere to stringent infrastructure requirements:
- **No mixing with other gases:** Hydrogen classified as an RFNBO cannot, at any point, be blended with other types of hydrogen or gases, even outside the EU. This means RFNBOs cannot be fed into public gas grids or mixed with fossil-derived hydrogen.
- **Dedicated infrastructure:** The entire supply chain, from production to import, must use a dedicated and separate infrastructure to preserve the integrity of the hydrogen as an RFNBO.

b.1 Electricity sourcing rules (Regulation 2023/1184)

Electricity sourcing is a pivotal aspect of RFNBO production. Hydrogen must be produced using electricity that meets the EU's renewable energy criteria.

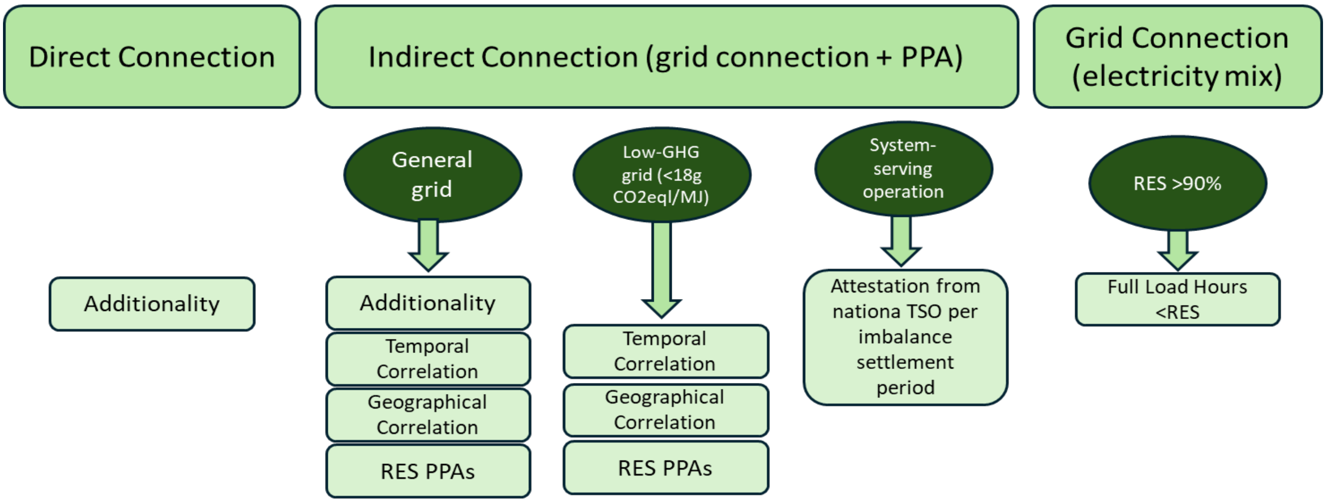

Figure 2: Delegated Act to Art. 27 REDII sets out criteria for the purchase of electricity for the production of RFNBOs (dena, 2024, Introduction into Hydrogen certification)

Options for electricity sourcing that can be combined:

- **Direct connection with renewable energy facilities:** The renewable energy source must operate without grid reliance for hydrogen production. A smart metering system ensures no grid electricity is used.
- **Grid electricity in zones with high renewable energy share:** Electrolysers can utilise grid electricity if the bidding zone has a renewable energy share of over 90% in its electricity mix. The 90% renewable energy share must have been achieved in at least one of the last five calendar years. Electrolysers are limited in their operational hours to prevent overloading the grid during non-renewable electricity supply periods.
- **Power Purchase Agreements (PPAs) with renewable energy providers:** Electrolysers may

[31] https://eur-lex.europa.eu/eli/reg_del/2023/1184/oj/eng

[32] https://eur-lex.europa.eu/eli/reg_del/2023/1185/oj/eng

source electricity via PPAs, enabling access to renewable electricity delivered through the grid. The renewable energy installation must be located in the same or an adjacent bidding zone. Offshore installations qualify if they are connected to the electrolyser's zone. Until 2029, the electricity used for RFNBO production must match production on a monthly basis. Starting in 2030, stricter hourly matching will apply, ensuring that hydrogen production closely aligns with renewable electricity generation. Grid electricity must have an emissions intensity below 18 gCO_2eq/MJ.

- **Electricity consumption to prevent curtailment of renewable energy:** Electrolysers can use electricity that would otherwise be curtailed due to grid imbalances, ensuring maximum utilisation of renewable energy. The hydrogen producer must demonstrate that their operations directly reduced renewable energy curtailment during redispatch events. Detailed energy audits and reporting mechanisms are required to validate claims of curtailment prevention. This method significantly reduces wasted renewable energy and optimises grid stability. It is particularly useful in regions where renewable energy generation frequently exceeds grid demand or capacity.

Particularities:

- **Additionality requirement:** Electricity used for RFNBO production must come from newly built renewable energy plants (e.g., wind or solar farms) that were commissioned after January 2028. This is to ensure that the demand for renewable energy is met without displacing existing renewable energy capacity.
  - Grandfathering clause: For renewable energy facilities that were operational before 2028, the additionality requirement does not fully apply (as per Article 11 of Delegated Regulation 2023/1184). These can be used for 10 more years, until the end of 2037. This provision allows older renewable installations to contribute to RFNBO production under certain conditions and supports, as the name grandfathering implies, the protection of existing operators.

b.2 Greenhouse gas accounting and savings threshold

A central requirement for RFNBO classification is compliance with GHG accounting rules, as specified in Delegated Act 2023/1185. These rules mandate that the lifecycle emissions of RFNBOs must achieve a minimum of 70% savings compared to the fossil fuel comparator (Regulation 2023/1185). The fossil comparator value for RFNBOs is 94 gCO_2/MJ. The formula to calculate the entire value chain (excluding the production of machines and equipment) is

$$E = e_i + e_p + e_{td} + e_u - e_{ccs}$$

E	Total emissions from the use of the fuel
e_i	Emissions from the provision of inputs
e_i **elastic**	Emissions from elastic input materials, i.e., input materials that increase with rising demand
e_i **rigid**	Emissions from fixed input materials, i.e. input materials that remain constant in terms of quantity despite increasing demand
e_i **ex use**	e ex-use = emissions from the previous use or whereabouts of the input materials
e_p	Emissions from processing
e_{td}	Emissions from transportation and provision
e_u	Emissions from the combustion of the fuel in its end use
e_{ccs}	Emissions savings through carbon capture and geological storage

Table 9: GHG Saving calculation, Source: dena 2024, Introduction to Hydrogen Certification

- **Lifecycle assessment (LCA):** GHG emissions are measured across the entire value chain, from energy production to final delivery. This includes upstream emissions (e.g., energy source) as well as emissions from transportation.
- **Transport emissions:** For both domestically produced and imported RFNBOs, emissions from transporting hydrogen or its derivatives are factored into the lifecycle assessment, emphasising the importance of low-emission logistics solutions.

While the same rules apply to hydrogen imports from outside the EU, there are significant challenges for compliance. Many non-EU countries like Kazakhstan do not have 'bidding zones' comparable to those defined in the EU electricity market. This makes verifying temporal and geographic correlation more complex. The European Commission has issued a Q&A document[33] addressing open questions about imports, including how to verify compliance in regions lacking EU-equivalent market structures.

4.1.2 Production rules for Low Carbon Fuels (LCF)

Key rules for LCFs

Unlike RFNBOs, LCFs, including blue hydrogen, are not regulated under RED II/III. Instead, the framework for LCFs is provided in the EU Gas Market Regulation 2024/1788[34], specifically in Article 9(5). While the rules for LCFs are not as mature as those for RFNBOs, the existing framework under Regulation (EU) 2024/1788 is highly detailed. The new Delegated Act[35] published on July 8, 2025, brings further clarity and formalises the GHG accounting requirements. For prospective exporters, attention to both the evolving LCF-specific rules and cross-references to existing EU regulations (e.g., Methane Regulation, RED II) will be essential for compliance and market access. Detailed implications for hydrogen production in Kazakhstan are to be assessed, especially with regard to the possibility of complying with the accumulated standard value (upstream carbon dioxide + upstream natural gas + nitrous oxide) and the EU's Methane Regulation (EU) 2024/1787[36].

4.1.3 Carbon Border Adjustment Mechanism (CBAM)

Another important piece of EU legislation that hydrogen exports to Germany and the EU need to comply with is the Carbon Border Adjustment Mechanism[37], a tool that prices carbon emitted during production of goods entering the EU with carbon-intensive production processes entailing the risk of carbon leakage. The goods considered under this label are cement, iron, steel, aluminium, fertilisers, electricity and hydrogen. By pricing the carbon entering the EU, the aim is to guarantee that imports get the same carbon price as domestic production that underlies carbon taxes within the EU. In this way, the EU wants to ensure attainment of its climate targets while still aligning with WTO rules and to prevent CO_2 emissions simply being outsourced. The CBAM is being introduced step-by-step with a transitional period from 2023–2025 and will apply in full by 2026. It is in line with the phase-out plans under the EU Emissions Trading System, the ETS. Based on an amendment proposed by the European Commission in February 2025 (Omnibus Package I), the EU has reached provisional agreement on excluding 90% of the importing companies previously subject to CBAM from the compliance burdens. A newly introduced 50-tonne threshold for imports will mean that companies importing less than 50 tonnes of CBAM goods annually will be exempt from CBAM obligations. Importers will still need to report and account for embedded emissions from January 1, 2026, yet the purchase of corresponding certificates has been postponed to 2027.

As mentioned, hydrogen and its derivative ammonia (that is commonly used as a fertiliser) fall under the CBAM regulation. Thus, potential hydrogen and derivatives produced in Kazakhstan face the prospect that its EU importers may have to pay for CBAM certificates starting in February 2027 if they cannot prove that a price has been paid for the embedded carbon emissions generated in the production. In the transitional phase, which started in 2023 and will expire by the end of 2025, EU importers need to monitor and report direct and indirect emissions. Direct emissions are those directly from the production process itself, thus typically emissions produced on-site at the production site. Indirect emissions of a facility or of a production process are equivalent to the emissions from the electricity consumed in the production process. The full regime of CBAM to commence in 2026 also covers indirect emissions for the sectors cement and fertilisers including ammonia. For hydrogen, only direct emissions are counted as hydrogen is classified as a

[33] https://ec.europa.eu/commission/presscorner/api/files/document/print/en/qanda_23_595/QANDA_23_595_EN.pdf
[34] https://eur-lex.europa.eu/eli/dir/2024/1788/oj/eng
[35] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/14303-Methodology-to-determine-the-greenhouse-gas-GHG-emission-savings-of-low-carbon-fuels_de
[36] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401787&pk_campaign=todays_OJ&pk_source=EURLEX&pk_medium=X&pk_keyword=energy_sector&pk_content=Regulation&pk_cid=EURLEX_todaysOJ
[37] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2023.130.01.0052.01.ENG&toc=OJ%3AL%3A2023%3A130%3ATOC CBAM

'simple' good and ammonia as a 'complex' one. Thus, CBAM applies to all hydrogen production pathways with carbon-intensive processes, including electrolysers powered by fossil-based electricity. It provides a strong incentive to transition away from non-renewable energy sources in hydrogen production. That assessment also holds true for upstream emissions resulting from, e.g., producing or transporting raw materials such as natural gas or electricity for ammonia production.

Hydrogen producers that want to export to the EU will thus have to calculate and report the direct and indirect emissions associated with their production process using recognised methodologies, such as the EU's Environmental Footprint Methods[38], to measure emissions. EU importers are responsible for submitting quarterly reports to the EU authorities and thus producers have to give accurate emission data to their import partners. Producers must be ready to provide data that can be verified by third parties. When the full CBAM comes into implementation and financial charges are imposed on embedded carbon emissions starting in January 2026, carbon prices tied to the EU ETS will be calculated. Thus, producers will have to purchase CBAM certificates. If the reporting of actual emissions is not successful, producers will have to provide proof that all 'reasonable efforts' have been taken to obtain data from suppliers and producers. In order to make this requirement clearer, the EU could specify when the 'all reasonable efforts' condition has been met in order to provide greater legal certainty.

4.2 Certification processes for hydrogen in the EU

Through comprehensive certification schemes, sustainability features can be verified in a credible and consistent manner. Certification can offer proof of compliance with legal and regulatory requirements which is useful for obtaining, for example, direct funding or tax exemptions. Clearly distinguishing renewable energy sources from fossil alternatives ensures that national and regional targets for renewable energies and, with that greater climate targets, are achieved. Certification can further help to build trust between importers and exporters, promoting global trade. It can contribute to the development of new value chains by encouraging consumers to actively demand renewable hydrogen. Clear rules can prevent green washing or double counting of renewable energy volumes of GHG savings.

