H2-diplo
DECARBONIZATION DIPLOMACY

Published by

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

Saudi Arabia's Potential to Enhance its Position as a Key Goods' Provider for the Energy Transition and the Upcoming Hydrogen Economy

Published by

PROJECT INFORMATION

Publisher	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Bonn and Eschborn, Germany Köthenerstr. 2-3 10963 Berlin Tel: +49 30 338424 186
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Publication Date	September 2023 (updated July 2024)

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The data collection for this publication was mainly carried out in Q2-2023.

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Citation: H_2-diplo(2023), Saudi Arabia's Potential to Enhance its Position as a Key Goods' Provider for the Energy Transition and the Upcoming Hydrogen Economy, Global Hydrogen Diplomacy, Riyadh.

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Executive Summary

- **Energy diversification as a core element of Saudi transformation:** With 17% of the world's proven petroleum reserves, Saudi Arabia is ranked second in the world in oil production after the United States. Historically and presently, the oil economy remains the backbone of Saudi Arabia's economy with more than 70% of its exports but faces uncertainties and vulnerability in times of global recession and low oil prices as budget deficits significantly increased in order to mitigate negative fiscal implications from decreasing oil revenues. Against this backdrop, economic diversification in the non-oil sector has emerged as a core element of Saudi transformation agenda "Vision 2030" in recent years.
- **Energy transition as a driver to address climate change:** The country is compelled to undertake an energy transition in order to address challenges of increasing vulnerability to the effects of climate change and fulfil the international obligations of climate agreements. At the same time, the country's energy consumption and growing population require reliable sources of energy; renewables are said to be an opportunity to diversify not only energy sources but also jobs.
- **Energy efficiency, renewable energy and hydrogen as key pillars of Saudi Arabia's energy transition:** Energy efficiency measures have been highlighted in several initiatives such as the Saudi Energy Efficiency Program (SEEP) or the Saudi Energy Efficiency Center (SEEC), created in 2010 in partnership with UNDP. It succeeded in improving energy efficiency in public buildings, establishing regulatory frameworks, implementing renewable energy products, and capacity building. Furthermore, Saudi Arabia aims to increase its share of renewables to 50% of the energy mix by 2030. In this regard, hydrogen has become a top priority in the Kingdom's energy diversification efforts. Saudi Arabia's flagship project, NEOM, is expected to produce 650 tons/day of green hydrogen by electrolysis and 1.2 million tons per year of green ammonia, making it one of the largest hydrogen production facilities being built globally.
- **The hydrogen supply and value chain**: Both the petrochemicals and minerals industries are large producers and consumers of hydrogen. Hence, they play an integral part throughout the entire hydrogen cycle. Refineries and petrochemical plants are the largest consumers of hydrogen. Since these processes are almost completely fossil-based, they emit large quantities of CO_2-emissions. Building on state-of-the-art industries, the Saudi hydrogen sector could benefit from outstanding R&D capacities and facilities, a well-equipped industry that provides regional networks and enhanced infrastructure, training and educational schemes for young talents and a growing industrial sector that is driven by localization, diversification, and nationalization. Definitely, hydrogen can enable many processes in the energy industry. In this regard, hydrogen can decarbonize many existing industrial processes. In addition, the hydrogen sector offers a variety of chances for job creation along the supply chain.

- **Green hydrogen needs critical minerals:** In terms of green hydrogen, Saudi Arabia will remain dependent on the import of critical minerals for building its H_2 economy. As such, Saudi Arabia aims to increase its nickel, iridium, copper, zinc and platinum production, all of which play crucial roles in low-carbon technologies. In the context of the pivotal role of 'electrification,' an increased demand for copper is anticipated due to the construction of more wires that rely on copper. Zinc, another abundant and well-established element, is essential for both onshore and offshore wind parks.
- **Petrochemicals as a driver for the hydrogen industry:** Petrochemical components are found in solar panels, wind turbine blades or batteries, all important components for providing the clean electrons for green hydrogen's production. For instance, ethylene vinyl acetate (EVA) film application are needed for solar panels. In this sense, Saudi Arabia has already started to explore this promising industrial field and aims to further localize parts of its nascent PV industry. Saudi Arabia is already a key producer and exporter of natural gas-based grey ammonia and could expand this sector towards green and blue ammonia.
- **High potential for upcycling key H_2 industries:** Focusing on the two primary sectors, Saudi Arabia's mining industry and petrochemical sector, this study identifies significant potential for the country to enhance its hydrogen production. Given the potential role of the mining and petrochemicals sectors, and the capacity of 'national champions' such as SABIC and Ma'aden, the Kingdom intends to acquire first-mover advantages that are also crucial for the ambitious goals to develop a competitive hydrogen economy. This holds particularly true for the petrochemical sector, which has been a cornerstone of the Kingdom's industrial landscape for an extended period. In contrast, the mining sector is in its early stages, and its development hinges on the availability of critical mineral resources in the country. Ongoing geological assessments are currently underway.
- **Remaining challenges:** Hydrogen is still an immature technology and many uncertainties remain. This includes mostly four areas such as (a) economic and technical consideration over the cost-efficiency and feasibility to produce, distribute and utilize hydrogen, (b) environmental considerations (e.g. growing water demand and unintended ecological risks), (c) geopolitical considerations (e.g. raw material global supply chains and transport routes) as well as (d) human capacity and labor market (e.g. lack of specialized skilled workers and talent). These challenges should be taken into consideration when visioning Saudi Arabia's potential for developing a hydrogen economy.

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List of Abbreviations

4IR	4th Industrial Revolution
ABS	Acrylonitrile butadiene styrene
AEL	Alkaline electrolysers
APC	Advanced Petrochemical Company
BoS	Balance of system
EOR	Enhanced oil recovery
ESG	Environmental, social, and governance
ETP	Engineering thermoplastics
EVA	Ethylene vinyl acetate
FDI	Foreign Direct Investment
FIT	Feed-in tariffs
GDP	Gross Domestic Product
GGFR	Global Gas Flaring Reduction Partnership
HCDP	Human Capability Development Program
HDPE	High-density polyethylene
HPAAS	High-Pressure Air Assist System
IMF	International Monetary Fund
IOC	Indian Oil Corporation
KACST	King Abdulaziz City for Science and Technology
KAPSARC	King Abdullah Petroleum Studies and Research Center
KAUST	King Abdullah University of Science and Technology
Mbpd	million barrels per day
MBS	Mohamed bin Salman
MoU	Memorandum of understanding
MSF	Multi-stage flash
MT	Metric tones
NDC	Nationally Determined Contributions
NIDLP	National Industrial Development and Logistics Program
NIS	National Industrial Strategy
NGL	Natural gas liquids
PABMEC	Prince Abdulaziz bin Moased Economic City
PEM	Polymer electrolyte membrane
PIF	Public Investment Fund
PPP	Public-private partnership
RHQ	Regional Headquarters
SABIC	Saudi Basic Industries Corporation
SAFCO	Saudi Arabian Fertilizers Company
SAMI	Saudi Arabian Military Industries Company
SDC	Saudi Downtown Company

SEEC	Saudi Energy Efficiency Center
SEEP	Saudi Energy Efficiency Program
SIDF	Saudi Industrial Development Fund
SME	Small and Medium Enterprises
SMR	Steam Methane Reforming
SIDF	Saudi Industrial Development Fund
USA	United States of America
UNDP	United Nations Development Programm
UNFCCC	United Nations Framework Convention on Climate Change
VAT	value-added tax

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Introduction

Saudi Arabia is undergoing a fundamental and ambitious energy transition by diversifying its energy mix. Despite the fact that the oil and gas sectors still accounts for about 50% of the gross domestic product (GDP), and more than 70% of export earnings, the Kingdom is investing heavily in alternative energy sources in order to adapt to a potential decline in global demand for conventional oil and gas products over the next decades. In this regard, Saudi Arabia is positioning itself as a new regional and global hub for hydrogen and pushes its efforts to develop comprehensive capacities to export clean hydrogen[1] (and derivatives) to global markets. Here, hydrogen offers an excellent business opportunity for the Saudi economy: it could generate additional export revenues, position the Kingdom as as an attractive location for hydrogen production and promote the country's expertise on hydrogen in specific sectors such as petrochemicals and mining on global level. Under the umbrella of the developmental agenda "Vision 2030", the Saudi government has introduced a plethora of initiatives and programs.

Based on large gas resources for blue and abundant solar radiations and wind speeds for green hydrogen and combined with outstanding expertise as a global energy leader, the Kingdom's potential to establish itself as a champion of hydrogen is excellent to generate return on investment and expand the potential of energy exports beyond oil; create new partnerships with international off-takers and access new markets in Europe and Asia; and promote job creation along the growing energy transition´s supply chains.

In particular, the petrochemicals and mining sectors are of outstanding relevance for Saudi Arabia's growing hydrogen industry as both sectors have emerged as key pillars of the country's economic and energy diversification. Over decades, the country has become a global leader in petrochemicals and mining and aims to further invest in such sectors. National champions such as SABIC or Ma'aden are drivers for business development in the petrochemicals and mining sectors. They have gained outstanding and world-class experiences in training, R&D, and industrial production, which makes both sectors attractive examples to further develop Saudi Arabia's hydrogen sector and integrate sustainable technologies into existing supply chains. Additionally, the mining and petrochemicals sectors provide brilliant opportunities to explore new sectors that are closely interlinked with each other: mining and

[1] Clean hydrogen include production forms that are based on renewable energy sources (green hydrogen) or "natural gas-based variants with extremely low methane emissions and high carbon capture rates (blue hydrogen)", see: Braun, Jan et al.: *Clean Hydrogen Deployment in the Europe-MENA Region from 2030 to 2050*, Fraunhofer CINES; Geostock (Karlsruhe 2023), https://www.cines.fraunhofer.de/content/dam/zv/cines/dokumente/Fraunhofer_CINES_Clean_Hydrogen_Deployment.pdf, p. 6.

petrochemical products are needed along the entire supply and value chain of producing low-carbon hydrogen. At the same time, hydrogen is needed to decarbonize both industries.

Against this backdrop, the study uses a holistic cross-sectoral approach to link economic diversification efforts and the Saudi energy transition with current trends in the petrochemicals and mining sectors. It evaluates the industrial development in correspondence to Saudi Arabia's energy transition and hydrogen aspirations and focuses on the interdependent relationship on both vertical (i.e. expanding sectors by introducing additional steps of the value chain) as well as horizontal diversification (i.e. expanding investments in non-hydrocarbon fields). Here, the study aims to bridge a research gap as it includes the mining and petrochemical sectors but also focuses on new industrial sectors that could become key drivers for Saudi Arabia's future hydrogen industry. It further presents chances and challenges for job creation and talent development in the hydrogen industry and its supply chain as well as social environmental awareness.

The study starts with a brief conceptual framework to outline the concept of supply and value chain analysis, and the methodological approach of the study. The second chapter provides a brief background of the current economic diversification efforts under "Vision 2030". Chapter 3 seeks a more in-depth and context-sensitive understanding and analysis of the value chain activities in the broader context of the Kingdom's energy transition with a special focus on its upcoming hydrogen economy. Here, the chapter shows the key industrial goods Saudi Arabia produces domestically and which of these are of particular relevance within the ongoing energy transition and the upcoming hydrogen economy. It also covers an analysis of the country's defined goals in terms of industrial production fostering the energy transition and paving the way towards net-zero targets. Based on those more general assessments, chapters 4 and 5 are explicitly dealing with the petrochemicals and mining sectors as they allow Saudi Arabia to increasingly transit towards an economic business model which is more diversified and less reliant on fossil fuel use and export. Furthermore, both chapters include new industrial sectors that are part of the supply chain in the petrochemcials and mining sectors. Therefore, domestic utilization of hydrogen or derivates is investigated and analyzed with regards to where Saudi Arabia could play a role in the future. Chapter 6 outlines Saudi Arabia's industrial potential for the hydrogen development with a special focus on petrochemicals and mining as well as new industrial sectors. Production, storage and distribution, application and utilization efforts are analyszed as well as future steps such as economic and technical, geopolitical, and human capacity considerations. In the conclusion (chapter 7), the main findings of the study are summarized by outlining existing and potential industrial sectors that could promote industrial diversification and ensuing export purposes. Against this backdrop, the conclusion also presents

perspectives on the educational sector and the job market to again highlight the close link between the emergence of a sustainable hydrogen economy and chances for job creation and human development.
The study significantly refers to the existing expertise at hand in the Kingdom which is reflected in the methodological approach based on interviews conducted with experts from the hydrogen, mining, and petrochemicals sectors. As such, it is not the study's intention to give external recommendations for Saudi decision-makers, rather to provide additional fruit for thought.

1. Theoretical Part

1.1 Conceptual Approach: Supply and Value Chain Analysis

In general, the proposed project applies a three-fold step of research including:

1. Identifying value chain activities in Saudi Arabia,
2. Determine these activities according to Saudi Arabia's energy transition targets.
3. Evaluating future activities and identifying opportunities for competitive advantage towards a hydrogen development.

To do so, it is necessary to shortly elaborate on the different theoretical threads we want to include. It was Michael Porter who laid out the fundament of a systematic supply and value chain analysis in his seminal book *Competitive Advantage: Creating and Sustaining Superior Performance* as a general framework in 1985[2].