4.2.1 Core certification framework

1. Mass balance as the foundation

The EU mandates a **mass balance system** as the primary method for tracking and certifying sustainability (via **Proofs of Sustainability**, PoS).

- **Mass balance:** Ensures that the amount of certified hydrogen (RFNBO or LCF) corresponds to the sustainable input materials used, with precise tracking across the supply chain.
- **Book & Claim:** Alternative systems like Guarantees of Origin (GoO) or **Herkunftsnachweise (HKN)** can be introduced by Member States on a **voluntary basis**, but these operate in parallel to the core mass balance requirement and do not replace it.

2. Key actors and roles

For hydrogen producers in Kazakhstan (or other non-EU states), understanding the procedural roles of different entities in the certification system is essential:

- **Private voluntary schemes (VS):**

Certification is not conducted by EU institutions or Member States but by **voluntary schemes (VS)** approved by the European Commission.

- Once recognised, these schemes can operate globally, including in non-EU countries such as Kazakhstan.
- Producers must work with a VS to certify their hydrogen and its compliance with EU sustainability criteria.

Certification bodies:

Audits of hydrogen producers and batches are conducted by **certification bodies** accredited by voluntary schemes. These bodies verify compliance with the sustainability and GHG accounting requirements.

[38] https://green-forum.ec.europa.eu/green-business/environmental-footprint-methods_en

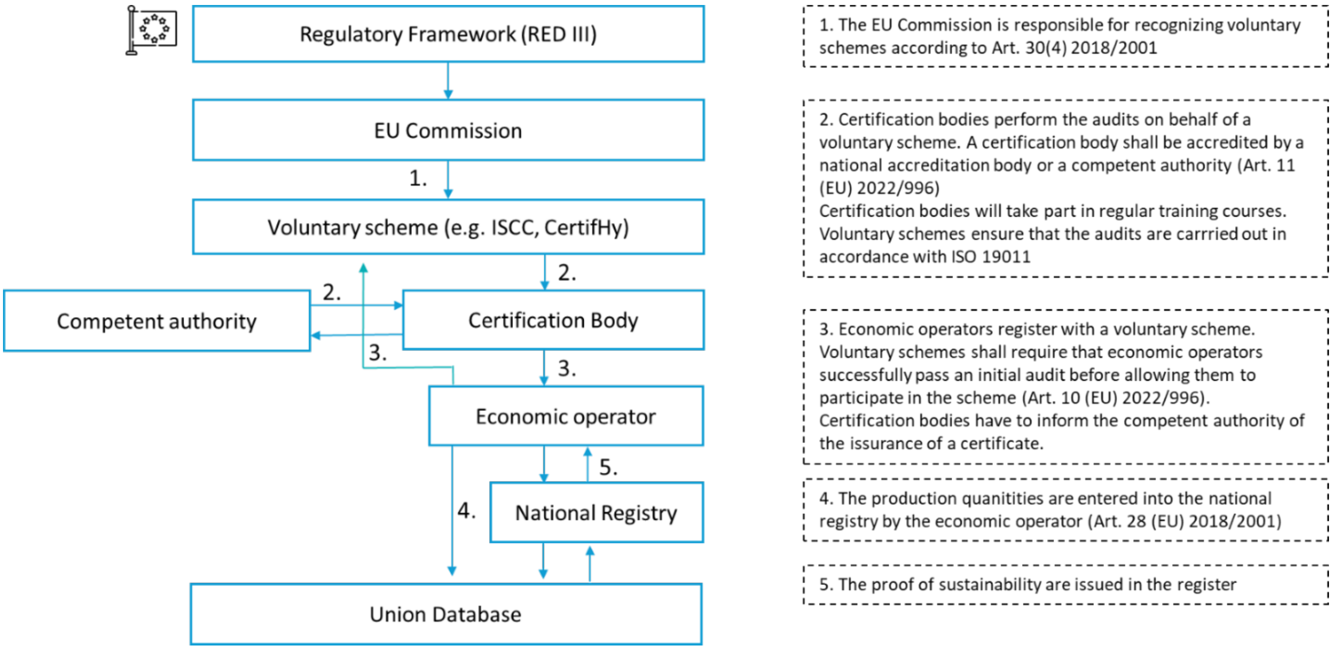

Figure 3: RED III legal framework: certification process (PoS) (dena, 2024, Introduction to Hydrogen Certification)

EU infrastructure – the Union Database:

The EU provides the **Union Database** (Article 31a of RED III) as a central infrastructure for tracking hydrogen and its derivatives.

All RFNBO and LCF batches must be logged in the Union Database to ensure transparency and traceability throughout the supply chain.

This database ensures a harmonised approach across Member States and enables real-time monitoring of hydrogen flows.

On 19 December 2024, the EU formally recognised three voluntary certification schemes for RFNBOs, thereby creating legal certainty for producers of renewable hydrogen. This formal recognition allows three auditing and certifying organisations to issue Proof of Sustainability certificates for hydrogen production plants. The three recognised certification schemes are CertifHY, REDcert and ISCC.

4.2.2 Additional national frameworks and registers

Alongside the Union Database, there are also national databases or registers that keep track of hydrogen certificates. Taking Germany as an example of how Member States are complementing the EU system:

- **Mass-balancing register:** Germany is developing a mass balance register (37th BImSchV) for tracking RFNBOs and LCFs.
- **HKN register:** A separate register for Guarantees of Origin (HKN), governed by the GWKHV, is being established to supplement the Union Database.
- **Integration:** These national systems will be linked to the Union Database and exchange data, partially in real time, for seamless integration with EU-level infrastructure.

4.3 Implications for Kazakhstan's hydrogen producers

1. Engagement with voluntary schemes:
   a. Hydrogen producers in Kazakhstan should partner with EU-recognised voluntary schemes for certification to ensure a maximum level of harmonisation. These schemes oversee the auditing and approval processes for hydrogen batches.
   b. Examples of existing schemes include CertifHy, ISCC and REDcert, which are active in certifying renewable fuels.
2. Union Database compliance:
   a. All certified hydrogen to be marketed in the European Single Market must be registered in the EU's Union Database. Producers and traders in Kazakhstan would have to ensure proper documentation and tracking of their products in line with database requirements.
3. Methane Regulation considerations:
   a. For LCF producers, compliance with methane emissions reduction requirements (as per the EU Methane Regulation) is crucial. Any methane leakage during hydrogen production and transportation must be minimised and accounted for in the certification process.

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4. Dedicated infrastructure:
   a. Hydrogen intended for certification must maintain its integrity throughout the supply chain. For Kazakhstan, this means ensuring dedicated infrastructure for transportation to prevent blending with non-certified gases.

Section 4 has provided comprehensive analysis of the importability and regulatory adaptation required for Kazakhstan to align its green hydrogen sector with European and international standards. While the country possesses significant potential as a supplier of green hydrogen, fully capitalising on this opportunity necessitates harmonising its domestic regulations with EU directives, developing robust certification systems and addressing infrastructure and logistical challenges. By focusing on these critical areas, Kazakhstan can strengthen its position as a reliable partner in the global hydrogen supply chain.

Building on this foundation, section 5 will explore the financial conditions and mechanisms necessary to support the hydrogen sector's development. This includes examining local financing opportunities, identifying relevant German funding programs, and leveraging EU support mechanisms to ensure sustainable growth and competitiveness in the green hydrogen market.

5 Financing for green hydrogen development in Kazakhstan

Financing is a key hurdle in establishing a hydrogen economy in Kazakhstan. To make use of its abundant renewable energy sources, evolving a sound national financial framework as well as support to close the financing gap through international instruments is necessary.

This analysis highlights the potential interplay between domestic financial institutions and international financing, particularly shedding light on the role Germany's hydrogen-related support instruments can play. Overall, this analysis underscores the importance of collaborative financing strategies and international partnerships in driving the growth of the green hydrogen sector. By harnessing local resources and leveraging EU and German support where needed, Kazakhstan could effectively position itself as a player in the global hydrogen market ramp-up, contributing to sustainable development and energy resilience on a larger scale. Closing gaps between local financing tools and international support mechanisms will be vital in overcoming barriers and unlocking the full potential of green hydrogen in Kazakhstan.

5.1 Local financing for green hydrogen in Kazakhstan

Kazakhstan is in the initial stage of developing its green hydrogen sector, leveraging its abundant renewable energy resources, availability of suitable land area and various financing mechanisms from local financial institutions and international development banks. The country's financial landscape for green hydrogen includes a range of instruments provided by national banks, drawing on international financial institutions and international partners such as Germany and the EU. In the context of German Chancellor Olaf Scholz' visit to Kazakh President Kassym-Jomart Tokayev, both heads of state on 16 September 2024 signed a joint declaration stating that the cooperation with the German Energy Agency (dena) shall be continued to explore possibilities for using green hydrogen projects and products in various economic sectors.[39] Correspondingly, as part of the opening of Germany's 'hydrogen diplomacy' office in Astana in October 2022, German Foreign Minister Annalena Baerbock highlighted the importance of sustainable growth linked to human rights and transparency in investments[40].

The local financing landscape in Kazakhstan is characterised by a mix of national and international financial instruments, with a focus on attracting private capital and fostering international cooperation.

Table 10 outlines the financing instruments for Kazakhstan's green hydrogen sector, organised to reflect a strategic approach that addresses key challenges through mechanisms emphasising risk mitigation, international standards alignment, capacity building, sustainability integration, infrastructure support and private sector incentives, while distinguishing between local and international funding sources for clarity.

[39] https://www.akorda.kz/ru/sovmestnaya-deklaraciya-o-sotrudnichestve-mezhdu-respublikoy-kazahstan-i-federativnoy-respublikoy-germaniya-1683715

[40] https://carnegieendowment.org/russia-eurasia/politika/2024/09/kazakhstan-eu-hydrogen-technology?lang=en

Local financing instruments in Kazakhstan

Instrument	Key points
Public-Private Partnerships (PPP)	• PPPs strategically distribute financial risks between public and private entities, mitigating investment uncertainties in high-capital hydrogen projects while creating attractive investment pathways that facilitate capital inflow and revenue predictability. • Governments leverage PPPs by providing comprehensive support through regulatory frameworks, financial incentives and targeted subsidies, effectively reducing investment barriers and enhancing project economic viability for hydrogen initiatives. • PPPs serve as critical knowledge transfer platforms, enabling skills development, technological expertise sharing and workforce training in emerging markets, particularly in regions with limited hydrogen technology experience. • Collaborative partnerships enable shared infrastructure investments and integrated energy solutions, combining renewable energy sources with hydrogen production to optimise resource utilisation, reduce individual project costs and create synergistic technological ecosystems.

Investment agreements	• Investment agreements provide a transparent, predictable legal framework that mitigates investor risks by clearly defining operational conditions, investment protection mechanisms and mutual obligations between the government and private entities.
	• These agreements enable large-scale transformative projects like Hyrasia One[41]:
	  • The investment agreement was signed in July 2022 setting out key project parameters, such as the provision of land, access to infrastructure, unhindered movement of goods and capital. This aims to create a stable economic and legal framework.
	  • Planned investment volume of $40–50 billion
	  • Financed by SVEVIND Energy Group, involvement of other co-investors planned
	  • Final investment decision planned for 2026
	  • H_2 production in Mangystau region scheduled to start between 2030–2032

Green bonds	• The Green Taxonomy of Kazakhstan, adopted by the government on 31 December 2021, covers seven project categories, including renewable energy, which encompasses wind, solar, geothermal, hydro, bioenergy, and supply chain and auxiliary infrastructure[42]. It defines the criteria for green projects eligible for financing through green bonds and green loans and explicitly mentions hydrogen production under the renewable energy category, without specifying the criteria under which hydrogen qualifies as a renewable fuel.
	• The state-owned Astana International Financial Centre[43] (AIFC) Green Finance Centre, as the only verifier in the Central Asia region recognised by the International Capital Markets Association (ICMA) and the Climate Bonds Initiative (CBI)[44], provides guidance to potential issuers through the green bond issuance process,

[41] https://hyrasia.one/?page_id=23813270
[42] https://www.gov.kz/memleket/entities/ecogeo/press/news/details/742376?lang=ru
[43] Astana International Financial Centre
[44] https://aifc.kz/news/climate-bonds-initiative-accredited-aifc-green-finance-centre/

Local financing instruments in Kazakhstan

Instrument	Key points
	ensuring alignment with international best practices and maintaining the integrity of green financial instruments[45], such as: • Help in obtaining interest rate subsidies of up to 7% of the coupon rate for green bonds, with a maximum bond size of 3 billion tenge, applicable for a maximum of 5 years. • Support in acquiring external review services, which are accepted by international bodies like the London Stock Exchange and which can cover up to 70% of the cost for obtaining second-party opinions on green bond frameworks[46]. • The Astana International Exchange (AIX)[47] adoption of ESG-Labelled Bond rules allows for various types of sustainable bonds, which could include those financing green hydrogen projects[48].
	• The Development Bank of Kazakhstan[49] (DBK) is generally interested in financing green hydrogen projects, contingent upon the bankability of this sector, which, in turn, relies on government support. • Under its Green and Sustainable Financing Framework, the DBK is actively involved in renewable energy financing, with nine projects in wind, solar and hydropower totalling 560 megawatts and approximately $633 million in financing[50]. • The DBK issued green bonds on the Astana International Exchange (AIX), with the first issuance amounting to $15 million at a coupon rate of 5.65%[51]. • The bank, while no specific timeline has been announced, can potentially develop specialised financial products for green hydrogen projects. These may include long-term loans with favourable terms and risk mitigation mechanisms like guarantees. • The bank's current strategy and experience with renewable energy projects suggests it could play a role in promoting Kazakhstan as an attractive investment destination for green hydrogen initiatives, building on its existing framework for supporting clean energy transitions.
	• The DAMU Entrepreneurship Development Fund[52] (DAMU) has not yet specifically targeted the green hydrogen sector but offers subsidised loans with competitive interest rates (6–10%), significantly lower than Kazakhstan's average bank lending rate of 16.987% as of November 2024.[53] • The fund provides various financial support mechanisms, including loan subsidies up to 10% of the interest rate and principal subsidies up to 40% (maximum 180 million tenge), with potential maximum loan amounts up to 15 billion tenge. • The fund's scope encompasses a wide range of green technologies, including renewable energy sources, energy efficiency projects[54].

Table 10: Financing instruments for green hydrogen in Kazakhstan

45 https://aifc.kz/news/renewables-in-kazakhstan-current-state-potential-and-financing-mechanisms/
46 https://aifc.kz/news/aifc-has-maintained-its-regional-leadership-in-green-finance-and-improved-its-position-in-the-global-ranking/
47 https://aix.kz/
48 https://aix.kz/products-services/segments/green-finance-2/
49 https://www.kdb.kz/en/
50 https://kdb.kz/en/pc/news/press-releases/14305/
51 https://damu.kz/en/programmi/subsidy/enterprise_development/
52 https://damu.kz/en/
53 https://www.ceicdata.com/en/indicator/kazakhstan/bank-lending-rate
54 https://damu.kz/en/programmi/subsidy/enterprise_development/

Multilateral development banks (MDBs) can provide crucial technical assistance and policy design support to create a robust framework for the emerging industry. By pooling international funds and offering risk mitigation instruments, MDBs can significantly reduce transaction costs and facilitate knowledge sharing across their global project portfolios.

International financing instruments

Instrument	Key points
Support from multilateral development banks (MDBs)	• The Asian Development Bank[55] (ADB) has committed significant funding, including $42 million for renewable energy initiatives and a $123 million infrastructure package for KEGOC, aimed at enhancing Kazakhstan's renewable energy capacity and grid infrastructure essential for green hydrogen development. • Through the Energy Transition Mechanism (ETM), the ADB is supporting Kazakhstan's shift from coal dependency by facilitating early retirement of coal plants and exploring infrastructure repurposing for renewable energy[56]. • Beyond direct financial assistance, the ADB provides technical advisory services on grid integration and renewable energy best practices. According to interview discussions, the ADB is exploring potential synergies with the agriculture and rare earth metals sectors through green hydrogen and green ammonia production.
	• The World Bank Group has approved $1.65 billion in renewable hydrogen loans in 2023 for emerging markets, offering concessional financing and blended finance models to help bridge the substantial financing gap for green hydrogen projects in economically promising regions. • Through initiatives like the Energy Sector Management Assistance Program (ESMAP), the World Bank can provide critical technical support, knowledge sharing and training programmes to enhance Kazakhstan's capabilities in developing a robust green hydrogen sector.
	• The Green Climate Fund[57] (GCF), which is an operating entity of the financial mechanism of the United Nations Framework Convention on Climate Change (UNFCCC), has allocated $110 million for renewable energy initiatives in Kazakhstan and can provide crucial financial resources through blended finance models. This can also help de-risk green hydrogen projects and make them more attractive to private investors.12 • The GCF offers comprehensive technical expertise, including support for regulatory frameworks, renewable energy grid integration, policy formulation and infrastructure development necessary for establishing a robust green hydrogen sector.
	• The Eurasian Development Bank[58] (EDB) is implementing a Development Strategy (2022–2026) that prioritises the water-energy complex in Central Asia[59]. • The EDB has established a Technical Support Fund to assist projects in their initial stages. This fund can finance pre-feasibility or feasibility studies, paving the way for subsequent commercial financing of projects. • According to information from the Strategic Project Division, the EDB is interested in conducting studies on green hydrogen production projects within the Eurasian Economic Union and considers the fuel as a tool for reducing greenhouse gas

[55] https://www.adb.org/
[56] https://www.adb.org/news/adb-kazakhstan-take-next-step-toward-early-coal-retirement-etm-agreement
[57] https://www.greenclimate.fund/
[58] https://eabr.org/en/
[59] https://primeminister.kz/en/news/a-mamin-eadb-otyrysyn-otkizdi-banktin-2022-2026-zhyldarga-arnalgan-strategiyasy-bekitildi-263112

emissions and enhancing energy system resilience. The bank is prepared to leverage its experience in public-private partnerships to facilitate green hydrogen project development, focusing on supporting the realisation of commercially viable hydrogen projects. While the bank can occasionally fund research through its Technical Support Fund, which can finance pre-feasibility and feasibility studies, its primary orientation is towards supporting commercially viable projects. Given that hydrogen is a new area, the Technical Support Fund's assistance may be crucial for project initiation, particularly in the early stages of development.

Table 11: International financing instruments

Analysis of the local financing instruments

Kazakhstan's local financing instruments demonstrate significant potential to support the development of its green hydrogen sector, leveraging public-private partnerships (PPPs), investment agreements and green bonds. PPPs strategically distribute financial risks between public and private entities, enabling shared infrastructure investments and fostering knowledge transfer in hydrogen technologies. Investment agreements, such as the one underpinning the Hyrasia One project with a planned $40–50 billion investment, provide a transparent legal framework that reduces investor risks and ensures stable economic conditions.

Additionally, green bonds, supported by Kazakhstan's Green Taxonomy and verified by the AIFC Green Finance Centre, offer financial incentives like interest rate subsidies and external review cost coverage, aligning with international standards.

Green bonds and loans have raised approximately KZT 150.2 billion over the past 3.5 years, primarily for renewable energy and energy efficiency projects.

The Damu Entrepreneurship Development Fund has been instrumental in issuing green bonds and providing interest rate subsidies, making green finance more accessible to SMEs. Additionally, the AIFC Green Finance Centre has emerged as a leading player, providing external reviews for nearly 60% of green bonds and loans issued in Kazakhstan and working on innovative financial products to attract further investment.

These instruments align with international standards such as the Green Bond Principles and the Climate Bonds Standard, ensuring credibility and transparency. However, scaling up green hydrogen projects will require enhanced financial mechanisms, including risk mitigation tools like guarantees and expanded loan subsidies, as well as strategic alignment with global hydrogen markets.

The survey of 18 companies in Kazakhstan reveals strong interest in enhanced financing options for hydrogen projects, with 80% of respondents exploring hydrogen production or technologies and 70% emphasising the need for renewable energy investments to sustain hydrogen production. While 60% identified financing needs for upgrading infrastructure to be hydrogen-compatible, 50% highlighted the importance of funding for research and feasibility studies, and 40% pointed to training staff in hydrogen technologies. Government support is deemed critical, with 90% stressing the need for subsidies or tax incentives, 75% favouring public-private partnerships to share financial risks and 85% advocating for technical assistance and supportive policies. Despite this readiness, key challenges include high initial costs (65%), insufficient expertise (55%) and inadequate infrastructure (70%), underscoring the need for strategic financing solutions to unlock Kazakhstan's green hydrogen potential.

By leveraging its existing green finance ecosystem and addressing infrastructure gaps, Kazakhstan can position itself as a competitive player in the global hydrogen economy.

The findings show that discovered instruments, initiatives and cooperation platforms can complement each other effectively. The hydrogen-related cooperation between Kazakhstan and Germany, exemplified by the Energy Dialogue between Kazakhstan's Ministry of Energy and Germany's Ministry for Economic Affairs and Energy (BMWE) as well as the 'hydrogen diplomacy' (H_2Diplo) office in Astana, illustrate a mutual commitment to a partnership on an equal footing.

According to the interview with the **ERG** representative, they emphasised that local financing conditions for green hydrogen projects in Kazakhstan are currently insufficient to make such projects economically viable without significant government support.

They noted that while financial instruments like green financing are important, they only help projects that are close to profitability. ERG stated that for a project with an Internal Rate of Return (IRR) of 10% when 14% is needed, banks might be able to help bridge that gap. However, for hydrogen projects that are currently in the negative profitability zone, financing alone is not enough. The company stressed that substantial government subsidies and regulatory support would be necessary to make green hydrogen competitive with current fuel sources like mazut and gas, estimating that a carbon price of around $300 per tonne would be needed for the technology to become economically feasible.

5.2 German funding programmes for hydrogen development

The German government provides a wide array of support mechanisms to promote international hydrogen projects. These instruments are designed to address diverse needs and foster global partnerships in the hydrogen sector. Given the variety of available tools, it is essential for applicants to evaluate each mechanism individually and establish direct communication with the relevant authorities or program representatives.

An overview of these support mechanisms is provided below, highlighting their key points and potential to facilitate international collaboration.

Instruments to support foreign trade and investment

Foreign trade & investment	**Foreign trade and investment instruments aim to facilitate market entry and involvement in foreign markets for German suppliers, importers and investors. They can serve as complementary tools for financing hydrogen-related projects.**
Instrument	**Key points**
Investment guarantees	• Protection against political and economic risks from the perspective of investors/ German companies • Reduces the risk to lenders through favourable financing conditions • Can help increase the attractiveness of the Kazakh market by hedging up to 95% of the invested amount for climate-friendly projects • Support for infrastructure and production projects
Untied Loan Guarantees (UFK-Guarantees)	• The covered obligation under the Untied Loan Guarantee is the policyholder's repayment claim against the foreign debtor as agreed in the loan contract • A prerequisite in this context is that German offtakers receive raw materials on the basis of a long-term offtake agreement and that the provision of these raw materials is of a macroeconomic interest • Suitable as Kazakhstan is a major supplier of raw materials + potential for hydrogen production
Export credit guarantees	• Export credit guarantees of the German government protect export transactions against payment default for commercial/political reasons, e.g., for export transactions from Germany to Kazakhstan and Central Asia on the purchase of hydrogen technology • The range of products available addresses the entire export value chain from production and delivery to payment of the final instalment.
Fortfaiting guarantee (Fortfaitierungsgarantie)	• Relevant particularly for exporting SMEs from the German side and Kazakh customers of H_2 technologies • Mechanism: payment term later than the delivery date; bank buys receivable from the exporter (forfaiting); German government guarantees the bank for this

	receivable, i.e., if the foreign buyer is unable to pay, the federal government compensates the bank for 80 per cent of the loss of the receivable • Order value of up to 10 million euros (small tickets)
Project Development Programme for Green Hydrogen Projects (PDP-H_2)	• This programme, as a key pillar of the BMWK's German Energy Solutions Initiative (see below), operates at the intersection of development cooperation and private sector engagement at the local level. • The PDP team collaborates with industry in Kazakhstan to support the switch from grey to green hydrogen. It provides free and neutral advice to local industry using grey hydrogen or derivates. It develops pre-feasibility studies on the switch to green hydrogen production and facilitates matchmaking with solution providers registered in the German Energy Solutions Initiative. • It also promotes market development through training and studies.

Table 12: Instruments to support foreign trade and investment

Investment guarantees[60]

Investments in international markets (such as developing and emerging countries) are attractive for German companies for reasons such as location conditions, direct access to raw material sources or good sales prospects. On the other hand, there are political uncertainties in many regions, which increase the economic risks of direct investments abroad. Investment guarantees can be particularly advantageous for the realisation of hydrogen projects in developing, emerging and transition countries, as they increase the creditworthiness of the projects, enable better financing conditions and reduce the risk through diplomatic support.

Guarantees for untied loan facilities (UFK)[61]

Untied Loan Guarantees are aimed at lenders of commodity projects outside the EU and protect them against economic or political credit default risks. Eligible products include metals and metalloids, rare earths and energy commodities such as green hydrogen, natural gas and liquefied natural gas. The guarantees can be helpful in the realisation of imports such as hydrogen and its derivatives.