According to Porter, a value chain "disaggregates a firm into its strategically relevant activities in order to understand the behavior of costs and the existing and potential sources of differentiation"[3]. These activities include the design, production, marketing, delivery, and support of a certain product. A value chain thus decompartmentalize and traces back the individual steps of a product or service from the idea to reality. Porter differentiated two key types, namely primary and support activities to which he added several components. Primary activities directly create products or services, while support activities indirectly assist them.

Later studies, which have attributed the globalization of industries and international business competition a greater role, have further elaborated on Porter's framework to highlight the entanglements between local and global value chains. For instance, a simplified model that includes the external environment can be divided in global (**top-down**) and local elements (**bottom-up**). Here, the top-down category describes dynamics of the industry at a global level such as:

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[2] Michael E. Porter, *Competitive Advantage: Creating and Sustaining Superior Performance: With a New Introduction*, 1st Free Press ed (New York: Free Press, 1998); Andrea Cordell and Ian Thompson, *The Category Management Handbook*, 1 Edition (New York: Routledge, 2018).
[3] Porter, *Competitive Advantage*, 33.

1. the **input-output structure**, which describes Porter's entire chain of primary activities but attributes a greater role to global processes (e.g. different markets);
2. the **geographic scope** that looks at where have the different activities been executed;
3. a **governance structure**, which examines lead firms in the sector, their location and how they interact with their supply base and their source of influence and power over them.

The bottom-up category, in turn, is divided into

4. **upgrading**, wich includes the degree and pursuit of moving to higher value activities;
5. the **local institutional context** that looks at political, economic and social scope conditions at the local level and
6. **industry stakeholders** that identify the various involved agencies and their interaction to achieve industry upgrading [4].

Top-down		
Input-output structure	Geographic scope	Governance structure: Lead Firms & Industry Organization
Bottom-up		
Upgrading	Local institutional context	Industry stakeholders

Table 1: Six dimensions of a Global Value Chain Model

1.2 The concept of energy transition

Throughout human history, there has been a number of energy transitions (e.g. from wood to coal, from coal to oil etc.)[5]. The current low-carbon energy or net-zero transition, which is meant here, comprises the transitional process towards climate change mitigation. Like previous energy transitions, the 'conventional' energy system will not be displaced by a 'newer' and 'cleaner' one overnight. Instead, we are already

[4] Gary Gereffi and Karina Fernandez-Stark, 'Global Value Chain Analysis: A Primer' (Duke Center on Globalization, Governance & Competitiveness (Duke CGGC), 2016).
[5] Gavin Bridge et al., 'Geographies of Energy Transition: Space, Place and the Low-Carbon Economy', *Energy Policy* 53 (February 2013): 331–40, https://doi.org/10.1016/j.enpol.2012.10.066.

experiencing a ‘hybridization’ where carbon-based and renewable energy systems coexist[6]. The implementation of new, low-carbon energy technologies is as much important as better energy efficiency and decarbonization solutions to conventional hydrocarbon-based energy sources.

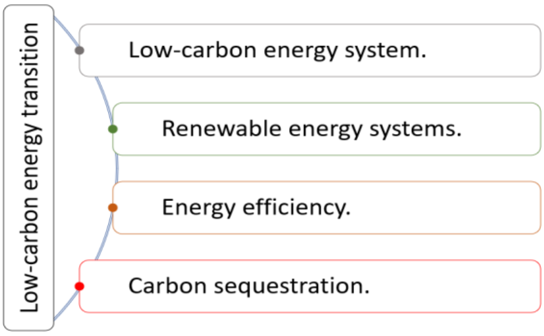

Figure 1: Overview of key elements of a low-carbon energy transition (own compilation)

As several studies have emphasized, “the nature and speed of low-carbon transitions varies enormously between different national, regional, and local contexts”[7], which demands a certain contextualization. It ranges from implementing centralized, remotely-sited large-scale utility energy models with long-distance transmission networks or super-grids (e.g. nuclear, offshore wind or large-scale solar), over local mini-grids to highly decentralized micro-generation (e.g. solar on rooftops)[8]. The choice can depend on economic and social preferences but also the type of political organization and decision-making. Additionally, further key aspects that influence deliberate acceleration of clean energy transitions include “technological capabilities; natural resource endowments, industrial specialization, and cultural repertoires”[9]. There are also a number of great uncertainties associated with the energy transition regarding prices, costs and financing mechanisms[10].

[6] Gordon Walker and Noel Cass, ‘Carbon Reduction, “the Public” and Renewable Energy: Engaging with Socio-Technical Configurations’, *Area* 39, no. 4 (December 2007): 458–69, https://doi.org/10.1111/j.1475-4762.2007.00772.x; Richard York and Shannon Elizabeth Bell, ‘Energy Transitions or Additions?’, *Energy Research & Social Science* 51 (May 2019): 40–43, https://doi.org/10.1016/j.erss.2019.01.008.
[7] Cameron Roberts et al., ‘The Politics of Accelerating Low-Carbon Transitions: Towards a New Research Agenda’, *Energy Research & Social Science* 44 (1 October 2018): 307, https://doi.org/10.1016/j.erss.2018.06.001; Kathryn Hochstetler, *Political Economies of Energy Transition: Wind and Solar Power in Brazil and South Africa*, 1st ed. (Cambridge University Press, 2020), https://doi.org/10.1017/9781108920353.
[8] Bridge et al., ‘Geographies of Energy Transition’, 331.
[9] Roberts et al., ‘The Politics of Accelerating Low-Carbon Transitions’, 307.
[10] Yousef M. Alshammari, ‘Scenario Analysis for Energy Transition in the Chemical Industry: An Industrial Case Study in Saudi Arabia’, *Energy Policy* 150 (March 2021): 112128, https://doi.org/10.1016/j.enpol.2020.112128.

1.3 Methodology

The study applies a mixed-method approach including qualitative assessments such as a content-analysis including both primary and secondary sources as well as semi-structured interviews and background talks with key stakeholders.

On the one hand, Saudi Arabia's current industrial production, archival and commentary material, official data and statistics as well as background analysis and relevant academic literature will be reviewed. Research material has been collected from internet searches in Arabic, English and German; from key academic databases, from the grey literature and from online newspaper archives. It has also used statistics collected by governmental and non-governmental organizations. A major part of the required data assemblage to achieve the above-mentioned research steps focus on official and governmental documents and additional open source research documents, policy studies and background information.

On the other hand, semi-structured interviews and informal background talks with key stakeholders have been conducted. Six interviews as well as three focus-group discussions have been conducted during a field trip to Saudi Arabia between May 21-26, 2023. Furthermore, four interviews have been collected virtually. The most common stakeholders in the targeted sectors included companies, industry associations, workers, educational institutions, government agencies and technocrats amongst others. The core aim was to identify entry points for enhancing domestic industrial development but also ensuing export purposes. In order to compare the different sectors and sketch out the greatest potential(s), it was important to understand the involved stakeholders and their interests. As Saudi Arabia is currently working under its own hydrogen strategy, the interviewees wished to be quoted anonymously.

2. Saudi Arabia's economic diversification efforts

2.1 A New National Project: "Vision 2030" as the Blueprint for Diversification

In contrast to previous development plans, "Vision 2030", initiated in 2016 and spearheaded by the Kingdom's Crown Prince Mohammed bin Salman Al Saud (MBS), follows a more comprehensive approach. It does not only include economic or labor market reforms, but also addresses fundamental pillars of Saudi national identity, cultural heritage, and social belonging. It can be defined as a blueprint to transform the Saudi social contract on all levels.[11] As such, "Vision 2030" proposes ambitious steps to diversify the economy through enhanced industrialization, incentivizing the growth of the private sector, develop Saudi Arabia as a "global investment powerhouse"[12] and a know-how society.[13] It further aims to transition employment from the public to the private sector[14] and takes the Saudi economic vulnerability from oil prices into consideration. Hence, investments in multi-sectoral projects such as in digital infrastructure, real estate, tourism, education, logistics, healthcare, energy, utilities, sports, and entertainment aim to create a modernized, diversified, and liberalized investment climate inside and outside the Kingdom.[15]

Intensifying industrialization efforts

Within the framework of the National Industrial Development and Logistics Program (NIDLP), Saudi Arabia aims to transform itself into a regional industrial powerhouse, a champion in the mining and energy industry, and a global logistics hub by enhancing local content and investing into the 4th Industrial Revolution (4IR).[16] By defining mining, industry, logistics and 4IR as the main sectors of Saudi Arabia's economic transformation and diversification, the Kingdom follows different long-term objectives:

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[11] So far, the social contract can be defined as a series of informal pacts between the leadership including its members of the Al Saud as well as with influential business elites and the Wahhabi religious establishment. However, "Vision 2030" addresses in particular the young Saudi generation and women whereas traditional veto players such as business or religious elites have been politically and economically marginalized since 2015.

[12] Havrlant, D., Darandary, A. (March 2021), *Economic Diversification under Saudi Vision 2030: Sectoral Changes Aiming At Sustainable Growth*, King Abdullah Petroleum Studies and Research Center.

[13] Nurunnabi, M. (March 2017), Transformation from an Oil-based Economy to a Knowledge-based Economy in Saudi Arabia: The Direction of Saudi Vision 2030, in *Journal of the Knowledge Economy*, No. 8: 536-564.

[14] Saudi Arabia's Government, *Vision 2030 Kingdom of Saudi Arabia*, https://vision2030.gov.sa/en.

[15] Ibid.

[16] Saudi Arabia's Government, *Vision 2030 Kingdom of Saudi Arabia*, https://vision2030.gov.sa/en.

Mining	• exploration to determine mineral quantities, conducting feasibility studies, improving mines, and processing raw materials • developing refining and smelting processes to manufacture raw materials such as aluminum and solid iron blocks. • transforming semi-finished products, such as iron sheets and aluminum, and final products, such as pipes and iron bars
Industry	• main sectors: military, automotive, food processing, machinery and equipment, industries and equipment, pharmaceutical, medical equipment and supply, aquaculture, aviation, marine industries, basic and intermediate chemicals, plastic and rubber • growth of industrial cities such as Jubail, Yanbu, Ras al-Khair, and the industrial cities of the Saudi Authority for Industrial Cities and Technology Zones (MODON) • development of skilled human resources in the industrial sector with a focus on chemical and petro-chemical industries • increasing manufacturing efficiency, reducing costs, enhancing competitiveness
Logistics	• enhancing efficiency, quality and speed • improving infrastructure quality • increasing capacity • decreasing freight costs by connecting to the various local networks • improving clearance procedures and cross-border movement of goods to support industrial growth and export and re-export of goods • increasing the efficiency of domestic distribution • strengthening governance and regulations • encouraging private sector contribution
4IR	• developing technologies like AI, IoT, 3D printing, robots, and smart mines, factories, and grids • creation of jobs for young tech-savvy Saudi talents • digital integration and interconnection between several industrial sectors and clusters • developing legal frameworks. • Improving the infrastructure of communication and digitalization technology • Supporting entrepreneurs and domestic tech companies • attracting foreign 4IR companies

	• localizing centers of excellence for research and development

Table 2: Overview of objectives in NIDLP main sectors[17]

Started in 2019, NIDLP has achieved a variety of strategy targets such as launching the largest of its kind geological survey program for the Arabian Shield region, improving international connectivity by adding five new shipping lines to the national ports, introducing multiple utility-scale renewable energy projects and promoting military localization. In doing so, NIDLP reacts to long-term and structural challenges the Saudi industrial sector was facing for decades: so far, highly energy-consuming basic industries formed the backbone of Saudi industry, which also shows high volatility in times of low oil prices or sinking global oil demand. As such, the NIDLP aims to improve the global and regional competitiveness of transformative industries by focusing on innovation, better linkages between industrial sectors and logistics, creating national expertise by investing in education and training and enhancing government regulations. Based on NIDLP, the National Industrial Strategy (NIS) was launched in October 2022 and focuses on 12 priority industrial sub-sectors in which industrial innovation and development should be improved. Strategically, the NIS aims to build national industrial resilience in times of growing global challenges such as the COVID-19 pandemic or climate change.

Developing new regional supply chains

Geostrategically, Saudi Arabia finds itself in an excellent position as it is bordering three continents, namely Africa, Asia, and Europe. Itborders relevant global maritime routes such as the Red Sea, which is connected with the Mediterranean Sea through the Suez Canal. Furthermore, the domestic logistic sector was suffering from fragmented governance and administrative structures. This made the harmonization of infrastructural and logistical procedures complicated as entities did not properly cooperate in the past to improve supply chains. Concrete steps have now been introduced: Among them, the private sector is more involved in the management and operation of the Jeddah Islamic Port and King Abdulaziz Port. New programs and institutions such as the logistics platforms initiative, the Logistics Services Committee, the merger of the Saudi Arabia Railway Company and the Saudi Railway Organization, improved digitalization in the trucks management systems, container shipments, automatic approvals, and easier e-commerce; digital documentation procedures also help to address the abovementioned challenges.[18] Such measures

[17] Kingdom of Saudi Arabia, National Industrial Development and Logistics Program Delivery Plan 2021-2025.
[18] Kingdom of Saudi Arabia, National Industrial Development and Logistics Program Delivery Plan 2021-2025.

seek to develop Saudi Arabia as a regional logistic and maritime champion. It will enhance the capacity for local and regional connectivity by expanding railway routes, shipping lanes and container ports capacities with strong implications for its hydrogen economy and export capacities.