Export credit guarantees (Hermes Cover)[62]

Export credit guarantees aim to enable business in challenging circumstances where the private insurance sector does not offer appropriate or sufficient cover. This results in a focus on emerging and developing countries to provide exporters with the necessary security against economically or politically induced losses. In addition, exporters receive support in opening markets or business relationships that are difficult to access. The German export credit guarantees are available for various sectors, including the hydrogen sector (if the project is eligible for cover and commercially viable including with regards to its risks). In many cases, ECGs are a prerequisite for bank finance as the German government with its investment-grade rating (AAA rating of Germany) lowers the credit risk, which improves the financing terms.

Forfaiting guarantee (Fortfaitierungsgarantie)[63]

Forfaiting guarantees are a financial instrument used to support the export of goods and services, including hydrogen technologies, by providing risk mitigation for exporters. These guarantees ensure payment security for companies that sell hydrogen-related products or services abroad, especially in cases where the buyer's creditworthiness is uncertain. Through forfaiting guarantees, exporters can receive immediate cash flow by selling their receivables to a financial institution, which assumes the risk of non-payment. This helps hydrogen technology companies expand into international markets, particularly in developing regions, and accelerates the global deployment of sustainable hydrogen solutions.

2nd funding guideline for international hydrogen projects[64]

After a successful first funding guideline for international hydrogen projects, a second version of

[60] https://www.bmwk.de/Redaktion/DE/Artikel/Aussenwirtschaft/investitionsgarantien.html
[61] https://www.ufk-garantien.de/en/products/guarantees/for-untied-loan-guarantees/untied-loan-guarantees.html
[62] https://www.exportkreditgarantien.de/en
[63] https://www.exportkreditgarantien.de/de/produkte/fuer-exporteure/ergaenzende-spezifische-absicherung/produktuebersicht/forfaitierungsgarantie.html
[64] https://www.ptj.de/en/project-funding/international-hydrogen-projects-bmwk-module-1

the funding guideline for international hydrogen projects was published on 15 November 2024 following the National Hydrogen Strategy Update of 2023. It is divided into two modules. Funding module 1 focuses on the industrial production of renewable hydrogen as well as accompanying research (e.g., feasibility studies). For projects to produce renewable hydrogen and derivatives, the investment costs that are eligible are up to a maximum of EUR 30 million per undertaking and investment project. Funding is generally available for companies with a branch or permanent establishment in Germany. Nevertheless, funding application is currently not possible and dependent on the future federal budget. Module 2[65] supports accompanying international basic and industrial research projects, scientific studies and training measures along the entire hydrogen value chain. Funding support relates exclusively to investment projects that are to be realised outside the European Economic Area + Switzerland.

Project Development Programme for Green Hydrogen Projects (PDP-H_2)[66]

The PDP- H_2 started in March 2024 in Kazakhstan. It has already identified a number of project opportunities and recently started to support project development on the switch from grey hydrogen and ammonia use to production of green hydrogen for Kazakh industry. A German Training Week on Hydrogen aimed at Kazakh industry with participation of German solution providers will take place in April 2025. Sector analysis on market potentials and risks is set to be published in June 2025. Its findings will be presented in a webinar to companies registered at the German Energy Solution Initiative.

H_2-specific financing instruments

H_2-specific funding instruments

Instrument	Key points
H_2Global	• Funding instrument for renewable hydrogen imports based on a competitive double auction model (Hydrogen Purchase Agreements and Hydrogen Sales Agreements) aimed at bridging the green premium for producers and offtakers backed by funding from the German budget • Contract conclusion with guaranteed purchase conditions
2nd funding guideline for international hydrogen projects	• Investment support for green hydrogen projects outside the European Economic Area + Switzerland regarding the construction of production plants for green hydrogen and its derivatives as well as feasibility studies and accompanying research projects. Funding of up to EUR 30 million for companies with a branch or permanent establishment in Germany (currently no funding available)
H_2Uppp	• Relevant if Kazakhstan is considered as a target market for German companies in the future • Supports market entry and development of H_2 projects (relevant for the early phase of the H_2 economy in Kazakhstan)
Green Hydrogen Fund at the EIB	• Fund to support renewable hydrogen projects and/or its derivative products through investment grants and/or technical assistance, encouraging and incentivising public and private sector investment. As of March 2025 the fund is not yet operational.
PtX platform	• German government and KfW offer joint funding and financing • For projects along all stages of the PtX value chain from renewable electricity to green hydrogen and derivatives • Particularly for developing and emerging economies

Table 13: H_2-specific financing instruments

[65] https://www.ptj.de/internationale-wasserstoffprojekte-modul2

[66] https://www.giz.de/en/worldwide/127673.html

H_2Global[67]

The H_2Global funding programme aims at supporting the import of green hydrogen and its derivatives from third countries. With the help of a double auction mechanism, the German government offsets the price difference between supply costs outside the EU and demand prices in Germany and aims to make a significant contribution to facilitating the market entry of renewable hydrogen while at the same time increasing its competitiveness compared to fossil fuels. H_2Global ensures long-term purchase agreements for green hydrogen products. A first Hydrogen Purchase Agreement (HPA) for renewable ammonia was announced in 2024 under the H_2Global pilot auction.

In December 2024, the European Commission approved the second round of tenders. On 19 February 2025 the official start was announced. The second supply-side auction is organised in four regional lots (funded by Germany) and one global lot (funded by Germany and the Netherlands[68]). For the regional lots, at least €484 million has been allocated, and for the global lot at least €567 million. The total amount is at €2.5 billion with the potential to increase to €3 billion depending on the final budget approvals. In the joint procurement lot with the Netherlands only molecular hydrogen will be purchased with projects from all continents eligible to apply for export to Germany and the Netherlands. Furthermore, Kazakhstan can apply for the regional lot for Asia. The pertinent tender documents can be requested from Hintco, the intermediary acting as the trading entity that develops and implements the H_2Global double-auction mechanism. Eligible products include RFNBO hydrogen, RFNBO ammonia and RFNBO methanol. H_2Global has opened up applications for the new auction round for companies to supply renewable hydrogen, ammonia or methanol to Germany from the four global regions: Africa, Asia, South America and Oceania, and North America on 4 July 2025. The round will be open until 12 September 2025.[69]

H_2Uppp[70]

H_2Uppp supports companies in identifying and developing pioneering projects for the production and utilisation of green hydrogen and Power-to-X applications. The programme also promotes knowledge transfer for project development in the field of green hydrogen and raises awareness among decision-makers for corresponding market opportunities. In this way, economic production and utilisation paths can be identified together with the partner countries, project opportunities along the value chain can be identified and business models can be developed. To this end, cooperation partnerships (PPPs) are entered into with companies from Germany and Europe that were previously identified in an ideas competition. PPPs are funded along the entire hydrogen value chain (production, storage, conversion, transport and utilisation). H_2Uppp is aimed at German and European companies as well as local companies in the target country as consortium partners. H_2Uppp helps to establish German technology in markets and is implemented in cooperation with the German Chambers of Commerce Abroad (AHK).

PtX platform[71]

The PtX platform offers financing solutions for Power-to-X projects and collects funding offers from the German government and the KfW Bankengruppe. Eligible for funding are German and European companies with locations in Germany that invest in PtX projects outside the EU/EFTA, as well as public and private actors from developing and emerging countries. The platform aims to promote the global hydrogen economy with a focus on green hydrogen in countries outside Europe. The PtX platform specifically wants to promote PtX projects that are not yet 'bankable', particularly in developing and emerging economies and close funding gaps. The KfW[72] offers support throughout the whole realisation of a project from advice, putting together a financing package and overseeing the implementation.

Green Hydrogen Fund (GHF)[73]

The GHF is a fund managed by the European Investment Bank (EIB) and financed by its contributor, the German Ministry for Economic Affairs and Climate Action, supporting renewable hydrogen projects in countries beyond Europe. The fund supports renewable hydrogen projects and/or its derivative products through investment grants and/or

67 https://www.h2-global.org/
68 https://www.hintco.eu/news/hintco-starts-second-h2global-auction-worth-eur-25-billion
69 https://www.hintco.eu/how-to-bid
70 https://www.bmwk.de/Redaktion/DE/Wasserstoff/Foerderung-International-Beispiele/10-h2uppp.html
71 https://www.kfw-entwicklungsbank.de/Unsere-Themen/PtX/
72 https://www.kfw-entwicklungsbank.de/Our-topics/PtX/
73 https://www.eib.org/en/products/mandates-partnerships/donor-partnerships/trust-funds/green-hydrogen-fund

technical assistance, in particular those intended for export to Europe. As of March 2025 the fund is not yet operational.**Development & investment banks**

Development & investment banks

Instrument	Key points
KfW IPEX	• For international projects and export financing, for German companies worldwide
KfW DEG	• Finance, advise and support private companies operating in developing and emerging markets
KfW Development Bank	• Financing solutions for banks in developing and emerging countries
European Bank for Reconstruction and Development (EBRD)	• Provides financing solutions for banks in developing and emerging countries, supports international projects and export financing, and offers financial and advisory services to private companies operating in these markets.

Table 14: Development & investment banks

KfW IPEX[74]

KfW IPEX-Bank primarily provides export and project financing, supporting German and European companies in their global business activities. KfW IPEX-Bank offers a range of financial services, including loans, guarantees and financial products tailored to large-scale projects in sectors such as energy, infrastructure, transport and industry. In addition to supporting private companies, KfW IPEX-Bank also finances public-sector projects, often in emerging and developing markets, with a focus on sustainable, green and energy-efficient solutions. Through its financial expertise and government-backed guarantees, it plays a key role in promoting global trade and investment, particularly in sectors that drive the energy transition.

KfW DEG[75]

KfW DEG supports the development of the hydrogen economy in developing and emerging markets by providing long-term financing, equity investments and advisory services to private sector companies involved in the hydrogen value chain. It focuses on enabling sustainable hydrogen production, infrastructure development and innovative technologies, particularly green hydrogen projects aligned with global decarbonisation goals. Through its initiatives, DEG promotes partnerships, helps mobilise additional investments and ensures adherence to environmental and social governance (ESG) standards, contributing to the global energy transition and fostering economic growth in its target regions.

KfW Development Bank[76]

KfW Development Bank concludes agreements with state actors in other countries on behalf of the German Ministry for Economic Cooperation and Development to launch the development of a sustainable hydrogen economy. These programmes promote the production and use of green hydrogen and its downstream products, such as hydrogen-powered vehicles and sustainable fuels. As a result, they improve economic efficiency and increase the interest of other private investors.

European Bank for Reconstruction and Development (EBRD[77]**)**

EBRD is actively engaged in green investments in Kazakhstan through initiatives like the $150-million Green Economy Financing Facility (GEFF) Kazakhstan II, which offers gender-sensitive green financing to businesses and households for energy efficiency, renewable energy and climate resilience projects[78]. KazREF, a €300-million renewable energy financing framework established by the EBRD and the Green Climate Fund, aims to support Kazakhstan in achieving its ambitious renewable energy targets by providing development support and debt finance for 8–11 renewable energy projects with a total capacity of 330 MW, focusing on technologies such as wind, solar, small hydropower, geothermal and biogas[79]. The EBRD's €252 million loan for modernising Almaty CHP-2 included contractual requirements for hydrogen-compatible equipment, ensuring future turbines and infrastructure can operate on gas-hydrogen. The EBRD is financing a pilot renewable hydrogen facility in Chirchiq (Uzbekistan), which will consist of a 20 MW electrolyser and a greenfield 52 MW WPP. This project is expected to produce up to

74 https://www.kfw-entwicklungsbank.de/Our-topics/PtX/
75 https://www.deginvest.de/
76 https://www.kfw.de/Internationale-Finanzierung/Briefing-Gr%C3%BCner-Wasserstoff/
77 https://www.ebrd.com/
78 https://www.ebrd.com/news/2023/ebrd-offers-fresh-funds-to-promote-green-investment-in-kazakhstan.html
79 https://www.greenclimate.fund/project/fp047

3,000 tonnes of green hydrogen annually and reduce annual CO_2 emissions by around 22,000 tonnes. The EBRD provides a $65-million financial package to ACWA Power UKS Green H_2, a joint venture between ACWA Power and Uzkimyosanoat (a fertiliser producer), a state-owned chemical industry holding company in Uzbekistan.

Additional measures to promote foreign projects and investments

Instrument	Key points
Germany Energy Solutions Initiative	• Networking platform • To contact German business partners for energy solutions
Agency for Business and Economic Development	• Agency has an advisory function and could also support German companies wishing to operate in Kazakhstan
Germany Trade and Invest (GTAI)	• Supporting international companies to come into German market by supporting networking, help with finance applications
International PtX Hub	• Promotion of acceptance and knowledge building about green H_2 technologies in Kazakhstan through consulting and training opportunities
Export Initiative for Environmental Protection (EXI)	• Supports international dissemination of green innovations, products and services by German green tech companies • Focuses on supporting projects in countries with a high demand for environmental and resource efficiency technologies and services

Table 15: Additional measures to promote foreign projects and investments

Germany Energy Solutions Initiative[80]

The Energy Solutions Initiative supports German companies in promoting sustainable energy solutions worldwide. It focuses on renewable energy, energy efficiency, smart grids and green hydrogen technologies. Through business delegations, training programmes and knowledge sharing, the initiative fosters international partnerships, strengthens local capacities and advances the global energy transition by showcasing innovative, German-engineered solutions tailored to diverse markets.