Figure 2: Saudi Arabia's excellent geographic location to explore international markets

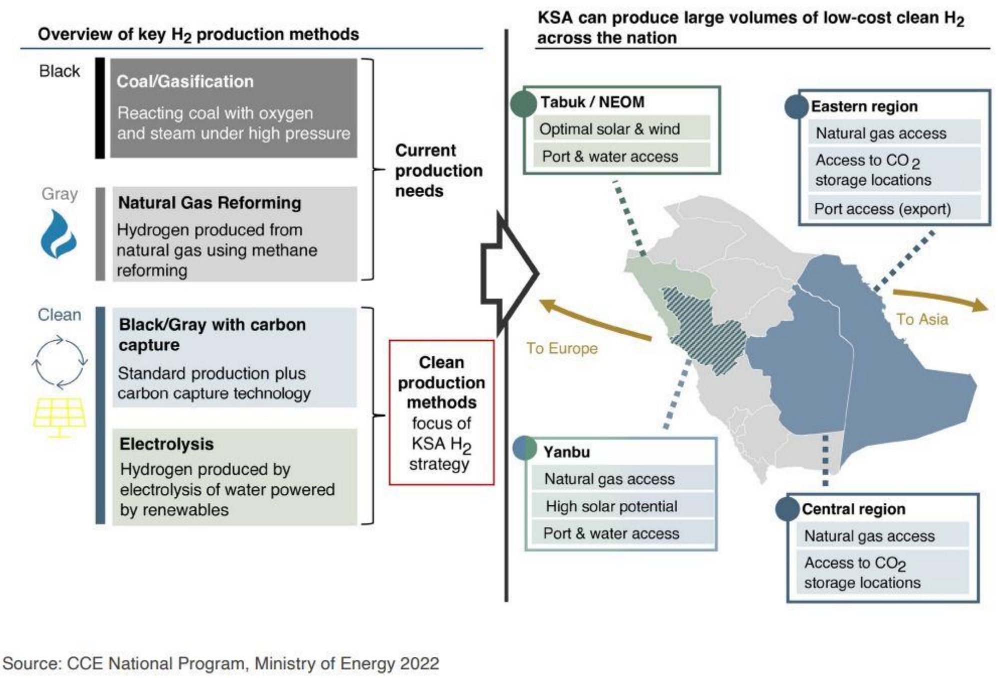

Figure 3: Overview of Saudi Arabia's central position and ability to develop new (energy) supply chains [19]

Creating local content and diversifying external partnerships

By promoting localization, Saudi policymaking intends to create local and national supply chains with the aim of achieving more autonomous industrial production in sectors such as petrochemicals, defense or entertainment. Projects such as the "Shereek" ("partner" program)[20] or the "Made in Saudi" campaign form part of a massive plan that includes insvetments by 2030 up to $1.3 trillion from private companies, $2.6 trillion from government spending, $1.3 trillion from private consumption spending, $1 trillion from the National Investment Strategy and $0.8 trillion stemming from injections of the leading sovereign wealth fund, the Public Investment Fund (PIF).[21] As part of those efforts, the Saudi Arabian Military Industries

[19] KAPSARC (2023): Advancing the Circular Carbon Economy in Saudi Arabia, file:///C:/Users/tobias/Downloads/KS-2022-WB10-Advancing-the-Circular-Carbon-Economy-in-Saudi-Arabia-1.pdf

[20] *Arab News* (April 30, 2021), Crown Prince launches $3.2tn program to boost Saudi private sector, https://www.arabnews.com/node/1834576/saudi-arabia.

[21] Nereim, V., Abu-Nasr, D. (March 30, 2021), Saudi Firms to Cut Dividends For Prince's $1.3 Trillion Plan, *Bloomberg*, https://www.bloomberg.com/news/articles/2021-03-30/saudi-plans-trillions-in-new-investments-to-boost-private-sector?utm_medium=email&utm_source=newsletter&utm_term=210331&utm_campaign=bop&sref=u92xaltB&leadSource=uverify%20wall.

Company (SAMI) is engaged in the localization of the Saudi defense industry which increased its share in the Saudi GDP from 2% in 2016 to 8% in 2020.[22] In addition, Saudi Arabia heavily invests in electric mobility by establishing a local industrial site of electric vehicles produced by the US company Lucid in which the PIF holds 67% of the shares. The plant which is currently under construction will start producing complete vehicles by 2025 or 2026, at an annual production capacity of 150,000 EVs.[23] Diversification of international partnerships has gained significant momentum in Saudi Arabia's policymaking by reaching out to regional players such as Turkey[24] or Qatar[25] with which bilateral relations were tense in recent years. Additionally, PIF started to establish sub-branches in selected countries such as Bahrain, Egypt, Iraq, Jordan, Oman and Sudan. PIF should also harmonize, regulate, and monitor Saudi investments with an estimated volume of $24 billion. Key sectors are infrastructure, real estate development, mining, healthcare, financial services, food and agriculture, manufacturing, telecoms, and technology.[26] For that reason, Saudi Arabia aims to position itself as a hub for trade and investment.[27] In 2014, the United States of America (USA) were replaced with China when trade volume with Beijing started to outnumber Saudi-US business ties. Today, China is the main import partner with a share of 19.8%, followed by the US with 10.6% and also features prominently in terms of exports. In geostrategic terms, such hedging approach became even more relevant in times of the Ukraine war underlining the emergence of a multipolar global order in which Saudi Arabia needs to position itself in the economic, security, and political realms.[28] While the United States remains a reliable partner in security, energy, and economics, Saudi Arabia's recent

[22] Kingdom of Saudi Arabia, *Vision 2030 Achievements 2016-2020*, https://www.vision2030.gov.sa/v2030/achievements/.
[23] Mihalascu, D. (June 2023), Lucid Starts Delivering Air Luxury EVs To Customers in Saudi Arabia, https://insideevs.com/news/671332/lucid-starts-delivering-air-luxury-evs-customers-saudi-arabia/.
[24] Dogan Akkas, B. (January 28, 2022), *Turkey's Ties With Saudi Arabia and the UAE: Walking Back 10 Years of Tensions*, Arab Gulf States Institute in Washington, https://agsiw.org/turkeys-ties-with-saudi-arabia-and-the-uae-walking-back-ten-years-of-tensions/.
[25] Davidson, C. (2021), Saudi Arabia's new politics: Understanding rapprochement in *Orient* III, https://orient-online.com/orient-iii-2021-rapprochement-in-the-gcc/.
[26] Darasha, B. (October 26, 2022), Saudi PIF starts investments firms in Jordan, Bahrain, Sudan, Iraq and Oman, *Zawya*, https://www.zawya.com/en/business/saudi-pif-starts-investments-firms-in-jordan-bahrain-sudan-iraq-and-oman-i0f9xe1z.
[27] Ashraf, E. (2020), Economic Visions and the Making of an Islamabad-Beijing-Riyadh Triangle: Assessing Saudi Arabia's Role in the China-Pakistan Economic Corridor, *Dirasat* 58, King Faisal Center for Research and Islamic Studies, https://www.kfcris.com/pdf/fff6a7d2d8c77030bd0243ca7632047c5f3d17b470b58.pdf.
[28] Alterman, J. B., Todman, W. (February 25, 2022), *Hedging, Hunger, and Hostilities: The Middle East after Russia's Invasion of Ukraine*, Center for Strategic and International Studies, https://www.csis.org/analysis/hedging-hunger-and-hostilities-middle-east-after-russias-invasion-ukraine.

"pivot to Asia"[29] has led to increased cooperation and a strategic partnership with China.[30] As such, "Vision 2030" aims to position Saudi Arabia as a regional and global trade and investment hub with estimated investment opportunities worth $3 trillion.[31] In order to achieve a greater degree of financial liability and increase privatization, the Saudi economy needs foreign direct investments (FDI) to push the vibrant private sector and create jobs for Saudi nationals. So far, main areas for FDI have been in the oil-related industry such as petrochemicals, minerals, and mining, infrastructure, power and water. However, current FDI policies aim to attract international companies to invest in further sectors such as entertainment or tourism and establish their regional headquarters in the Kingdom to manifest Saudi Arabia's position as a regional business hub.[32] To boost the Kingdom's business position, international companies need to relocate their regional headquarters to Saudi Arabia as outlined in the Regional Headquarters (RHQ) Programme which was launched by the Ministry of Investment and the Royal Commission for Riyadh City and comes into effect by January 1, 2024.[33] It prevents all Saudi government agencies from contracting with companies that do not have a RHQ in the country. In October 2022, more than 70 companies received licenses to relocate their RHQ to Saudi Arabia.[34] Furthermore, Saudi Arabia has introduced a number of legal and political initiatives to attract FDI such as permitting full foreign ownership of engineering, health and education companies in 2017.[35] Additionally,the government announced the launch of commercial courts in 2017[36], instituted the National Center for Privatization in 2017,[37] or established the "Made in Saudi" brand by the Saudi Export Development Authority in 2020 in order to market Saudi-made products

[29] Van Genugten, S. (2017), The Gulf States: Channeling Regional Ambitions in Different Directions, in Mezran, K., Varvelli, A., eds., *Foreign Actors in Libya's crisis*, Milano: ISPI: 41–56.
[30] Fulton, J. (August 2020), *Strangers to Strategic Partners: Thirty Years of Sino-Saudi Relations*, Atlantic Council, https://www.atlanticcouncil.org/wp-content/uploads/2020/08/Sino-Saudi-Relations_WEB.pdf.
[31] *Reuters* (January 14, 2021), Saudi crown prince says kingdom offers $6 trillion investment opportunities over next decade - state news agency, https://www.reuters.com/article/saudi-economy-investments-idUSKBN29I37O.
[32] Mondaq (December 1, 2022), *The KSA Regional Headquarters (RHQ) Program*, https://www.mondaq.com/government-contracts-procurement--ppp/1256540/the-ksa-regional-headquarters-rhq-program.
[33] Clyde & Co. (January 18, 2023), *Saudi Arabia Regional Headquarters Programme: Contracting with government entities*, https://www.clydeco.com/en/insights/2023/01/saudi-arabia-regional-headquarters-programme.
[34] *Economy Middle East* (October 26, 2022), 70 new global companies to relocate regional headquarters to Saudi, https://economymiddleeast.com/news/70-new-global-companies-to-relocate-regional-headquarters-to-saudi/.
[35] *Reuters* (August 8, 2017), Saudi Arabia to allow full foreign ownership of engineering firms, https://www.reuters.com/article/us-saudi-companies-idUSKBN1AO0XQ.
[36] *Arabian Business* (October 21, 2017), Saudi Arabia Unveils Commercial Courts in Three Cities, https://www.arabianbusiness. com/politics-economics/381365-saudi-arabia-unveils-commercial-courts-in-three-cities.
[37] National Center for Privatization and PPP, *Program Description*, https://www.ncp.gov.sa/en/Pages/Privatization_Program_ppp.aspx/.

to global markets.[38] Between 2016 and 2020, the FDI influx tripled from $1.42 billion to $4.7 billion whereas the number of small and medium enterprises (SME) increased by 40% (from 447,749 in 2016, to 626,669 in 2020) according to official Saudi data.[39] However, FDI still only contributes 2.31 of GDP. Thus, the influx of FDI still lags behind official expectations: The new investment strategy targets to attract FDI worth of $100 billion annually by 2030. To reach this goal, industrial diversification aims to attract additional FDI to meet the ambitious targets.

Creating jobs for Saudi nationals

By investing into non-oil sectors and promoting industrialization, jobs are aimed to be created for a vast majority of young Saudi nationals with a particular focus on women.[40] According to the Saudi census from 2023, the ratio between Saudi nationals and non-Saudi nationals stands at 58.4 percent to 41.6 percent.[41] So far, the Saudi economy is relying on international experts as educational schemes, vocational training capacities, comprehensive data for graduates, job seekers, and vacancies, are lacking. Based on the King Abdullah Scholarship Program, thousands of young Saudi students went abroad and are now providing expertise on industrial and economic diversification. In addition, national universities are reforming their curricula and new research centers such as KAPSARC, KAUST, KACST and others have heavily invested in human capital and academic resources with a special focus on topics related to the energy transition.[42] Nevertheless, international experts in environmental education are still needed as the local human capital and the educational institutions do not meet the high expectations of the Saudi energy transition yet.[43] Against this backdrop, the state showed growing interest in nationalization efforts and introduced a number of initiatives such as the Nitaqat program.[44] In this regard, significant progress has been achieved, in particular for female participation in the workforce: Between 2017 and 2022, female job market

[38] *Arab News* (November 11, 2020), 'Made in Saudi' to Boost Non-Oil Exports, https://www.arabnews.com/node/1761421/saudi-arabia.
[39] Government of Saudi Arabia, *Vision 2030. A Story of Transformation*, https://www.vision2030.gov.sa/media/hzzcrhmu/story-of-transformation-v2.pdf.
[40] Nurunnabi, M. (March 2017), Transformation from an Oil-based Economy to a Knowledge-based Economy in Saudi Arabia: The Direction of Saudi Vision 2030, in *Journal of the Knowledge Economy*, No. 8: 536-564.
[41] Saudi Census 2022. https://portal.saudicensus.sa/portal.
[42] Kingdom of Saudi Arabia, National Industrial Development and Logistics Program Delivery Plan 2021-2025.
[43] https://www.gtai.de/de/trade/saudi-arabien/specials/saudi-arabien-gruenes-image-mit-vielen-fragezeichen--795556.
[44] Launched in 2011, it adopted more flexible quotas for private-sector employment, based on the numbers of nationals that the most localized companies in each sector actually manage to employ.

participation increased from 17.5% to 33.6%[45]. Around 38% of Saudi SME are run by females[46] as the government has introduced a variety of efforts to promote women entering the job market in sectors such as aviation, tourism, military or law. As such, the increased participation rate of women in the workforce has already exceeded the 2030 target. By 2015, the number of women exceeded the number of men attending colleges and universities.[47] Despite such efforts to promote female empowerment, the vast majority of unemployed nationals are still females (27.9%). In general, unemployment among the young generation (15-24 years) is still relatively high with 16.6% (see table 3) in 2022 whereas even 40% of the early twenties are without job.[48] During the pandemic, unemployment increased[49] again due to the implementation of curfews and lockdowns with negative implications on newly emerging sectors such as entertainment, hospitality, or tourism in which mainly young nationals are employed. By 2030, up to 4.5 million young Saudi nationals are expected to enter the job market who cannot be absorbed by the over-bloated public sector anymore.[50] Therefore, the development of a vibrant industrial economy including new industrial sectors is key to creating jobs.

Saudi youth 15-24 years	25.2%	29.4%	17.2%	16.6%
Saudi youth 15-24 years (female)	51.6%	51.5%	22.8%	27.9%
Saudi youth 15-24 years (male)	17.2%	21.6%	14.9%	10.9%

Table 3: Youth Unemployment Rates (Q3 2019-Q3 2022) [51]

[45] International Monetary Fund (August 17, 2022), IMF Country Report No. 22/274: Saudi Arabia, https://www.imf.org/en/Publications/CR/Issues/2022/08/11/Saudi-Arabia-2022-Article-IV-Consultation-Press-Release-and-Staff-Report-522189.
[46] Government of Saudi Arabia, *Vision 2030. A Story of Transformation*, https://www.vision2030.gov.sa/media/hzzcrhmu/story-of-transformation-v2.pdf.
[47] Alsharif, F. (2019), Empowering women: Educational Programs and Reforms in a Diversified Saudi Economy, King Faisal Center for Research and Islamic Studies, https://www.kfcris.com/en/view/post/239.
[48] Harvard Kennedy School Evidence for Policy Design (n.y.) The Labor Market in Saudi Arabia: Background, Areas of Progress, and Insights for the Future. https://epod.cid.harvard.edu/sites/default/files/2019-08/EPD_Report_Digital.pdf.
[49] General Authority for Statistics, *Saudi Unemployment Increases to 15.4% in Q2/2020*, 2020, https://www.stats.gov.sa/sites/default/files/LM_2Q2020 %28Press release_EN %29.pdf.
[50] McKinsey & Company (December 2015), *Saudi Arabia Beyond Oil: The Investment and Productivity Transformation. Executive Summary*, https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Employment%20and%20Growth/Moving%20Saudi%20Arabias%20economy%20beyond%20oil/MGI%20Saudi%20Arabia_Executive%20summary_December%202015.pdf.
[51] General Authority for Statistics; World Bank 2023.

2.2 SWOT analysis of the Saudi diversification efforts

Strengths	Weaknesses	Opportunities	Threats
Abundant oil and gas resources	Strong dependence on global oil market	Development projects under the framework of "Vision 2030"	Volatility in oil market
state-of-the-art petrochemical industry	Volatile state budget	Comprehensive privatization	Governmental interventions in private sector
High financial reserves	Dominant role of the state as main decision-maker	High investments in oil and gas production	Inefficient local content regulations for foreign investors
Technical and infrastructural advancements in the mineral sector and digitalization.	Lacking nationalization and over-reliance on public sector	Development of renewable energy and green hydrogen	Regional conflicts
	Still conservative society and inefficient rule of law	Development of infrastructure	Focus on cost-intensive giga projects
	Low FDI and dominance of state incentives and investments through PIF	Reforms of curricula	Water scarcity (relying on costly and energy-intensive water desalination and non-renewable groundwater resources)
	Existence of a small number of influential business families	Promotion of physical activities and investments in community sports	Growing climate threats (occasional hazards like flash floods and long-term effects like rising temperature and humidity)
		Motivated and well-educated young and female population	

Table 4: SWOT analysis of the Saudi diversification efforts

3. Saudi Arabia's Energy Transition

3.1 Overview

After addressing the main drivers and objectives of Saudi Arabia's economic diversification, this chapter aims to shed more light on the Kingdom's energy transition. Amidst decreasing oil prices and demand, and a rise in internal energy demand, Saudi Arabia considers energy transition as a main element of its economic diversification. As outlined above, the Saudi economy remains largely dependent on oil and petroleum-related industries including petrochemicals and petroleum refining. This is happening either directly (e.g. through oil revenues and manufacturing of oil derivates) or indirectly through transportations and logistics or investments in research and technology, for instance. Regarding the latter, it is suggested that many of the prosperous sectors heavily rely upon structures that have been created over the long-term selling of fossil fuels. This includes aspects such as low-cost energy, capital, and foreign labor.
For decades, Saudi Arabia was the prototype of a mono-sectoral[52] rentier economy[53] driven by vast oil revenues,. Historically, the oil economy remains the backbone of Saudi Arabia's economy but faces uncertainties and vulnerability in times of global recession and low oil prices as budget deficits significantly increased in order to mitigate negative fiscal implications from decreasing oil revenues (see figure 7)

[52] Havrlant, D., Darandary, A. (March 2021), *Economic Diversification under Saudi Vision 2030: Sectoral Changes Aiming At Sustainable Growth*, King Abdullah Petroleum Studies and Research Center.
[53] Beblawi, H. Luciani, G. (1987), *The rentier state*, London: Routledge.

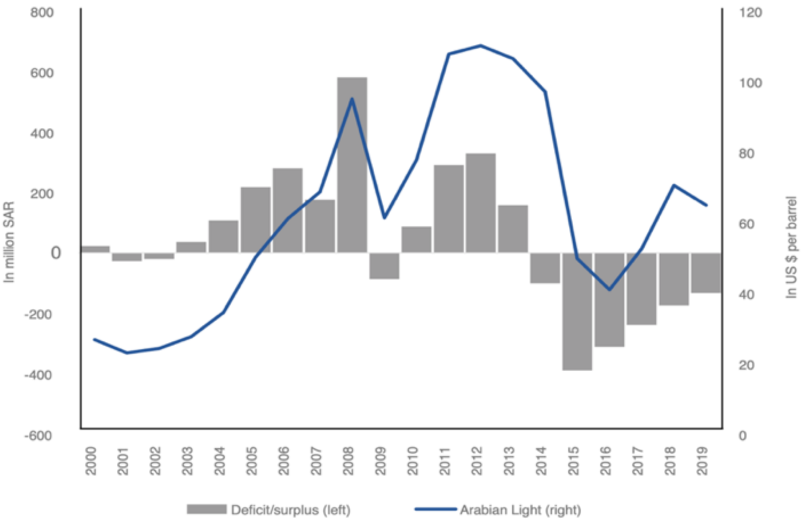

Figure 4: Oil price and government deficits[54]

Oil rents contributed to more than 54% of GDP in 2008 but fell significantly to 39% in 2010 due to the global financial crises and saw another decline in 2016 to 19.6% when oil prices dropped again.[55] During the COVID-19 pandemic Saudi Arabia faced again a structural contraction of its economy (the so-called "double shock"[56] or the "twin shocks"[57]). Against this backdrop, economic diversification in the non-oil sector has emerged as a core element of Saudi transformation with a significant growth in general terms and in specific sectors (see figure 8 and 9):

[54] David Havrlant, Abdulelah Darandary, *Economic Diversification under Saudi Vision 2030: Sectoral Changes Aiming At Sustainable Growth,* King Abdullah Petroleum Studies and Research Center, March 2021.
[55] El-Katiri, L. (December 2016), *Vulnerability, resilience, and reform: The GCC and the oil price crisis 2014-2016*, Columbia Center on Global Energy Policy, https://www.energypolicy.columbia.edu/report-finds-future-climate-policy-is-major-fiscal-risk-to-coal-reliant-regions/; World Bank (January 2018), *With the Benefit of Hindsight: The Impact of the 2014-16 Oil Price Collapse*, https://thedocs.worldbank.org/en/doc/910311512412250749-0050022017/original/GlobalEconomicProspectsJan2018TopicalIssueoilpricecollapse.pdf.
[56] Arezki, R., Ngyuen, H. (April 14, 2020), Coping with a Dual Shock: COVID-19 and Oil Prices, *Brief*, World Bank, https://www.worldbank.org/en/region/mena/brief/coping-with-a-dual-shock-coronavirus-covid-19-and-oil-prices.
[57] World Bank (April 2021), *Macro Poverty Outlook: Saudi Arabia*, https://thedocs.worldbank.org/en/doc/cfe892579f0c3ec9f329e40f3a93c21d-0280012021/original/15-mpo-sm21-saudi-arabia-sau-kcm2.pdf.

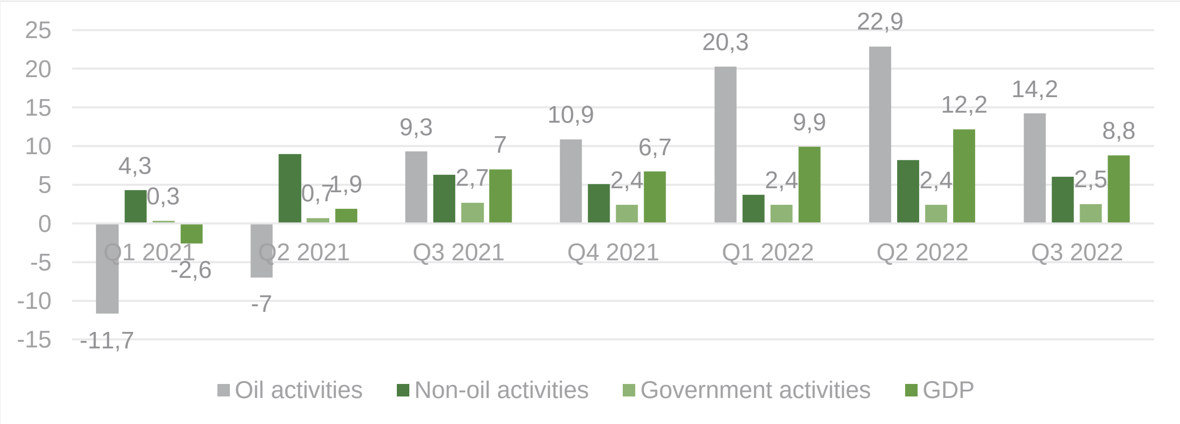

Figure 5: Real GDP Growth Rates (Year-on-Year, %)[58]

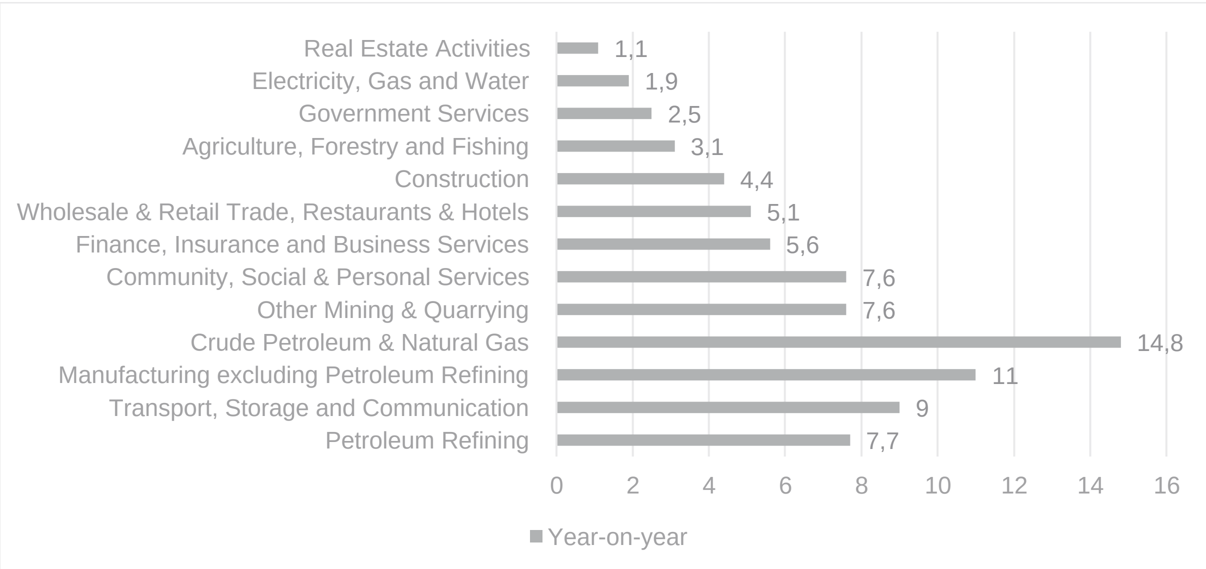

Figure 6: Growth of Real GDP by Economic Activities 2020-2021 (%)[59]