Agency for Business and Economic Development[81]

The Agency for Business and Economic Development (AWE) supports businesses in engaging with sustainable development projects in emerging and developing markets. It provides free advice on financing, funding programmes and partnerships, helping companies navigate opportunities in sectors like renewable energy, green hydrogen and infrastructure. AWE acts as a bridge between private sector initiatives and development cooperation, fostering impactful investments aligned with global sustainability goals.

Germany Trade and Invest (GTAI)[82]

Germany Trade & Invest (GTAI) supports international companies entering Germany's hydrogen market by offering market insights, investment guidance and access to subsidies. It connects businesses with local partners, facilitates funding applications and promotes collaboration on green hydrogen production, storage and technologies.

International PtX Hub[83]

The International PtX Hub supports the global development of Power-to-X (PtX) technologies, focusing on sustainable production and use of green hydrogen and its derivatives. It facilitates knowledge sharing, policy advice and international partnerships to promote PtX as a key solution for decarbonising industries, transportation and energy systems. By advancing PtX projects and fostering global collaboration, the Hub contributes to the transition to a climate-neutral economy.

Export Initiative for Environmental Protection (EXI)[84]

The Export Initiative for Environmental Protection, led by the German government, supports hydrogen projects by promoting the export of green technologies, including renewable hydrogen solutions. It provides funding, advisory services and networking

80 https://www.german-energy-solutions.de/GES/Navigation/EN/Home/home.html
81 https://wirtschaft-entwicklung.de/en/partners-in-transformation/about-us
82 https://www.gtai.de/en/invest/industries/energy/green-hydrogen
83 https://ptx-hub.org/
84 https://www.exportinitiative-umweltschutz.de/

opportunities to help German companies develop and market innovative hydrogen technologies internationally. By facilitating access to global markets, the initiative drives the adoption of green hydrogen, fosters international partnerships and strengthens Germany's role as a leader in sustainable energy solutions, contributing to global decarbonisation efforts.

Analysis of the German instruments

The German government offers a robust and multifaceted set of funding mechanisms tailored to support hydrogen projects across their entire lifecycle. These instruments stand out for their ability to reduce investment risks, foster international collaboration and comprehensively support innovation in green hydrogen technologies. A key strength of the German funding landscape is that guarantee instruments for foreign trade promotion are complementary to genuine funding measures for non-European hydrogen projects and can be used in conjunction with loans from German and European development banks. Nevertheless, Germany's funding portfolio has yet to prove that it can contribute to scaling up the global market and to realising imports of hydrogen and hydrogen derivatives.

One distinctive feature is the emphasis on mitigating risks associated with investments in emerging and high-risk markets. Programmes such as investment guarantees and export credit guarantees (Hermes Cover) can shield German companies from the most severe losses of economic and political uncertainty, making international hydrogen ventures less risky and more viable. Another factor is project flexibility. For this, Untied Loan Guarantees (UFK) offer a case in point. On top of their primary purpose of enabling raw material imports to Germany, they can also help realise swap agreements in which raw material offtakers can swap quantities and qualities as opposed to importing them directly from the mine to Germany. Based on contractual agreements, raw materials of equivalent quantity and quality, such as hydrogen for instance from a third electrolyser, can be delivered to the German offtaker in return for the swapped resources (more information[85]).

Germany's funding instruments also prioritise international cooperation and partnership development, with – among others – H_2Global and H_2Uppp serving as pivotal mechanisms that address distinct objectives. H_2Global, a flagship programme under Germany's hydrogen import strategy, is specifically designed to bridge the 'green premium' by offsetting the cost differential between high production costs of green hydrogen or its derivatives in third countries and the competitive prices demanded by buyers in Germany and Europe. This instrument might become particularly relevant for Kazakhstan, given its vast renewable energy resources and potential to become a key supplier of green hydrogen and derivatives such as ammonia or methanol to Germany.

In contrast, H_2Uppp targets the early-stage development of hydrogen projects in emerging markets. For Kazakhstan, H_2Uppp represents an opportunity to accelerate the establishment of decentralised hydrogen ecosystems by supporting local SMEs and fostering technical expertise. Through H_2Uppp, German technology and expertise can be transferred to Kazakh stakeholders, helping to build capacity and enhance the country's readiness to scale up green hydrogen production. To effectively navigate this complex funding landscape, companies must align their project scope and objectives with the peculiarities of these instruments, engaging with the representatives of the individual funding measure or with advisory services that can provide insights into available programmes and their specific requirements. Furthermore, combining complementary funding mechanisms – such as investment guarantees with public-private partnership initiatives – can maximise support and mitigate risks. Strategic partnerships facilitated through platforms like the International PtX Hub can also enhance market access and ensure the successful execution of hydrogen projects.

The German funding ecosystem offers opportunities for advancing international hydrogen initiatives. By leveraging these instruments strategically and adopting a tailored approach, companies can position themselves at the forefront of the global energy transition while benefiting from Germany's extensive support and expertise.

[85] https://www.ufk-garantien.de/en/solutions/covering-risks/project-structures.html

5.3 EU support mechanisms

EU support mechanisms for international hydrogen projects

Grants and subsidies

Instrument	Key points
IPCEIs	• Support mechanism for 'Important Projects of Common European Interest' • Only for EU Member States
Horizon Europe	• Fosters partnerships like the Clean Hydrogen Joint Undertaking • For collaboration between public and private sectors
Innovation Fund	• Supports innovation in low-carbon technologies and processes across EU member states
Connecting Europe Facility (CEF)	• Expansion of infrastructure projects in EU
InvestEU Fund	• Finance tool boosting public and private funding • Only for EU Member States
European Investment Bank (EIB)	• Also finances H_2 projects beyond EU
European Hydrogen Bank	• Financing instrument to accelerate the adoption of renewable hydrogen

Table 16: Grants and subsidies

Subsidies and grants

State Aid for Important Projects of Common European Interest (IPCEIs)[86]

Several EU Member States are involved in supporting hydrogen projects through IPCEIs. The aim of the initiative is to achieve renewable electrolysis capacities of 40 GW by 2030. Hy2Tech is the first IPCEI and comprises 41 projects relating to the development of innovative technologies along the hydrogen value chain. While Hy2Use deals with the development of hydrogen-related infrastructure and industrial applications, Hy2Infra is concerned with infrastructure projects and Hy2Move with mobility.

Horizon Europe[87]

Key initiatives include partnerships like the Clean Hydrogen Joint Undertaking, which fosters collaboration between the public and private sector to develop scalable and cost-effective hydrogen solutions. Horizon Europe aims to accelerate breakthroughs in renewable hydrogen, helping decarbonise hard-to-abate sectors and supporting the EU's transition to a clean energy economy.

Innovation Fund[88]

The Innovation Fund, one of the world's largest funding programmes for clean technologies, plays a key role in advancing hydrogen projects within the EU. By providing grants to first-of-a-kind projects, the Innovation Fund helps accelerate the commercialisation of green hydrogen, fostering decarbonisation in energy-intensive industries and transport, and contributing to the EU's climate neutrality goals.

Connecting Europe Facility (CEF)[89]

The Connecting Europe Facility (CEF) supports hydrogen projects by funding infrastructure critical for the EU's clean energy transition. It focuses on cross-border hydrogen infrastructure, including pipelines, storage facilities and refuelling stations, to create a pan-European hydrogen network. CEF prioritises projects that integrate hydrogen into the Trans-European Networks for Energy (TEN-E), enabling the transport and distribution of renewable hydrogen across Member States. By improving connectivity and market access, the CEF helps accelerate hydrogen adoption in industry and transport, supporting the EU's goals of decarbonisation and energy resilience.

InvestEU Fund[90]

InvestEU provides an EU budgetary guarantee worth €26.2 billion to the EIB Group and selected implementing partners. It aims to facilitate access to finance for riskier projects in four policy areas which represent important priorities for the Union:

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86 https://competition-policy.ec.europa.eu/state-aid/ipcei_en

87 https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

88 https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/what-innovation-fund_en

89 https://cinea.ec.europa.eu/programmes/connecting-europe-facility_en

90 https://investeu.europa.eu/investeu-programme/investeu-fund/about-investeu-fund_en

sustainable infrastructure (€9.9 billion); research, innovation and digitisation (€6.6 billion); small and medium-sized businesses (€6.9 billion) and social investment and skills (€2.8 billion). The InvestEU Fund supports hydrogen projects by providing financing for investments that advance the EU's green transition. It focuses on boosting private and public funding for projects in renewable hydrogen production, infrastructure and industrial applications.

European Investment Bank (EIB)[91]

The European Investment Bank (EIB) is the long-term lending institution of the European Union owned by its Member States. It is a key financier of renewable hydrogen projects across the entire value chain, supporting the EU's transition to a carbon-neutral economy. The EIB has committed to channeling at least half of its annual financing volume towards climate-relevant projects.

European Hydrogen Bank (EHB)[92]

The European Hydrogen Bank (EHB) is an EU initiative to accelerate the adoption of renewable hydrogen, supporting the transition to clean energy and decarbonisation of industries. It was launched in 2022 and is run internally by the European Commission as a financing instrument to create investment security and business opportunities for European and global renewable hydrogen production. The goal is to enable private investments for an entire hydrogen value chain. The EHB also aims to support renewable hydrogen import through hydrogen partnerships with non-EU countries.

Analysis of EU financing instruments

The EU offers a comprehensive suite of financing mechanisms and support instruments that are highly relevant to Kazakhstan's efforts to scale up its green hydrogen sector. The EU provides diverse financial and strategic tools to support hydrogen projects, targeting innovation, infrastructure and the green transition.

Key instruments include the EHB, which promotes private investments across the entire hydrogen value chain by providing financial security and fostering renewable hydrogen imports through international partnerships. Additionally, the EIB supports hydrogen initiatives globally, extending financing to projects
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that include renewable hydrogen production, transport infrastructure and industrial applications.

The Innovation Fund, one of the world's largest clean technology funding programmes, is another critical tool. It supports first-of-a-kind green hydrogen projects, accelerating the commercialisation of low-carbon solutions in energy-intensive sectors. Infrastructure-focused mechanisms such as the CEF prioritise the creation of hydrogen networks, including pipelines, storage facilities and refuelling stations, essential for integrating renewable hydrogen into broader energy systems.

While many mechanisms are designed for EU Member States, instruments like the EIB and EHB are particularly relevant for non-EU countries, including Kazakhstan. They enable international collaboration, financing infrastructure and partnerships that align with EU standards. Kazakhstan can also benefit indirectly from collaboration opportunities facilitated by programmes such as Horizon Europe, which emphasises public-private partnerships for technological advancements and scalable hydrogen solutions.

The application of these mechanisms in Kazakhstan would necessitate strategic alignment with EU funding priorities and early engagement with EU institutions to navigate eligibility and compliance requirements. By leveraging these tools, Kazakhstan can address critical financing gaps, attract private investments and foster partnerships that accelerate its green hydrogen development while contributing to the global energy transition.

To proceed effectively, stakeholders should evaluate eligibility by determining which mechanisms align with the project's goals, geographic scope and funding requirements. They would need to engage early and establish direct communication with relevant EU bodies to understand application processes and compliance criteria. Furthermore, it is also important to consider the possibility of existing synergies by exploring combinations of instruments to maximise support for large-scale or cross-border initiatives.

A tailored approach, guided by expert advice or consultation with EU representatives, is crucial for successfully navigating the support landscape.

[91] https://www.eib.org/en/index

[92] https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen/european-hydrogen-bank_en

6 Recommendations

Legal, regulatory and infrastructure recommendations for Kazakhstan's hydrogen sector

Kazakhstan's evolving hydrogen industry holds significant potential for both domestic use and export. However, realising this potential requires a transparent legislative environment, a supportive regulatory framework and robust infrastructure. The following consolidated recommendations outline key reforms, policies and measures aimed at aligning Kazakhstan's hydrogen sector with climate goals, enhancing investment attractiveness and fostering sustainable growth.

Introduction and strategic context

Kazakhstan has abundant renewable energy resources, making it well positioned to develop a competitive green hydrogen economy. Under the Strategy for Carbon-Neutral Kazakhstan by 2060, hydrogen is identified as a pillar for decarbonising industry, transport and power. At the same time, evolving European Union requirements and global low-carbon standards underscore the need for clear regulations that encourage clean hydrogen production, support international trade and ensure environmental sustainability.

Research on the hydrogen supply strategy highlights immediate opportunities for hydrogen use in existing infrastructure such as refineries and chemical facilities, mid-term prospects in steel and heavy transport, and long-term possibilities in industrial heating and aviation. Realising these opportunities calls for legislative clarity, financial incentives and international partnerships that cultivate innovation and address water, emissions and infrastructure constraints.

1. Institutional structure and governance for hydrogen development

The successful implementation of Kazakhstan's hydrogen strategy requires a robust institutional framework to coordinate efforts across various sectors and stakeholders. Given the cross-cutting nature of hydrogen technologies and their potential impact on multiple industries, a well-structured governance approach is essential for effective policy-making, project implementation and international collaboration.

To establish an effective governance structure for hydrogen development in Kazakhstan, the following institutional arrangements are recommended:

A Cross-ministerial governance structure

A Hydrogen Coordinating Council should be established under the Ministry of Energy to serve as the primary coordination mechanism. This council would convene representatives from key ministries – including Industry and Construction, Ecology and Natural Resources, National Economy, and Foreign Affairs – alongside private-sector stakeholders to facilitate strategic alignment, policy coherence and international cooperation. This approach builds upon proposals previously presented to Kazakh officials during their engagement with Germany's hydrogen coordination bodies.

B Departmental specialisation

The Ministry of Industry and Construction should establish a Department for Decarbonisation Policy to address the current institutional gap in industrial decarbonisation oversight. This department would develop and implement comprehensive strategies for industrial carbon reduction, including hydrogen technologies integration and the utilisation of hydrogen derivatives as industrial feedstock, ensuring alignment with broader climate objectives.

Concurrently, a dedicated Hydrogen Department should be established within the Ministry of Energy to centralise strategic coordination. Working in close collaboration with the Decarbonisation Policy Department, this structure would optimise expertise deployment, resource allocation and cross-sectoral collaboration between energy generation and industrial applications.

C Market development mechanism

A Unified Hydrogen Purchaser (UHP) should be instituted under joint oversight from the Ministries of Energy and Industry to catalyse market development. The UHP would undertake five critical functions: conducting comprehensive market research to map hydrogen production and consumption potentials; identifying and engaging strategic consumers domestically and internationally; securing long-term corporate and intergovernmental contracting arrangements; managing domestic supply through structured agreements with local entities; and coordinating production development through auctions and pilot projects.

These institutional arrangements would establish clear responsibilities while ensuring necessary coordination across ministries. This governance framework provides the foundation for effective hydrogen policy implementation while Kazakhstan continues to refine its national hydrogen strategy and institutional structures.

2. Establish specific hydrogen legislation

A dedicated hydrogen law would streamline regulations for production, distribution, storage, usage and export of hydrogen. This approach reduces fragmentation, clarifies investor requirements and fosters a stable environment for large-scale hydrogen projects. Key legal components should include:

Dedicated definitions and scope

Clearly define hydrogen types (green, blue, renewable, low-carbon) and delineate responsibilities of producers, distributors and authorities.

Amendments to existing codes

Introduce targeted updates to the Entrepreneurial Code, Water Code, Environmental Code, electricity laws and renewable energy laws to reflect hydrogen-specific needs.

Hydrogen purchase rules

Formulate standardised contract templates for hydrogen transactions, along with provisions for a Unified Hydrogen Purchaser (UHP) to centralise procurement, market research and long-term contracting.

Electrolyser placement and correlation

Regulate where electrolysers can be deployed, ensuring alignment with water resource availability and mandating temporal/geographical correlation with renewable power sources. A phased approach can begin with monthly matching of renewable electricity and hydrogen production, transitioning to hourly matching by the end of 2029.

Green production standards

Establish quality, safety and environmental standards for green hydrogen production to align with international standards on emissions, water usage and renewable energy integration. The Green Taxonomy of Kazakhstan must incorporate specific thresholds – such as maximum carbon intensity limits, minimum renewable energy requirements for electrolysis, water consumption benchmarks and internationally aligned verification protocols – to ensure transparency and global compatibility in classifying hydrogen as ‘green’.

3. Strengthen environmental and resource management

Hydrogen production, particularly via electrolysis, must address water usage, emissions and broader ecological impacts:

Hydrogen-specific environmental assessments

Require project-level analysis focusing on water consumption, emissions control and land use. Set maximum allowable water consumption per kilogram of hydrogen produced.

Amend the Water Code

Prioritise water allocation for green hydrogen in water-scarce regions, emphasising recycled, desalinated or treated wastewater to safeguard local communities and ecosystems.

Climate impact evaluations

Supplement environmental impact assessments with a climate-focused evaluation. Projects should outline how their hydrogen production pathways contribute to carbon reduction and align with net-zero goals.

Additionality requirements

Adopt provisions ensuring new hydrogen projects draw on added renewable capacity rather than displacing existing clean power. This prevents undermining of broader decarbonisation efforts.

4. Incentivise green hydrogen production and utilisation

Kazakhstan can leverage tax breaks, subsidies and carbon credit mechanisms to encourage green hydrogen while phasing out subsidies for fossil fuel generation:

Tax relief and subsidies

Extend renewable energy incentives to green hydrogen producers, offering tax credits on infrastructure, equipment and operations that lower the carbon intensity of hydrogen projects.

Carbon credit trading

Develop a specialised trading system allowing green hydrogen producers or consumers to earn credits for low-emission outputs. Align these credits with national carbon-neutrality targets to attract climate-focused investors.

Tiered emissions thresholds

Gradually tighten hydrogen production emission limits. Provide stronger incentives for projects meeting increasingly stringent thresholds, culminating in net-zero hydrogen by 2060.

5. Encourage public-private partnerships and innovative financing

Long-term success depends on diversified funding sources and structured collaboration between government, private investors and international partners:

Transparent legal framework for PPPs

Consolidate relevant laws to clarify roles, rights and obligations in hydrogen-focused PPPs. This fosters risk-sharing mechanisms and helps pilot advanced hydrogen technologies.

Green bonds and blended finance

Issue green bonds to raise capital from environmentally responsible investors and combine concessional finance with private sector funding to reduce financial risk for large-scale projects.

Investment incentives

Offer tax credits, grants or low-interest loans for hydrogen infrastructure – particularly for storage, pipelines and refuelling networks. Link these incentives to compliance with emissions benchmarks and integration of renewable energy.

International collaboration

Engage with multilateral organisations and specialised agencies to secure insights and funding. Joint initiatives with the EU, Germany and experienced hydrogen economies can support technical transfer, capacity building and standardisation.

6. Build and integrate hydrogen infrastructure

Coordinated infrastructure development is vital for scaling production and export capabilities:

Production hubs and co-located facilities

Encourage electrolyser installation at existing industrial sites to minimise logistics costs, secure water resources and tap into existing energy infrastructure.

Transport and storage networks

Expand pipelines or repurpose existing gas infrastructure for hydrogen. Where pipelines are unavailable, explore shipping via ammonia or methanol. Implement rigorous safety standards aligned with international guidelines.

Refuelling and distribution

Support widespread deployment of hydrogen fuel stations, focusing on crucial transport corridors and industrial centres. Introduce pilot projects for heavy transport, steel production and other hard-to-abate industry sectors, and integrated power-to-x solutions.

7. Technological and innovation ecosystem

A robust technological and innovation ecosystem is crucial for Kazakhstan to become a competitive player in the global hydrogen market, driving advancements in production, storage and utilisation technologies:

Establish hydrogen research and innovation centres

Set up laboratories for fundamental and applied R&D; facilitate collaboration among scientists, engineers and startups; and provide infrastructure for testing and validating new hydrogen technologies.

Provide R&D grants

Offer tiered grants for both early-stage and scale-up projects; emphasise carbon reduction impacts in funding criteria; and pair grants with mentorship or incubator programmes to enhance commercialisation outcomes.

Develop education and training programmes

Integrate hydrogen modules into vocational and university curricula; develop short-course certifications for technicians; and partner with industry to provide hands-on training on electrolysers, fuel cells and system maintenance.

Create innovation hubs

Encourage co-location of production, storage and end-use; enable shared pipelines or transport infrastructure; and provide common testing facilities and joint procurement frameworks.

Foster international technology partnerships

Launch joint R&D initiatives with premier institutes; form bilateral or multilateral agreements to harmonise standards; and share best practices through consortia focused on policy, technical guidelines and safety benchmarks.

8. Adopt safety standards and certification protocols

A robust safety framework reinforces public trust and operational consistency:

Regulations for hydrogen equipment

Mandate approvals and periodic inspections for manufacturing, handling and storage facilities. Adopt or update existing ISO requirements and implement national standards that govern operations across the hydrogen value chain.

Training and workforce development

Establish certification programmes for technical staff. Engage academia and industry in creating hydrogen-focused curricula that ensure qualified operators and continuous skills upgrades.

Clean hydrogen certification

Develop transparent certification benchmarks (e.g., emissions intensity, water usage, renewables integration) that showcase Kazakhstan's adherence to international standards. Such classification assures foreign buyers of hydrogen's sustainability.

9. Facilitate international hydrogen trade

Establishing Kazakhstan as a reliable exporter requires well-defined rules, compatible standards and stable trade relationships:

Export licensing and harmonisation

Develop specialised export licences, customs procedures and contractual terms for hydrogen and its derivatives. Align with recognised standards to boost acceptance in target markets.

Intergovernmental agreements

Pursue bilateral and multilateral arrangements that simplify cross-border hydrogen logistics. Address shared infrastructure, transit routes and consistent safety-inspection measures.

Compatibility with global markets

Update certifications, labelling and sustainability criteria in line with ISO and international carbon-intensity regulations. This harmonisation provides Kazakhstan's green hydrogen with broader market access.

10. Cross-sector integration and regional cooperation

The hydrogen economy extends beyond power and transport, offering opportunities in mining, petrochemical processes and agro-industries:

Cross-sector policies

Encourage synergy among industries – especially steel, chemicals, aviation and shipping – where hydrogen adoption supports decarbonisation without compromising competitiveness.

Regional partnerships in Central Asia

Collaborate with neighbouring countries to form a green hydrogen hub. Combine each nation's strengths (e.g., hydropower, solar, natural gas expertise) to optimise resource allocation and infrastructure development.

Intergovernmental platforms

Host regular summits for stakeholders to align policies, share best practices and strengthen cohesion across Central Asia. Develop consistent standards for water use, emissions and trade to mitigate geopolitical risks.

Building a robust hydrogen ecosystem in Kazakhstan entails legal clarity, strategic infrastructure investment, responsible water and environmental management, and alignment with international standards. Through a unified hydrogen law, targeted amendments to existing legislation and incentives for renewable-based production, Kazakhstan can bolster investor confidence and accelerate its transformation into a key player in the global low-carbon economy.

Proposed phased implementation roadmap

Phase 1 (2025–2030):

- Develop legislative framework
- Establish institutional structures
- Initial infrastructure investments
- Pilot project implementations

Phase 2 (2030–2045):

- Scale up hydrogen production
- Expand international trade
- Advanced technological integration
- Comprehensive infrastructure development

Phase 3 (2045–2060):

- Achieve 'Net Zero Hydrogen' production
- Full international market integration
- Advanced sustainable practices
- Global leadership in hydrogen economy

Key performance indicators

Dimension	Target metric	2030 goal	2045 goal	2060 goal
Production capacity	Hydrogen volume	10 million tonnes	50 million tonnes	100 million tonnes
Renewable integration	% Renewable energy	50%	75%	100%
Emissions reduction	CO_2 threshold	4 $kgCO_2/kg\ H_2$	2 $kgCO_2/kg\ H_2$	Net zero
Export market share	Global market penetration	5%	15%	25%

Table 17: Key performance indicators

By fostering innovation, strengthening regional collaboration and integrating advanced safety and certification standards, Kazakhstan will be well positioned to unlock new export markets while meeting its own net-zero objectives. A phased, deliberate approach – encompassing secure financial mechanisms, strong public-private partnerships and a forward-thinking policy stance – allows Kazakhstan to chart a sustainable hydrogen future that underpins national prosperity and global climate goals alike.

7 Conclusion

Central Asia, particularly Kazakhstan as the regional energy transition frontrunner, is undergoing significant changes in its energy landscape, transitioning from traditional hydrocarbon-based energy generation to renewable energy technologies. The region's rich renewable resources and strategic geographical position between Europe and Asia open up considerable opportunities for developing green hydrogen exports and decarbonisation of the local economy through green hydrogen.

The region demonstrates a balanced distribution of energy resources, with Kazakhstan and Uzbekistan leading the transition to wind and solar energies, while Kyrgyzstan and Tajikistan traditionally excel in hydropower, complementing the region's energy balance and creating a foundation for further renewable energy development. The development of energy connectivity in Central Asia has great potential to enable the integration of renewable energy facilities and balanced operation of the unified energy system of Central Asia as a whole.