The International Monetary Fund (IMF) estimates that non-oil GDP could increase from 4.2% in 2021 to 8.8% in 2026 whereas non-oil revenues have already doubled from 2017 to 2021 to reach 12.8%. As calculated in “Vision 2030”, non-oil GDP is expected to increase to 50% whereas FDI should jump from

[58] General Authority for Statistics, 2022.
[59] General Authority for Statistics, 2022.

currently 0.8% to 5.7% of GDP.[60] The introduction of a 5% value-added tax (VAT) in 2018 and its increase to 15% in 2020[61] resulted in a hike in additional state revenues: from 3.4% in 2017 before the introduction of VAT to 8.6% in 2020[62], and contained inflation at 3.1% in 2021 and at 2.8% in 2022.[63] As oil prices have significantly recovered in the pre-COVID-19 era[64], and in light of the Russian war against Ukraine since February 2022, Saudi Arabia's economy also sees a boom as the Kingdom could re-establish its status as a global oil producer.[65] In 2021, economic growth rose to 3.2% and to 7.6% in 2022, and should remain constant by 2025. As a consequence, momentum for economic progress improved as high oil prices and production led to comparatively low inflation and a resilient financial sector: The 2023 budget forecasts spending of approximately $296 billion and revenues of approximately $300 billion leading to a 0.4% fiscal surplus.[66] As a consequence, the improving socio-economic situation also provides capacities and resources to promote energy transition

3.2 Energy transition as a driver to address climate change

Saudi Arabia is compelled to undertake its own energy transition in order to address challenges of increasing vulnerability to the effects of climate change and fulfil the international obligations of climate agreements.[67] In its Nationally Determined Contributions (NDC), the country states that "the Kingdom is developing and implementing holistic and harmonized programs, policies, initiatives, and collaboration

[60] Government of Saudi Arabia, *Vision 2030*, https://www.vision2030.gov.sa/media/rc0b5oy1/saudi_vision203.pdf.
[61] Rashad, M., Barbuscia, D. (May 11, 2020), Saudi triples VAT rate in austerity push to counter oil slump, virus, *Reuters*, https://www.reuters.com/article/us-health-coronavirus-saudi-economy/saudi-triples-vat-rate-in-austerity-push-to-counter-oil-slump-virus-idUSKBN22N05M.
[62] World Bank (2023), *Tax revenue (% of GDP) – Saudi Arabia*, https://data.worldbank.org/indicator/GC.TAX.TOTL.GD.ZS?locations=SA.
[63] International Monetary Fund (August 17, 2022), *IMF Country Report No. 22/274: Saudi Arabia*, https://www.imf.org/en/Publications/CR/Issues/2022/08/11/Saudi-Arabia-2022-Article-IV-Consultation-Press-Release-and-Staff-Report-522189.
[64] Neve, F., The Kingdom's Response to the COVID-19 Outbreak: Steps That Have Been Taken to Date, King Faisal Center for Research and Islamic Studies.
[65] United Nations (November 2020), *Socio-Economic impact of COVID-19 in the Kingdom of Saudi Arabia and how to Build Back Better*, https://saudiarabia.un.org/sites/default/files/2020-12/Socio-Economic%20impact%20of%20COVID-19%20in%20the%20Kingdom%20of%20Saudi%20Arabia%20and%20how%20to%20Build%20Back%20Better%2C%20Diagnostics%20paper%2C%20UN%20in%20KSA%2C%20November%202020.pdf.
[66] McBurney, N. (January 10, 2023), *Saudi Arabia – The ambition versus the reality of Vision 2030*, Control Risks, https://www.controlrisks.com/our-thinking/insights/middle-east-ksa.
[67] Badawi, Fahad a. 2022. "Saudi Arabia Energy Transition." Saudi Arabia Smart Grid 2022. https://www.researchgate.net/publication/366633917_Saudi_Arabia_Energy_Transition.

platforms to address climate change challenges at the national, regional, and global scale[68]. Examples include:

A. The Saudi Green Initiative[69],
B. the Middle East Green Initiative[70],
C. the Circular Carbon Economy National Program[71],
D. the National Renewable Energy Program[72], and
E. the Saudi Energy Efficiency Program[73].

The Kingdom is also a member and active participant in major international initiatives such as the Global Methane Initiative, Mission Innovation, Clean Energy Ministerial, and Net-Zero Producers Forum[74]. Ultimately, the country aims to reach net zero by 2060. That said, past actions have shown that Saudi Arabia intends to continue fossil-related business activities but reduce the associated emissions. At the same time, the country's energy consumption and growing population require reliable sources of energy; renewables are said to be an opportunity to diversify not only energy sources but also jobs.

Saudi Arabia has encouraged the reduction of flaring. Saudi Arabia and Saudi Aramco endorse an initiative by the partnership Zero Routine Flaring by 2030, in which they agree to publish data on flaring annually. From the Kingdom's first reported data in 2019, Saudi Arabia decreased flaring by 11%[75], with technologies such as the High-Pressure Air Assist System (HPAAS), invented and patented by an engineer in Saudi Arabia[76]. Other noteworthy contributions to the decrease in emissions are energy efficiency measures. For Saudi Arabia to reach its net zero targets by 2060, it must decrease its reliance on fossil fuels through more energy efficiency strategies and drastically accelerate renewable energy´s ramp up.

[68] Kingdom of Saudi Arabia. 2021. Updated First Nationally Determined Contribution, 2021 Submission to UNFCCC, 4. https://unfccc.int/sites/default/files/resource/202203111154---KSA%20NDC%202021.pdf.
[69] Saudi Green Initiative: Aimed at promoting the greenification of Saudi Arabia. Includes initiatives such as the planting of 10 billion trees and restoring 40 million hectares of land
[70] Middle East Green Initiative: Regional initiative announed by Saudi Arabia for environmental protection and sustianable development
[71] Circular Carbon Economy National Program: Aimed at achieving carbon neutrality using carbon capture technology and promoting energy efficient and renewable energy technology
[72] National Renewable Energy Program: Aimed at increasing renewable energy to 50% by 2030
[73] Saudi Energy Efficiency Program: Aimed at improving energy efficiency in industries of heavy energy use such as buildings, transportation, and industry
[74] Kingdom of Saudi Arabia. 2021. Updated First Nationally Determined Contribution, 2021 Submission to UNFCCC, 2. https://unfccc.int/sites/default/files/resource/202203111154---KSA%20NDC%202021.pdf.
[75] World Bank. n.d. "Zero Routine Flaring by 2030 (ZRF) Initiative." World Bank. Accessed February 15, 2023. https://www.worldbank.org/en/programs/zero-routine-flaring-by-2030/about.
[76] Rebecca Wallace. September 21, 2020. "An invention with great flare." Saudi Arabian Oil Co. Accessed April 19, 2023. https://www.aramco.com/en/magazine/elements/2020/an-invention-with-great-flare

3.3 Energy Efficiency

Three sectors, 1) industry, 2) building, and 3) land transportation account for 90% of the national energy demand, for which energy efficiency standards are being developed. This includes key aspects of energy efficiency (e.g. for air conditioning), cleaner transportation (e.g. etiring inefficient light-duty vehicles) and improving the efficiency of feedstock utilization in key strategic sectors"[77]. The National Energy Services Company (Tarshid) "plans to retrofit the entire pool of public and governmental assets and facilities which include 2 million street lights, 110,000 government buildings, 35,000 public schools, 100,000 mosques, 2,500 hospitals and clinics".[78] Energy efficiency measures have been highlighted in several initiatives such as the Saudi Energy Efficiency Program (SEEP), created in 2010 in partnership with UNDP. It succeeded in improving energy efficiency in public buildings, establishing regulatory frameworks, implementing renewable energy products, and capacity building.[79]

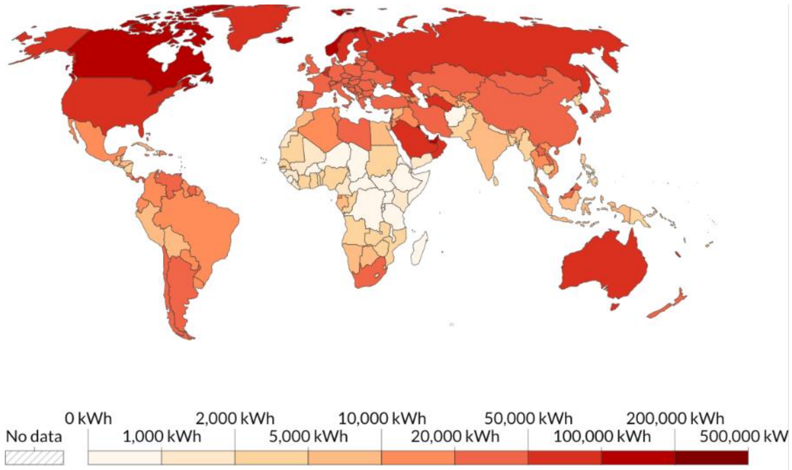

Figure 7: Energy use per person, 2021[80]

[77] Kingdom of Saudi Arabia. 2021. Updated First Nationally Determined Contribution, 2021 Submission to UNFCCC, 4. https://unfccc.int/sites/default/files/resource/202203111154---KSA%20NDC%202021.pdf.
[78] Kingdom of Saudi Arabia. Updated First Nationally Determined Contribution. 2021 Submission to UNFCCC. 2021. UNFCCC NDC Registry, https://unfccc.int/sites/default/files/resource/202203111154---KSA%20NDC%202021.pdf, p. 4.
[79] Santos, Tiago Q., Saudi Energy Efficiency Center, and UNDP. 2019. Final Evaluation Report National Energy Efficiency Program: Phase 2 (NEEP 2).
[80] Roser, Max, Hannah Ritchie and Esteban Ortiz-Ospina. "Energy Production & Changing Energy Sources." Our World in Data. Accessed April 19, 2023. https://ourworldindata.org/energy-production-consumption.

Saudi Arabia's new development projects such as "The Line" also highlight its ambitious endeavors in improving energy efficiency. The city aims to replace the use of cars with an underground, clean transportation system.[81] Furthermore, "The Line" is planned to be powered completely by renewable energy.[82] Current cities also benefit from new energy strategies: Saudi Arabia has a new building code set by the Saudi Energy Efficiency Center and has progressed to include low-rise residential buildings from just very large buildings.[83] Additionally, the government increased its commitment to enhancing public transportation infrastructure by constructing a metro system in Riyadh (with plans in construction for Mecca), establishing light rail transit (LRT) to connect major cities, and implementing bus rapid transit (BRT) networks in key urban locations[84].

3.3 Alternative non-fossil energy sources

Renewable Energy

Saudi Arabia aims to increase its share of renewables to 50% of the energy mix by 2030, which the country intends to reach through the National Renewable Energy Program.[85] Additionally, renewables are expected to diversify the economic tissue and create job opportunities, of which non-governmental sector employment opportunities are a key objective in the National Transformation Plan 2020[86].

From peak usage of total energy in 2016 of 2,045 Terrawatt-hours, Saudi Arabia has reached 1,831 Terawatt-hours in 2021.[87] That said, renewable energy still represents a negligible fraction of the total demand:

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[81] Badawi, Fahad a. 2022. "Saudi Arabia Energy Transition." Saudi Arabia Smart Grid 2022. https://www.researchgate.net/publication/366633917_Saudi_Arabia_Energy_Transition.
[82] Kingdom of Saudi Arabia. n.d. "A Sustainable Saudi Vision." Vision 2030. Accessed February 14, 2023. https://www.vision2030.gov.sa/v2030/a-sustainable-saudi-vision/.
[83] Santos, Tiago Q., Saudi Energy Efficiency Center, and UNDP. 2019. Final Evaluation Report National Energy Efficiency Program: Phase 2 (NEEP 2).
[84] Badawi, Fahad a. 2022. "Saudi Arabia Energy Transition." Saudi Arabia Smart Grid 2022. https://www.researchgate.net/publication/366633917_Saudi_Arabia_Energy_Transition.
[85] Kingdom of Saudi Arabia. Updated First Nationally Determined Contribution. 2021 Submission to UNFCCC. 2021. UNFCCC NDC Registry, https://unfccc.int/sites/default/files/resource/202203111154---KSA%20NDC%202021.pdf, p. 4.
[86] Salam, Mohammad A., and Sami A. Khan. 2018. "Transition toward sustainable energy production - A review of the progress for solar energy in Saudi Arabia." Energy Exploration & Exploitation 36 (1): 3-27. Journals.sagepub.
[87] Our World In Data. n.d. "Energy consumption by source, Saudi Arabia." Our World In Data. https://ourworldindata.org/grapher/energy-consumption-by-source-and-country?stackMode=absolute&country=~SAU.

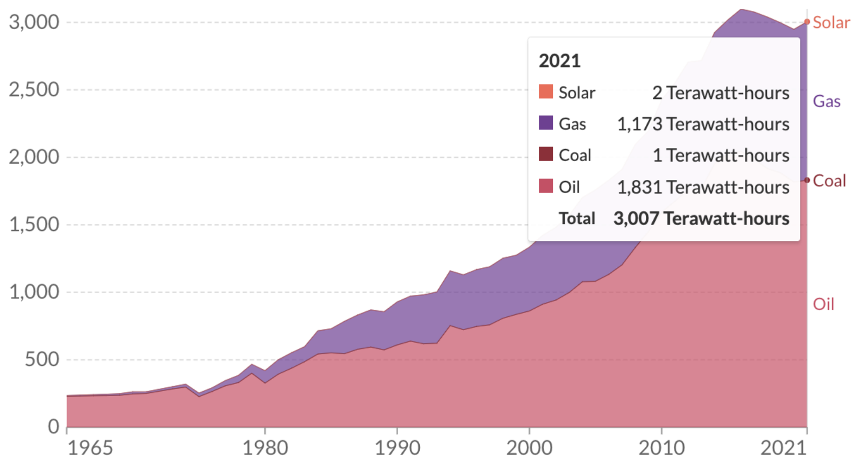

Figure 8: Energy consumption by source, Saudi Arabia[88]

Saudi Arabia is placed in one of the best geographical locations for the production of solar and wind energy[89]. The World Bank has ranked the country 7th in terms of practical solar PV power potential based on zonal statistics[90].The following map shows areas of high solar irradiance in Saudi Arabia, as calculated by AlGhamdi from KAPSARC.

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[88] (OurWorldInData) BP Statistical Review of World Energy https://ourworldindata.org/grapher/energy-consumption-by-source-and-country?stackMode=absolute&country=~SAU

[89] ITP. 2021. "Saudi Arabia closes in on 30% renewable energy target." Arabian Business, June 30, 2021. https://www.arabianbusiness.com/industries/energy/465442-saudi-arabia-closes-in-on-30-renewable-energy-target.

[90] ESMAP. 2020. Global Photovoltaic Power Potential by Country. Washington DC: World Bank.

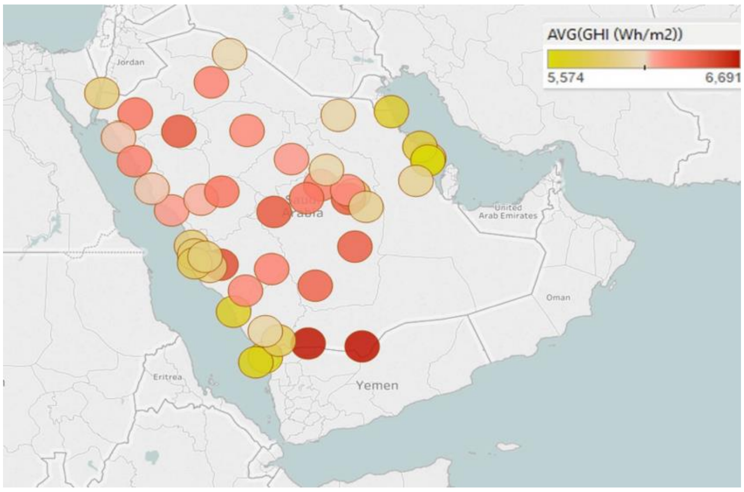

Figure 9: Average global horizontal irradiance (GHI) (Watthours per meter squared [Wh/m2])[91]

Saudi Arabia has a significant wind energy potential, particularly in the coastal and western regions. Through satellite observations, ground measurements, and numerical modeling techniques, studies estimate that the potential wind energy capacity of Saudi Arabia could be several times higher than the country's current electricity demand. Studies also suggest that with further development of wind energy technologies, Saudi Arabia could become a major exporter of renewable power to other countries in the region[92]. The following map shows areas of high average wind speed in Saudi Arabia, as calculated by AlGhamdi from KAPSARC.

[91] AlGhamdi, Abeer. 2020. Saudi Arabia Energy Report 2020. Riyadh: King Abdullah Petroleum Studies and Research Center. 10.30573/KS--2020-DP25.
[92] ITP. 2021. "Saudi Arabia closes in on 30% renewable energy target." Arabian Business, June 30, 2021. https://www.arabianbusiness.com/industries/energy/465442-saudi-arabia-closes-in-on-30-renewable-energy-target; Chen, Wanfang, Stefano Castruccio, Marc G. Genton, and Paola Crippa. 2018. "Current and Future Estimates of Wind Energy Potential Over Saudi Arabia." Journal of Geophysical Research: Atmospheres 123 (12): 6443-6459. https://doi.org/10.1029/2017JD028212.

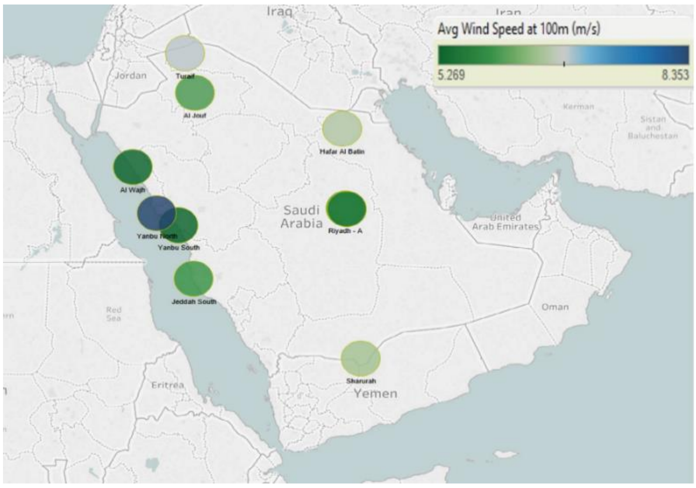

Figure 10: Average wind speed at 100 meters (meters per second)[93]

Nuclear Energy

The European Commission had concluded that nuclear-generated hydrogen will be considered 'renewable', generating political will in developing nuclear power in Saudi Arabia.[94] In January 2023, Minister of Energy Prince Abdulaziz bin Salman shared plans to utilize their domestic uranium supplies for nuclear power[95]. This ambition was supported by the signing of a memorandum of understanding (MoU) with France, which has shown interest in sustaining the use of nuclear power[96].

3.4 Remaining challenges

Despite promising achievements in technical installations, legal framework implemnention, governmental commitment and private sector engagement in renewable energies, challenges remain. Barriers to meeting solar and wind energy potentials in Saudi Arabia remains are found in all of the following four segments:

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[93] AlGhamdi, Abeer. 2020. Saudi Arabia Energy Report 2020. Riyadh: King Abdullah Petrolum Studies and Research Center. 10.30573/KS--2020-DP25.

[94] Rushton, Simon. 2023. "EU approves nuclear-generated hydrogen for green targets." The National, February 13, 2023. https://www.thenationalnews.com/world/europe/2023/02/13/eu-approves-nuclear-generated-hydrogen-for-green-targets/.

[95] El Yaakoubi, Aziz, Maha El Dahan, and Nadine Awadella. 2023. "Saudi Arabia plans to use domestic uranium for nuclear fuel." Reuters. https://www.reuters.com/business/energy/saudi-arabia-plans-use-uranium-entire-nuclear-fuel-cycle-minister-says-2023-01-11/; El Yaakoubi, Aziz. 2022. "Saudi Arabia calls for flexibility in energy transition." Reuters, January 12, 2022. https://www.reuters.com/business/energy/saudi-energy-min-calls-flexibility-complicated-energy-transition-2022-01-12/.

[96] Menon, Nirmal. 2023. "Saudi Arabia and France sign cooperation MoU in the field of energy." Arab News. https://www.arabnews.com/node/2243851/business-economy.

Technical challenges: the ability of photovoltaic (PV) panels to withstand harsh desert conditions, mainly heat and soiling, is challenging. The lack of data and completed solar projects in the region also make it difficult to assess the performance of solar energy systems in the Saudi Arabian environment. Next, there is limited knowledge and familiarity with PV technology among local contractors and officials. Infrastructural issues related to grid stability, power quality, and power transmission also need to be addressed, along with the need for energy storage systems, smart grids, and advanced control systems.[97]
Economic/market-related challenges: the lack of assurance of investment security and return on investment for potential investors represents another challenge. Then, the low energy costs of oil and gas, make solar and wind less competitive in the market yet. The Saudi government also still subsidizes energy, which poses a cost-competitive challenge to renewable energy adoption.
Governmental challenges: Yet, the complex bureaucratic process poses a challenge to receive licenses or permits. Despite the fact that the Saudi government has already improved e-governance structures, legal framework and has established efforts to improve conditions for investments in renewable energy, more measures are under discussion. The promotion of public-private partnerships (PPPs) for investment, in addition to policies such as feed-in tariffs, renewable portfolio standards, economic incentives, pricing laws, or quota systems are considered to have improved.[98] Additionally, low end-user electricity tariffs are an indicator to explain delays in investment.[99] The introduction of market-independent feed-in tariffs (FIT) for market restructuring, such as a fixed price, a market-dependent FIT model to reap the comprehensive benefits of the FIT model and the signing of international treaties can also support renewable energy adoption in the country.
Cultural challenges: Finally, cultural challenges towards renewable energy adoption still exist in Saudi Arabia, including a strong trader mentality from traditional Arab culture that prioritizes short-term financial returns over long-term gains from research and entrepreneurship.[100] Still, public knowledge about renewable energy is lacking. However, governmental and non-governmantal initiatives aim to raise awareness by providing environmental education, training skills, and capacity development for the Saudi

[97] Ai-Sarihi, Aisha, and Noura Mansouri. 2022. "Renewable Energy Development in the Gulf Cooperation Council Countries: Status, Barriers, and Policy Options." Energies 15 (5); Salam, Mohammad A., and Sami A. Khan. 2018. "Transition toward sustainable energy production - A review of the progress for solar energy in Saudi Arabia." Energy Exploration & Exploitation 36 (1): 3-27. Journals.sagepub.
[98] Ai-Sarihi, Aisha, and Noura Mansouri. 2022. "Renewable Energy Development in the Gulf Cooperation Council Countries: Status, Barriers, and Policy Options." Energies 15 (5); Salam, Mohammad A., and Sami A. Khan. 2018. "Transition toward sustainable energy production - A review of the progress for solar energy in Saudi Arabia." Energy Exploration & Exploitation 36 (1): 3-27. Journals.sagepub.
[99] ESMAP. 2020. Global Photovoltaic Power Potential by Country. Washington DC: World Bank.
[100] Auktor, G. V., McElvaney, L., Samulewicz, D., & Alsaleh, Y. (2012). An empirical examination of the development of a solar innovation system in the United Arab Emirates. Energy for Sustainable Development, 16(2), 179-188. doi:10.1016/j.esd.2011.12.002

public. Hence, parts of the young Saudi population have started to engage in climate action initiatives at a grassroots level and are considering renewable energy as an attractive future job market. In this regard, green entrepreneurship has emerged as a potential niche for young Saudi nationals to enter the job market. Against this backdrop, the educational system and governmental and non-governmental institutions such as the MiSK Foundation are taking more action in the field of environmental education with topics such as green recovery, environmentalism, and measures to mitigate climate change have become an integral part of the Saudi social fabric and identity.

3.5 Saudi Arabia's Hydrogen Strategy

Hydrogen plays a central part of Saudi Arabia's energy transition. The expectations towards hydrogen are high, as the country unfolds multiple assets such as its "high-yield solar and wind resources", "abundance of natural resources, underground carbon storage capacity, and CCUS technology expertise".[101] . As a result, the reduction of the dependence on fossil fuels and the promotion of hydrogen could increase resilience and energy security, both as an export commodity and for domestic use.[102]
In recent years, the Kingdom has invested heavily to promote the hydrogen industry as it wants to position itself as a regional and global hydrogen hub. As part of this endeavor, Saudi Arabia's flagship project, NEOM, "is expected to produce 650 tons/day of green hydrogen by electrolysis and 1.2 million tons per year of green ammonia" [103], making it as of now the largest hydrogen production facility being built globally. Notably, Saudi Arabia has invested more heavily in blue hydrogen. In October 2021, the Kingdom announced plans to invest $110 billion to use shale gas to produce hydrogen, earmarking a considerable portion of the Jafurah field.[104] The hydrogen plant in Jubail Industrial City was also upgraded for this purpose. Further eight hydrogen plants were agreed upon by January 2022.[105] Low-carbon hydrogen projects have called for global partnerships. Saudi Arabia has signed MoUs on hydrogen with different countries, including the following:

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[101] Kingdom of Saudi Arabia. n.d. "A Sustainable Saudi Vision." Vision 2030. Accessed February 14, 2023. https://www.vision2030.gov.sa/v2030/a-sustainable-saudi-vision/.
[102] Koch, Natalie. 2022. "Gulf hydrogen horizons: Wh are Gulf oil and gas producers so keen on hydrogen?" Geographies of the Arabian Peninsula, (November). DOI:10.48481/iass.2022.044.
[103] Kingdom of Saudi Arabia. 2021. Updated First Nationally Determined Contribution, 2021 Submission to UNFCCC. https://unfccc.int/sites/default/files/resource/202203111154---KSA%20NDC%202021.pdf.
[104] Ugal, N., & News Reports. (2021, October 25). Saudi Arabia poised to tap $110bn Jafurah gas project for blue hydrogen. Upstream Online. https://www.upstreamonline.com/energy-transition/saudi-arabia-poised-to-tap-110bn-jafurah-gas-project-for-blue-hydrogen/2-1-1087974
[105] Ansari, Dawud. 2022. "The Hydrogen Ambitions of the Gulf States." SWP Comment 44 (July), 4.