The fact that Kazakhstan has successfully initiated its transition to wind and solar energy production over the past decade can stimulate the introduction of new energy technologies and help improve the odds of becoming a renewable hydrogen exporter. This transition also presents significant economic opportunities. The development of renewable energy sources has attracted substantial foreign investment, leading to job creation and economic diversification. The history of renewable energy development in Kazakhstan, its lessons and achievements, instill confidence that within a 10-year horizon, green hydrogen will be widely used in the country as the most reliable, environmentally friendly and accessible form of energy. The government of Kazakhstan demonstrates commitment to sustainable energy development through initiatives such as the Strategy for Achieving Carbon Neutrality by 2060, the Concept for Hydrogen Energy Development and the adoption of international standards. In 2022, NC KazMunaiGas JSC established the Hydrogen Energy Competence Center at its subsidiary, KMG Engineering LLP, now the Department of Alternative Energy. This initiative centralises expertise and accelerates research in the field. The government also supports hydrogen energy advancements by funding university research through grants from the Ministry of Science and Higher Education.

The relative geographical proximity to key markets in Europe and Asia as compared to other prospective hydrogen producing countries without a land connection enhances Kazakhstan's export potential in the field of green hydrogen. However, geopolitical challenges, such as regional instability and political dynamics, as well as technical obstacles like infrastructure development, transportation and the need for advanced technology, could impact the country's ability to fully capitalise on this potential. The country could play a significant role in the supply of hydrogen and/or its derivatives such as ammonia to the EU if it meets the standards set by the Carbon Border Adjustment Mechanism (CBAM) and the body of EU energy regulation.

To unlock the potential of the region's hydrogen economy, a comprehensive approach integrating regulatory, financial and technological elements is necessary. Regionalisation can further enhance this potential by fostering collaboration across neighbouring countries, streamlining infrastructure development and creating economies of scale. By pooling resources and expertise, regional cooperation can also reduce costs, improve market access and accelerate the deployment of green hydrogen technologies. This includes harmonising local legislation with international standards to facilitate access to global markets, utilising international funding programmes while developing domestic investment incentives and strengthening partnerships with the EU and Germany for knowledge exchange and technology transfer. Specifically, Joint Working Groups should focus on aligning Kazakhstan's regulatory framework with EU import standards, particularly in certification and sustainability criteria. Activities should encompass public awareness campaigns and training decision-makers on the benefits of hydrogen energy, alongside developing critical infrastructure including production hubs, pipelines and storage facilities. Success will depend on continued investment in research and development to reduce production costs and improve the efficiency of hydrogen technologies, while strengthening regional cooperation and maintaining clear communication channels among all stakeholders.

Future prospects

The region's diverse energy resources and developing infrastructure provide a solid foundation for becoming a new energy centre of the future. Kazakhstan stands at a critical juncture in defining its hydrogen economy trajectory. By accelerating regulatory reforms, prioritising infrastructure investments – including scaled electrolyser deployment and pipeline retrofitting – and deepening strategic partnerships with EU and German institutions, the country could secure a competitive position in global hydrogen markets. Coordinated efforts between government, industry and international stakeholders will be essential to ensure long-term sustainability, enhance investment attractiveness and strengthen trade competitiveness.

With decisive political will and strategic vision, Central Asia's transition to a hydrogen economy represents a transformative opportunity to achieve sustainable growth while advancing global decarbonisation goals. Addressing infrastructure bottlenecks, harmonising regulations with EU standards (e.g., RED III, CBAM) and fostering innovation through programmes like Germany's H_2Global and Horizon Europe could enable Kazakhstan to emerge as a leading producer and exporter of green hydrogen. By 2040, these actions could position the region as a key supplier to EU markets, leveraging its renewable energy potential and geopolitical connectivity. Success hinges on maintaining momentum through phased reforms, cross-sector collaboration and sustained engagement with international partners to balance economic growth with environmental stewardship.

Annex 1. Trends in electricity costs and capacity factors for RES affecting the levelised cost of hydrogen (LCOH)

The tables below collectively illustrate that combined solar and WPPs outperform standalone systems in capacity factors and full-load hours, while solar-only systems face high electricity costs and low efficiency, and wind-only systems show improving capacity factors but are reliant on optimal geographic conditions.

Table 18 demonstrates the superior performance of combined solar and WPPs in terms of capacity factor (46–57%) and full-load hours (4,029.6–5,016.4 hours) compared to standalone solar or wind systems.

	2024	2025	2026	2027	Units
Discount rate	8	8	8	8	%
Lifetime electrolyser system	20	20	20	20	years
Lifetime stack (manufacturer's data)	80,000	80,000	80,000	80,000	h
Annuity factor	0.102	0.102	0.102	0.102	-
Specific energy consumption	50	50	50	50	kW·h /kgH_2
Full-load hours	4,029.6	4,292.4	4,666	5,016.4	h
Capacity factor	0.46	0.49	0.53	0.57	-
System pressure	30	30	30	30	bar
Compressor efficiency	80	80	80	80	%
Electricity costs	36.81	36.49	36.74	36.38	€/MWh
OPEX	5	5	5	5	% of CAPEX per year
CAPEX electrolyser system (low/high estimate)	800/1,500	800/1,500	800/1,500	800/1,500	€/kW
EPC	20	20	20	20	% of CAPEX electrolyser system
Stack replacement costs	30	30	30	30	% of CAPEX electrolyser system
CAPEX system without stack (low/high estimate)	600/800	600/800	600/800	600/800	€/kW
Building	150	150	150	150	€/kW

Table 18: Input data for combination of solar and WPP

Table 19 highlights the limitations of solar-only systems, with consistently high electricity costs (€46.46/MWh) and low capacity factors (16–18%).

	2024	2025	2026	2027	Units
Discount rate	8	8	8	8	%
Lifetime electrolyser system	20	20	20	20	years
Lifetime stack (manufacturer's data)	80,000	80,000	80,000	80,000	h
Annuity factor	0.102	0.102	0.102	0.102	-
Specific energy consumption	50	50	50	50	kW·h /kgH_2
Full-load hours	1,401.6	1,401.6	1,600	1,600	h
Capacity factor	0.16	0.16	0.18	0.18	-
System pressure	30	30	30	30	bar
Compressor efficiency	80	80	80	80	%
Electricity costs	46.46	46.46	46.46	46.46	€/MWh
OPEX	5	5	5	5	% of CAPEX per year
CAPEX electrolyser system (low/high estimate)	800/1,500	800/1,500	800/1,500	800/1,500	€/kW
EPC	20	20	20	20	% of CAPEX electrolyser system
Stack replacement costs	30	30	30	30	% of CAPEX electrolyser system
CAPEX system without stack (low/high estimate)	600/800	600/800	600/800	600/800	€/kW
Building	150	150	150	150	€/kW

Table 19: Input data for SPP

Table 20 showcases wind-only systems' improving capacity factors (30–39%) but underscores their dependence on favourable geographic conditions.

	2024	2025	2026	2027	Units
Discount rate	8	8	8	8	%
Lifetime electrolyser system	20	20	20	20	years
Lifetime stack (manufacturer's data)	80,000	80,000	80,000	80,000	h
Annuity factor	0.102	0.102	0.102	0.102	-
Specific energy consumption	50	50	50	50	kW·h /kgH_2
Full-load hours	2,628	2,890.8	3,066	3,416.4	h
Capacity factor	0.30	0.33	0.35	0.39	-
System pressure	30	30	30	30	bar
Compressor efficiency	80	80	80	80	%
Electricity costs					€/MWh
OPEX	5	5	5	5	% of CAPEX per year
CAPEX electrolyser system (low/high estimate)	800/1,500	800/1,500	800/1,500	800/1,500	€/kW

	2024	2025	2026	2027	Units
EPC	20	20	20	20	% of CAPEX electrolyser system
Stack replacement costs	30	30	30	30	% of CAPEX electrolyser system
CAPEX system without stack (low/high estimate)	600/800	600/800	600/800	600/800	€/kW
Building	150	150	150	150	€/kW

Table 20: Input data for WPP

Annex 2. Trends for regional cooperation, stakeholders, infrastructure and transportation pathways for a Caspian-EU Clean Energy Corridor

This Annex highlights key treaties shaping the Caspian Sea's resource management, overviews hydrogen strategies in Azerbaijan, Georgia and Turkey, and maps existing transport routes for oil, gas and future hydrogen. It also identifies main stakeholders and outlines regional green energy projects aimed at connecting Caspian resources to European markets.

Table 21 below summarises hydrogen-focused policies and capacities in Azerbaijan, Georgia and Turkey, covering published strategies, production potential, cost projections and infrastructure plans, emphasising each country's approach to green hydrogen and export pathways.

Criteria	Azerbaijan	Georgia	Turkey
Hydrogen Strategy (Published/Date)	**National Strategic Review for Hydrogen** is presented at COP 29, focusing on green hydrogen, local use and regional export partnerships.	**Not yet published**, with a focus on feasibility studies for hydrogen in the domestic market and export corridors.	**Published in 2023**, focuses on green hydrogen scaling, domestic applications, and positioning Turkey as an export hub to Europe.
Hydrogen Production Potential	Significant potential for both blue hydrogen from natural gas (using CCS) and green hydrogen from offshore wind.	Potential for green hydrogen mainly through surplus hydropower, with supplementary wind power to balance seasonality.	Strong potential for blue and green hydrogen, targeting **5 GW electrolyzer capacity by 2035** and **70 GW by 2053**.
Cost of Production	Green hydrogen LCOH is around **2.92 EUR/kg** (2030), with blue hydrogen costs potentially lower but dependent on CO_2 storage and gas prices.	Approx. **2.70 EUR/kg** in mid-2020s, with a projected decrease to **1.54 EUR/kg by 2050**.	Green hydrogen production costs currently **$6–10 per kg**; targeted reductions to **below $2.4 per kg by 2035** and **$1.2 per kg by 2053**.
Renewable Energy Sources	**3,000 MW target by 2030**, primarily offshore wind and solar, with a part dedicated to hydrogen production. During COP 29, it was highlighted that achieving the balanced and accelerated scenarios for green hydrogen production by 2050 will necessitate renewable energy investment capacities of 9 GW and 18 GW, respectively.	Predominantly hydropower with a capacity of **1,300 MW**, with some surplus allocated for green hydrogen production, especially during high-flow seasons.	Extensive solar, wind, hydropower, and geothermal resources, with renewable integration for green hydrogen production.
Water Source	Desalinated Caspian Sea water for green hydrogen	Hydropower reservoirs, with surplus energy during	Primarily freshwater, with potential future

Criteria	Azerbaijan	Georgia	Turkey
	production to avoid inland freshwater usage.	peak seasons, support hydrogen production.	desalination for coastal green hydrogen production.
Infrastructure and Export	Utilizes Southern Gas Corridor (SGC) for potential hydrogen blending, with planned routes to Europe through pipelines.	Exploring hydrogen blending in natural gas pipelines (up to 30%), with export possibilities via Black Sea ports.	Strategic use of the Southern Gas Corridor for European exports, with plans to adapt existing gas infrastructure for hydrogen and build dedicated pipelines.
Domestic Market Plan	Focus on reducing emissions in domestic industries like petrochemicals and power generation, with plans to expand hydrogen use in transport and heating.	Exploring green hydrogen production primarily for domestic sectors with seasonal hydropower surpluses.	Emphasis on green hydrogen for industry, transportation, and energy sectors to reduce fossil fuel dependency and enhance energy security.

Table 21: Hydrogen strategies in Middle Corridor countries

Table 22 highlights key international and regional treaties shaping legal, environmental and resource extraction frameworks around the Caspian Sea, detailing their implementation status and ongoing challenges.

Year	Document/Convention	Description	Implementation
1994	Energy Charter Treaty	Framework for international energy cooperation, including transit rights (not Caspian-specific).	Facilitates energy transit and investment, but Russia's withdrawal limits its impact in the Caspian region. Political tensions complicate joint projects and energy trade.
2003	Tehran Framework Convention for the Protection of the Marine Environment of the Caspian Sea	Legally binding regional agreement to prevent marine pollution and protect ecosystems.	Created a foundation for environmental protection; however, pollution from industrial activities persists due to inconsistent enforcement and voluntary reporting.
2011	Protocol on Regional Preparedness, Response, and Cooperation in Combating Oil Pollution Incidents (Tehran Convention)	Coordinates oil spill response efforts among Caspian states.	Provides a framework for coordinated oil spill response, but real-time implementation can vary by country.
2012	Protocol on the Protection of the Caspian Sea Against Pollution from Land Based Sources an Activities	Aims to reduce pollution from industrial, agricultural, and urban activities along the coast.	Some pollution controls are implemented, but enforcement remains uneven. Industrial pollution from oil and gas operations continues to be a major issue.

Year	Document/Convention	Description	Implementation
2014	Agreement on the Conservation and Sustainable Use of Biological Resources of the Caspian Sea	Measures for biodiversity protection and sustainable use of marine resources.	Some protections for endangered species like the Caspian seal are in place, but lack of funding and enforcement limit overall effectiveness, especially where economic interests conflict with conservation.
2018	Convention on the Legal Status of the Caspian Sea	Defines territorial waters, seabed resources, and navigation rights for all five littoral states.	A landmark for regional cooperation, though unresolved boundaries between some states continue to create tensions. Resource extraction rights are still being negotiated in certain areas.
Ongoing	Protocol on Environmental Impact Assessment (EIA) in a Transboundary Context	Aims to ensure environmental assessments for projects with transboundary impacts in the Caspian region.	It is still under negotiation; it is intended to improve environmental oversight for major projects, but the real-world impact is pending agreement and enforcement from all countries involved.

Table 22: Agreements and conventions related to the Caspian Sea

Table 23 lists major public and private organisations, government ministries and international entities involved in shaping hydrogen initiatives across the Caspian region, describing how each influences policy, investment and technological deployment.

Stakeholder category	Organisation/entity	Role	Relevance
Governments Kazakhstan	Ministry of Energy, Ministry of Ecology and Natural Resources, Ministry of Industry and Construction, Ministry of Transport, Ministry of Foreign Affairs	Manage energy policies, ensure environmental compliance, promote industrial and transport infrastructure for hydrogen, and facilitate international partnerships.	Essential for positioning Kazakhstan as a major hydrogen producer, supporting sustainable development, advancing industrial applications, enabling low-carbon transportation, and attracting foreign investment.
	National Energy Companies: KazMunayGas (KMG), QazaqGaz, Samruk-Energo	Explore hydrogen production and infrastructure integration	A key player in transitioning from fossil fuels to hydrogen-based solutions, blending hydrogen with gas network
	Financial entities: Kazakh Invest, National Wealth Fund ‘Samruk-Kazyna’	Provide financial support and incentives for hydrogen projects	Attract investments and fund large-scale hydrogen infrastructure projects
Azerbaijan	Ministry of Energy, SOCAR, Azerbaijan Renewable Energy Agency (AREA)	Manage national oil and gas resources, renewable initiatives	A pivotal player in the Caspian Sea energy trade, links Central Asia with Europe

Stakeholder category	Organisation/entity	Role	Relevance
Georgia	Ministry of Economy and Sustainable Development, Georgian Oil and Gas Corporation (GOGC), Ministry of Environmental Protection and Agriculture, Georgian State Electrosystem (GSE).	Oversee transit routes, manage energy infrastructure, support green hydrogen production from renewables, and ensure environmental protection.	Serve as a strategic link on the Caucasus transit corridor, connecting the Caspian region to Europe, balancing energy needs and facilitating green hydrogen integration into the national grid.
Turkey	Ministry of Energy and Natural Resources, Ministry of Environment and Urbanization, Turkish Petroleum (TPAO), BOTAŞ.	Manage energy resources and transit infrastructure, and ensure environmental compliance for hydrogen projects.	Key transit country between Asia and Europe, controlling significant natural gas infrastructure with potential for hydrogen integration, supporting sustainable hydrogen development aligned with national climate goals.
Romania	Ministry of Energy, Romgaz, Transgaz	Oversee energy infrastructure	Critical link from the Black Sea to the EU, potential hydrogen transport role
Bulgaria	Ministry of Energy, Bulgartransgaz	Control key European energy routes	Strategic location on the route to Europe for hydrogen transport
Regional authorities	Port authorities (Baku, Aktau, Constanța, Istanbul)	Manage ports and customs	Facilitate hydrogen and energy trade across the Caspian and Black Sea
	Caspian Sea Regional Cooperation Bodies	Oversee maritime routes for energy transport	Essential for regional trade and stability
Regulatory bodies	Kazakhstan: KazStandard	Regulates environmental and quality standards	Ensures compliance with safety and environmental standards for hydrogen production
	Turkey: Turkish Standards Institute (TSE), TÜBİTAK	Set quality and R&D standards	Support Turkey's role as an energy transit hub
	EU: ECHA, EEA, European Hydrogen Strategy, Fit for 55, TEN-E ISO- international standards	Set environmental and infrastructure standards	Influence hydrogen import standards into Europe
International organisations	International Energy Agency (IEA), International Renewable Energy Agency (IRENA), Hydrogen Council	Provide data, analysis, policy guidance and industry advocacy to support the global transition to clean energy, focusing on renewable energy adoption, hydrogen development and decarbonisation strategies.	Key influencers on global hydrogen policies and standards, driving international energy policies, promoting renewable energy cooperation and advancing hydrogen as essential to the clean energy transition.
	Organization of the Petroleum Exporting Countries (OPEC)	Manages policies for energy production among member countries.	Influences global policies on hydrogen production and exports among oil-producing nations.
	United Nations (UN) Agencies – United Nations Environment Programme (UNEP), United Nations Industrial Development Organization (UNIDO), United Nations Economic Commission for Europe (UNECE)	Provide environmental standards, promote sustainable industrial development and facilitate economic cooperation and regulatory frameworks,	Crucial for advancing hydrogen projects globally by setting sustainability standards, supporting industrial adoption in emerging markets and promoting policy alignment

Stakeholder category	Organisation/entity	Role	Relevance
		particularly for hydrogen projects and infrastructure.	and cooperation, especially across Europe and Central Asia.
	Deutsche Gesellschaft für Internationale Zusammenarbeit /German development agency (GIZ), Deutsche Energie-Agentur/ German Energy Agency (dena)	Provide technical assistance, strategic guidance and policy advice for sustainable energy solutions, focusing on renewable energy, energy efficiency and hydrogen development.	Key partners in advancing energy transition by supporting international cooperation, helping countries like Kazakhstan build sustainable energy infrastructure, integrating hydrogen, and leveraging German and European expertise in hydrogen technologies to reduce carbon emissions.
Environmental agencies and NGOs	Greenpeace, WWF, The Nature Conservancy	Advocate for environmental protection	Monitor and influence hydrogen projects for ecological safety
	Caspian Environment Program, Central Asia Regional Economic Cooperation Program (CAREC)	Regional environmental management	Focus on protecting ecosystems, especially the Caspian Sea. CAREC is fostering sustainable energy practices and regional connectivity in Central Asia. Its work in energy cooperation and infrastructure supports member countries in transitioning to renewable sources, strengthening energy security.
	Association for the Conservation of Biodiversity of Kazakhstan (ACBK)	Implements conservation projects for endangered species and habitats, supports protected area creation and promotes environmental awareness and sustainable resource use.	Crucial in preserving Kazakhstan's biodiversity, aiding ecosystem conservation and supporting sustainable development, which is vital for ecologically sensitive areas connected to hydrogen and other energy projects.
Logistics providers and private sector	DP World, Maersk, Mediterranean Shipping Company (MSC)	Transport and logistics for hydrogen	Enable efficient hydrogen transit across the Caspian and Black Sea regions
	Caspian Shipping Company	Maritime transport in the Caspian Sea	A key regional player in hydrogen logistics
	Siemens Energy, Linde, Air Liquide, Shell, TotalEnergies	Infrastructure development	Provide technology for hydrogen production, storage and transport
	Hydrogen Europe	Industry association for hydrogen	Fosters collaboration between hydrogen stakeholders across Europe
	European Investment Bank (EIB), Asian Development Bank (ADB), European Bank for Reconstruction and Development (EBRD)	Financial institutions	Their investments and expertise are essential for facilitating the transition to a low-carbon economy, particularly in emerging markets, and for promoting environmental

Stakeholder category	Organisation/entity	Role	Relevance
			sustainability in line with regional and global climate goals.
Public-Private Partnerships (PPP)	Hydrogen Europe, EU Clean Hydrogen Alliance	Promote hydrogen technologies in Europe	Support collaborative efforts to scale hydrogen across Europe
	European Hydrogen Backbone	Network of gas transmission companies for hydrogen	Establishes a hydrogen pipeline network to connect Europe
	KMG and SOCAR collaborations	Possibility of developing a regional transportation system for hydrogen	Leverage existing assets for hydrogen export and infrastructure development
	SVEVIND	SVEVIND is a project developer based in Germany, specialising in large-scale wind and solar energy projects.	SVEVIND plays a key role in advancing green hydrogen production in Kazakhstan, where it is developing one of the world's largest green hydrogen projects.

Table 23: Stakeholders and their role and relevance

Table 24 the key routes and techniques for transporting oil, natural gas and hydrogen – ranging from pipelines and rail to maritime shipping – while noting infrastructure adaptability for hydrogen and its implications for regional energy trade.

Resource	Transportation method	Description	Key route
Oil	**Caspian Pipeline Consortium (CPC)**	The primary route for transporting oil from Kazakhstan to the Sangachal Terminal in Azerbaijan.	The CPC pipeline runs from the Tengiz oil field to Novorossiysk, Russia, then shipped to Azerbaijan.
	Rail transport	Used for smaller volumes of oil or when pipeline capacity is limited.	Railways transport oil from inland production sites to the Sangachal Terminal.
	Integration with Baku-Tbilisi-Ceyhan (BTC) Pipeline	Oil is processed at the Sangachal Terminal and prepared for entry into the BTC pipeline for export to Turkey and Europe.	The Sangachal Terminal serves as a hub for consolidating oil from various sources.
Gas	**Caspian Pipeline Consortium (CPC)**	A major route for transporting natural gas from Turkmenistan and Uzbekistan through Kazakhstan to Russia.	Connects to various pipelines for further distribution in Europe.
	Kazakhstan-China Gas Pipeline	Transports natural gas directly from Kazakhstan to China.	Connects western Kazakhstan to the eastern borders for access to the Chinese market.
	Integration with regional networks	Gas is integrated with regional networks for export to neighbouring countries and Europe.	Key pipelines like the Central Asia Center (CAC) and Bukhara-Urals are crucial for transporting natural gas through Kazakhstan to other regions.
	LNG export	Explored for liquefied natural gas exports, although less developed compared to pipeline transport.	LNG facilities enable the transport of gas in liquefied form to global markets.

Resource	Transportation method	Description	Key route
Hydrogen	**Pipeline construction**	New pipelines can be constructed or existing gas pipelines adapted for hydrogen transport.	Proposed route: the Trans-Caspian International Transport Route
	Compressed hydrogen	Transporting hydrogen in high-pressure cylinders or specialised vehicles for smaller-scale distribution.	Direct transport to distribution points or refuelling stations within Kazakhstan and neighbouring regions.
	Liquid hydrogen	Hydrogen cooled to cryogenic temperatures and transported as a liquid in cryogenic tanks.	Shipping from Aktau Port to Baku, Azerbaijan, then by maritime routes to Black Sea ports.
	Hydrogen carriers	Transporting hydrogen in chemical forms (e.g., ammonia, methanol) that release hydrogen when processed.	Similar maritime routes, shipping from Kazakhstan to Baku and then to European markets.
	Rail transportation	Utilising rail infrastructure to transport hydrogen overland.	Rail from production sites in Kazakhstan to Aktau Port, then across the Caspian Sea.
	Maritime transport	Shipping hydrogen via specialised vessels, either in liquid form or as a hydrogen carrier.	From Aktau Port to Baku and onward to Black Sea ports like Constanta (Romania) or Varna (Bulgaria).

Table 24: Transportation methods for existing oil, gas and possible hydrogen from Kazakhstan

Table 25 presents major cross-border initiatives aimed at exporting green energy from the Caspian region to Europe, detailing capacities, routes, investment costs and geopolitical considerations for submarine cable and electricity grid interconnections.

Project	Black Sea Submarine Cable	Caspian Sea Electricity Project
Description	Transports green energy from Azerbaijan to Europe	Connects energy grids of Azerbaijan, Kazakhstan, Uzbekistan for electricity exports
Capacity	1,000 MW	Expected to reach 1,000 MW
Length/Location	1,200 km, across the Black Sea from Georgia to Romania	Across the Caspian Sea
Energy Source	Primarily wind (onshore & offshore) and solar in Azerbaijan	Wind and solar in the Caspian region
Partners	Azerbaijan, Georgia, Romania, Hungary	Azerbaijan, Kazakhstan, Uzbekistan
Timeline	Agreements signed in 2022; JV established in 2023	MoU signed in 2024; feasibility studies ongoing
Investment Cost	Estimated > €2.3 billion due to technical/geopolitical challenges	Not yet finalized; feasibility study in progress
Purpose	Export green electricity to reduce EU dependence on fossil fuels	Export clean electricity to Europe
Geopolitical Risks	Proximity to Crimea; potential security threats from Russia	Regional instability, infrastructure security
Water and Environmental Impact	Minimal water use	Minimal water use

Table 25: The Caspian-EU Green Energy Corridor projects

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