Date	Country	Purpose
September 2020	Japan	Cooperation on the development of a hydrogen supply chain, the first shipment of blue ammonia by Saudi Aramco
March 2021	Germany	MoU on the enhancement of cooperation on hydrogen production, transportation, and utilization
March 2021	South Korea	Bilateral energy policy dialogue and concluded on the expansion of bilateral cooperation of energy (including nuclear, renewable, and hydrogen)
February 2023	France	Establishment of a framework for sustainable energy

Table 5: Overview of Saudi Arabia hydrogen MoUs with international community[106]

In the future, while feasibility remains questionable, Saudi officials showed optimism in their partnership with Europe by suggesting the potential of building a pipeline to transport green hydrogen to Europe, as the region is increasing its demand for alternative sources of energy[107].

Despite promising achievements in Saudi Arabia's hydrogen economy, the Kingdom has some challenges to overcome. First and foremost, this could disrupt their fossil-fuel-based economy. There is a significant amount of investment in infrastructure, technology, retraining and reskilling of the current workforce to decrease the cost of hydrogen[108]. Also, there are regulatory and legal barriers, which had primarily

[106] Al-Sarihi, A. (2022, June 21). Gulf States Hedge Against Global Energy Transition, Now With Hydrogen. Arab Gulf States Institute in Washington. https://agsiw.org/gulf-states-hedge-against-global-energy-transition-now-with-hydrogen/; Abdallah, Nayera, Peter Graff, and Leslie Adler. 2022. "Japan minister signs clean energy cooperation document during Saudi visit." Reuters. https://www.reuters.com/business/energy/japan-minister-signs-clean-energy-cooperation-document-during-saudi-visit-2022-12-25/.; Ewing, Richard. 2021. "Saudi Arabia and Germany sign green hydrogen MoU." ICIS, Mar 12, 2021. https://www.icis.com/explore/resources/news/2021/03/12/10616981/saudi-arabia-and-germany-sign-green-hydrogen-mou/.; Menon, Nirmal. 2023. "Saudi Arabia and France sign cooperation MoU in the field of energy." Arab News. https://www.arabnews.com/node/2243851/business-economy.

[107] Kane, Frank. 2021. "Saudi Arabia offers Europe 'green' hydrogen by pipeline." Arab News, February 27, 2021. https://www.arabnews.com/node/1816761/business-economy.

[108] Koch, Natalie. 2022. "Gulf hydrogen horizons: Why are Gulf oil and gas producers so keen on hydrogen?" Geographies of the Arabian Peninsula, (November). DOI:10.48481/iass.2022.044.

supported the oil and gas industry.[109] More specifically, the logistics for storage and transport of green hydrogen to offtaker markets must be sorted out. Historically, hydrogen has usually been produced and used locally. Nevertheless, Saudi Arabia is also eyeing at exporting hydrogen, as shown in 2020 when Saudi Aramco shipped 40 tons of blue ammonia to Japan. This was the world's first demonstration of blue ammonia supply chains, entailing the production and international shipping of the product. Converting hydrogen into ammonia makes it easier to ship. The costs of blue and green hydrogen are reliant on whether or not other technologies are scaled up. With domestic natural gas prices at $1.25/MMBtu, the following projections can be made about the price of blue hydrogen.[110]

	Current Price ($)	Price by 2030 ($)
Blue hydrogen	1.34/kg	1.13/kg
Domestic natural gas	$1.25/MMBtu	

Table 6: Overview of current and future prices of blue hydrogen[111]

Similarly, with "realistic scenarios" of a falling solar electricity price and a gradual electrolyzer capital cost decreasing to $400 by 2050, KAPARC predicts the following prices:[112]

	Current Price ($)	Price by 2030 ($)	Price by 2050 ($)
Green hydrogen	2.16/kg	1.48/kg	1/kg
Solar electricity price	18.3/MWh	13/MWh	10/MWh

[109] Koch, Natalie. 2022. "Gulf hydrogen horizons: Why are Gulf oil and gas producers so keen on hydrogen?" Geographies of the Arabian Peninsula, (November). DOI:10.48481/iass.2022.044.
[110] KAPSARC. 2022. "KAPSARC Identifies Hydrogen Opportunities in Saudi Arabia." KAPSARC. https://www.kapsarc.org/news/kapsarc-identifies-hydrogen-opportunities-in-saudi-arabia/.
[111] KAPSARC. 2022. "KAPSARC Identifies Hydrogen Opportunities in Saudi Arabia." KAPSARC. https://www.kapsarc.org/news/kapsarc-identifies-hydrogen-opportunities-in-saudi-arabia/.
[112] KAPSARC. 2022. "KAPSARC Identifies Hydrogen Opportunities in Saudi Arabia." KAPSARC. https://www.kapsarc.org/news/kapsarc-identifies-hydrogen-opportunities-in-saudi-arabia/.

Electrolyzer capital			$400/kW

Table 7: Overview of current and future prices of green hydrogen[113]

Plus, some skepticism about those partnerships exists as countries are not only looking to 'greenify' their energy mix. In the case of Germany, Zumbraegel suggests that the MoU is driven more by geopolitical considerations to decrease dependence on natural gas from Russia in times of the Ukraine war.[114]

[113] KAPSARC. 2022. "KAPSARC Identifies Hydrogen Opportunities in Saudi Arabia." KAPSARC. https://www.kapsarc.org/news/kapsarc-identifies-hydrogen-opportunities-in-saudi-arabia/.
[114] Zumbrägel, Tobias. 2022. "Hydrogen partnerships between Germany and the Gulf: Too fast and too soon?" TRENDS Research and Advisory, October 27, 2022. https://trendsresearch.org/insight/hydrogen-partnerships-between-germany-and-the-gulf-too-fast-and-too-soon/.

4. Saudi Arabia's petrochemical sector

4.1 Overview

Saudi Arabia's petrochemical sector has not only a comparatively long tradition in the Kingdom, it is also the second most important sector after the conventional hydrocarbon business. The development of this new branch of industry was a consequence of the oil crisis and the associated diversification attempts during the early/mid-1970s. As such, the First Five-Year Development Plan (1970-1975) underlined a great relevance to the petrochemical industry and prioritized the production of petrochemicals as well as fertilizers in large quantities. While there are more than hundreds different companies involved, eight petrochemical companies are listed in the Saudi stock market, Tadawul. The Saudi Basic Industries Corporation (SABIC) is by far the largest, which is why much of our analysis will focus on this top performer.

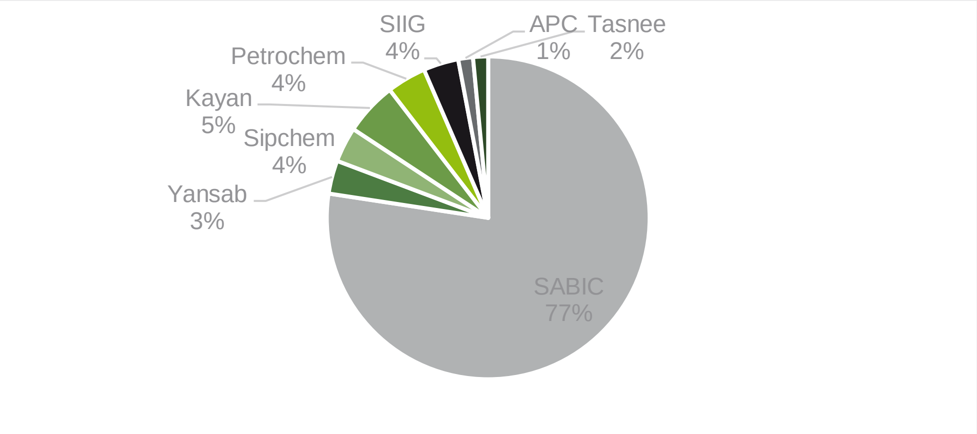

Figure 11: Key petrochemical companies in Saudi Arabia and its share (measured in terms of their revenues in 2020) [115]

The creation of SABIC in 1976 can be seen as a milestone in Saudi Arabia's petrochemical development. Since then, it is responsible for the Kingdom's petrochemical industry and has become one of the world's

[115] Zia, A. (January 2022) Saudi Petrochemical Sector – on the road to recovery... https://argaamplus.s3.amazonaws.com/a2e39481-42be-49d7-8219-9658d0c67882.pdf

top petrochemical manufacturers. The creation of two specialized industrial zones by the Royal Commission for Jubail and Yanbu, which was established in 1975, helped SABIC's rise as the two areas provided the necessary feedstock of fuel, water, electricity and manpower. Within a short period of time after inception, SABIC managed to transform the country from an importer to an exporter of petrochemical products.[116]

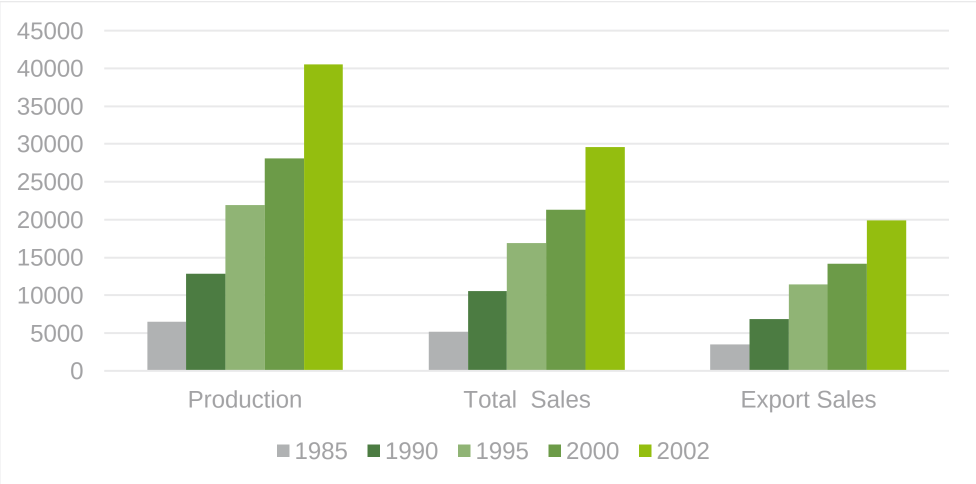

Figure 12: SABIC production and sales between 1985 and 2002 (measured in kilo metric ton (kmt)[117]

SABIC is also an early prime example of how Saudi Arabia has successfully overcome obstacles inherent to its rentier-based business model. As in other sectors, the Kingdom lacked a number of crucial elements to exploit a new industrial sector.

[116] Abdulrahman Al-Ankari, 'Technology Transfer: A Case Study Analysis of the Saudi Oil and Petrochemical Sectors' (Cranfield University, 2004).
[117] Al-Ankari, 126.

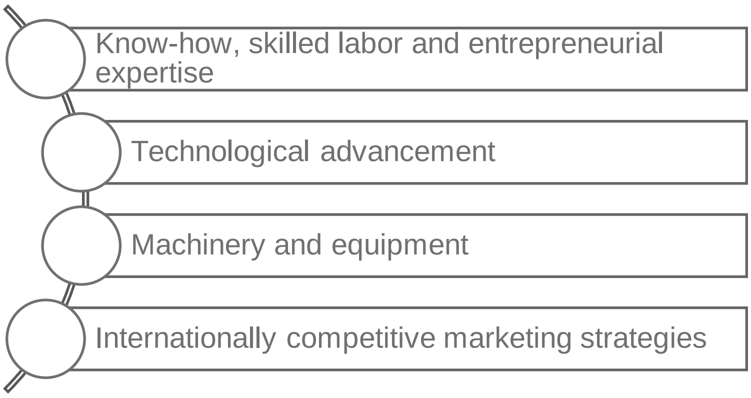

Figure 13: Overview of key aspects of SABIC's early success[118]

The negative example of a turnkey approach, exemplified by the early operation of Saudi Arabian Fertilizers Company (SAFCO), revealed that Saudi Arabia was not able to perform all stages of a highly sophisticated capital-intensive petrochemical industry.[119] Thus, the country had to rely on external expertise and partners, who shared their vital know-how and technology. However, importing capital goods and foreign investment as well as licensing key technology from industrialized countries made Saudi Arabia dependent and losing control over its key industries. SABIC marked the beginning of a new strategy. It was created as a state-affiliated but independent company to establish and run petrochemical joint ventures with foreign companies. The joint venture agreements included a number of conditions: next to the fact that the Saudi side preferred mostly long-term partnerships, the foreign companies also had shown proven experience in the specific field; record of profitable operations; ability to market products from proposed projects; possession of the required technology; and a willingness and ability to train Saudi manpower.[120] Due to those high requirements and standards, it is not surprising that most joint ventures had been established with big players (or their subsidiaries) such as Dow Chemical, ExxonMobil, Shell and Mitsubishi.[121]

[118] Rashid Masood, ‘Petrochemical Industry in Saudi Arabia: Prospects for Exports’, *Foreign Trade Review* 23, no. 1 (April 1988): 80–104, https://doi.org/10.1177/0015732515880106.
[119] Masood; Al-Ankari, ‘Technology Transfer: A Case Study Analysis of the Saudi Oil and Petrochemical Sectors’.
[120] Al-Ankari, ‘Technology Transfer: A Case Study Analysis of the Saudi Oil and Petrochemical Sectors’, 76; Makio Yamada, ‘Gulf-Asia Relations as “Post-Rentier” Diversification? The Case of the Petrochemical Industry in Saudi Arabia’, *Journal of Arabian Studies* 1, no. 1 (June 2011): 99–116, https://doi.org/10.1080/21534764.2011.576054.
[121] Al-Ankari, ‘Technology Transfer: A Case Study Analysis of the Saudi Oil and Petrochemical Sectors’.

When looking at the broader development of the petrochemical sector, one can differentiate different periods, which were often shaped by broader impacts on the most important feedstocks for producing petrochemicals, namely oil and gas.

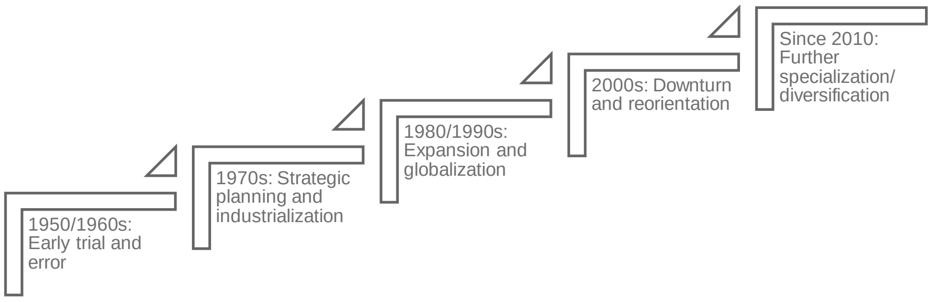

Figure 14: Overview different phases of Saudi Arabia's petrochemical sector development (own compilation)

The latest proliferation of producing many different petrochemical end-products was also a consequence of a more diversified industry. The establishment of a number of other petrochemical companies such as Sipchem, Kayan, Yansab, Tasnee and Petro Rabigh were also a key enabler for this development. As a result, Saudi Arabia became a leading producer and exporter of petrochemical products such as ethylene glycol, methanol as well as polyethylene and polypropylene.

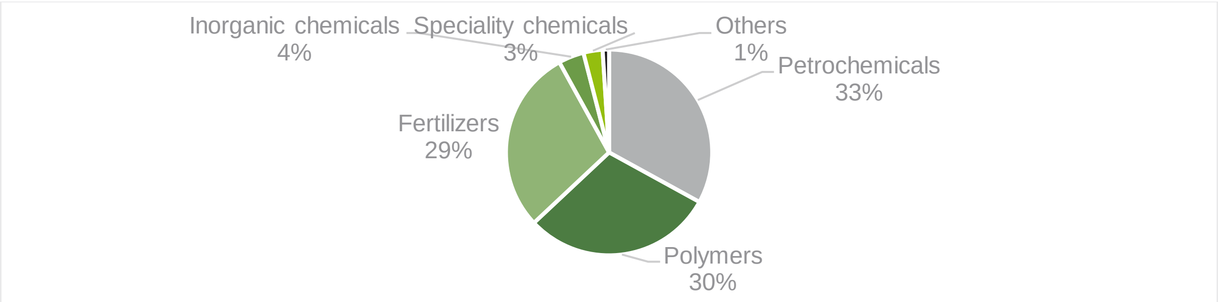

Figure 15: Overview Chemical exports share by product 2021-2022[122]

[122] Maersk (January 2023) Resilient supply chains for Saudi petrochemical businesses, https://www.maersk.com/de-de/insights/resilience/petrochemical-supply-chain

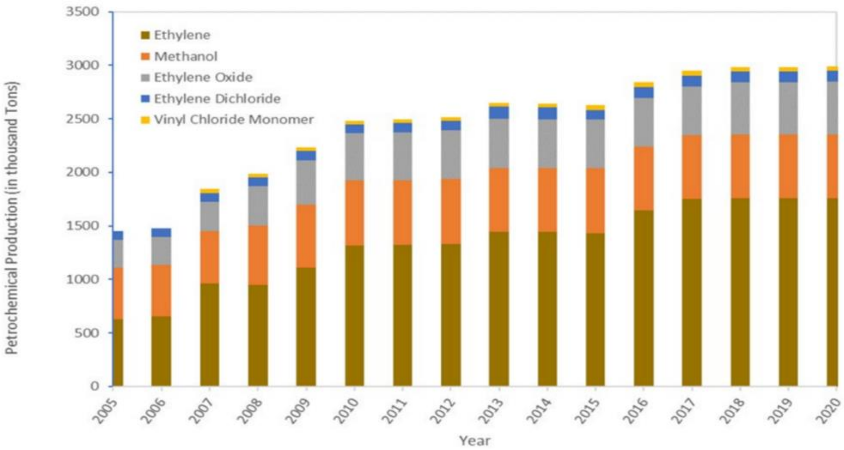

Figure 2. Breakdown of the growth of different petrochemical products in Saudi Arabia.

Figure 16: Individual growth of key petrochemical products in Saudi Arabia between 2005 and 2020[123]

Such a shift in production capacity to high-value intermediate and derivative products helps to lower the risks of a volatile global energy market while also benefitting financially from higher parts of the value chain. This was also done by a stronger focus on international collaboration with other petrochemical companies to gain technical know-how to establish facilities that yield high-value petrochemical derivatives. Overall, Saudi Arabia's petrochemical industry can be seen as a success story which centers around three main factors, namely (free) access to competitive priced feedstock and energy resource advantage, a technological edge, and a marketing capability. In the following, we want to zoom into these different conditions and capabilities.

4.2 The petrochemical sector's supply and value chain Input-output structure

Having one of the world's largest hydrocarbon reserves, Saudi Arabia took a strategic decision to turn attention towards the petrochemical sector as oil and gas constitutes the key component. For instance, raw material for most petrochemical processes are either naphtha (refined from crude oil) as well as ethane

[123] Rahman et al., 'Greenhouse Gas Emissions in the Industrial Processes and Product Use Sector of Saudi Arabia—An Emerging Challenge', 6.

and methane from natural gas liquids, which are mainly obtained from the associated natural gas that is recovered as part of crude oil production.

Another resource, namely water, is not so easily and widely available. The increase of desalination plants close to the petrochemical sectors has helped to develop the sector but this technology is still costly, energy-intensive and ecologically harmful (e.g. brine discharge and disposal of other chemicals) as the majority of desalination plants rely on the multi-stage flash (MSF) technology. While already the 6th Five-Year Plan (1995-2000) called for improved efficiency and utilization of non-conventional water resources, such as treated wastewater, the continuous growing demand of potable water remains a critical issue.

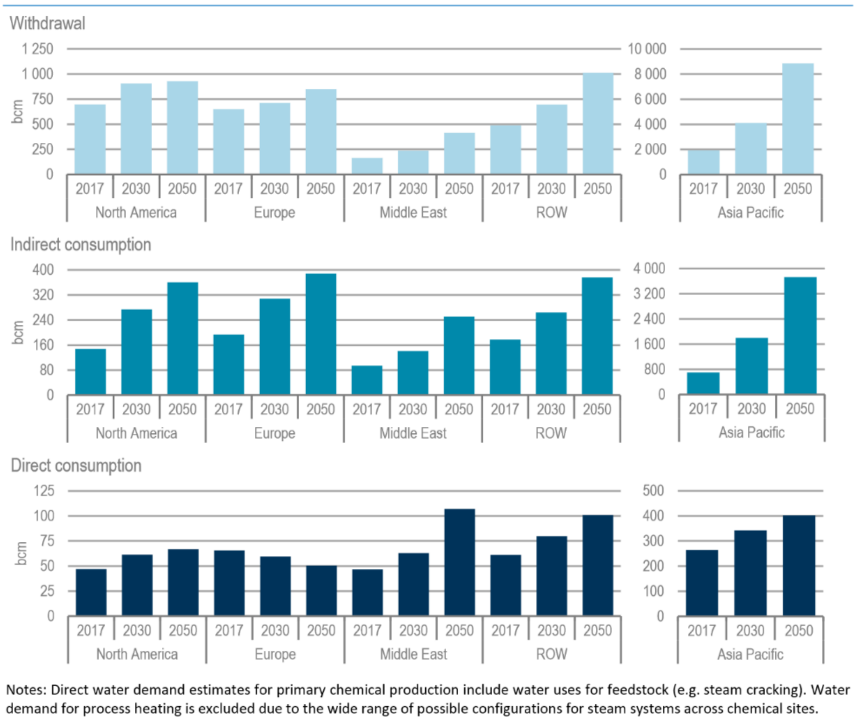

Figure 17: Water demand for primary chemical production[124]

Given the advantageous feedstock of abundant and low-cost hydrocarbons, Saudi Arabia was able to diversify its petrochemical sector and produce a wide range of final products. Alone SABIC delivers

124 IEA.

products such as olefins, glycols, aromatics, oxygenates, and a variety of functional chemicals, alongside a portfolio of polymers, and engineering thermoplastics (ETP) and other blends.[125] In 2015, SABIC launched a transformation program to further streamline the operating model. It reduced the previous business units into three strategic units, namely petrochemicals, agri-nutrients and specialties.[126] While other smaller petrochemical companies such as Tasnee also have a broad and very diversified portfolio of products, other firms are more specialized. This includes, for instance, Advanced Petrochemical Company (APC), which has a leading position in the production of titanium dioxide and focuses on pure polypropylene.

Almost all petrochemical companies have their operations based in Saudi Arabia, close to the production of feedstocks. Throughout the operation process of petrochemical products, Saudi Arabia's leading company SABIC has established a high-class entitlement. It has even created its own program, the Operation Excellence Initiative, which is dedicated to applying the highest standards in ensuring a smooth operation for the entire value chain. In terms of further end-products' logistics and distribution, Saudi Arabia's petrochemical sector benefits from the strategic location next to the industrial complexes of Yanbu and Jubail with their large deep-seaports and further transportation networks. While especially the COVID-19 pandemic interrupted global supply chains and created higher shipping and storage costs, the petrochemical industry in Saudi Arabia was well equipped to circumvent those obstacles. For instance, the Danish shipping and logistics mega-player Maersk has lately set up a massive logistic hub at the King Abdullah Port, north of Jeddah, between Thuwal and Rabigh. It is specifically dedicated to support the various petrochemical companies in Saudi Arabia in their logistical requirements. This includes growing challenges of timely loading, production continuity, container availability, and inventory management.[127] Furthermore, there are cross-functional and cross-regional command teams and special sections and logistics affiliate companies such as the SABIC Supply Chain Services (SSCS) to secure shipping and storage capacities and ensure the functioning of the global supply chain.[128]

Governance structure: Lead Firms & Industry Organization and National policies

As already stated above, SABIC is by far the business champion with a volume that is more than hundredfold the size of other important petrochemicals companies which are also listed in the Saudi stock

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125 SABIC, 'SABIC Annual Report 2021' (Riyadh, Saudi Arabia, 2022), file:///C:/Users/tobias/Downloads/SABIC_Annual_Report_2021_EN_tcm1010-32120.pdf.
126 SABIC.
127 Gulf Petrochemical and Chemical Association, 'Sustainability: The New Imperative', GPCA Insight, 2021, https://www.gpca.org.ae/wp-content/uploads/2021/10/Insight-Newsletter_September2021-1.pdf.
128 SABIC, 'SABIC Annual Report 2021'.

market. However, SABIC also owns large percentages of some of the above-mentioned companies including 51,95% in Yansab or 35% in Kayan.[129]

Company	2018	2019	2020
SABIC	169,128	135,396	116,949
Yansab	7,628	6,065	5,035
Sipchem	5,036	5,440	5,323
Kayan	12,263	9,536	8,007
Petrochem	8,930	7,435	5,941
SIIG	5,036	5,440	5,323
APC	2,748	2,595	2,231
Tasnee	3,065	3,019	2,272

Table 8: Overview various petrochemical companies in Saudi Arabia and their revenues between 2018-2020 (in USD/t [130]

As the petrochemical sector is a key element of Saudi Arabia's diversification efforts (see chapter 2), the Saudi government has supported early on the industrial growth of this sector. It thus provides the necessary infrastructure and investment incentives for both national and international stakeholders. The government intends to further boost this industrialization process and provide more incentives.[131]
Amid financial losses of the net income in the first quarter of 2020 caused by the COVID-19 pandemic, the national oil giant, Saudi Aramco, completed its purchase of a 70 percent stake in SABIC. The deal in Saudi Arabia's third most valuable brand SABIC, worth around $69 billion, strengthens Saudi Aramco's downstream activities and makes it to one of the world's leading preeminent producers of petrochemicals. The acquisition, which was previously held by the PIF, further provides the state-led vehicle with new cash inflows to fund other costly domestic development projects. The purchase also marks an important milestone in Saudi Aramco's 'oil-to-chemicals' division (i.e. downstream sector) and the Kingdom's economic diversification. Accordingly, it enables Aramco to focus on fuel products whereas SABIC continues its role as leading petrochemical company and operates as the 'chemical arm of Aramco' from now on.

[129] SABIC, 128.
[130] Zia, A. (January 2022) Saudi Petrochemical Sector – on the road to recovery...
https://argaamplus.s3.amazonaws.com/a2e39481-42be-49d7-8219-9658d0c67882.pdf
[131] Mohammed Ziaur Rehman, Muhammad Nauman Khan, and Imran Khokhar, 'Select Financial Ratios as a Determinant of Profitability Evidence from Petrochemical Industry in Saudi Arabia', *European Journal of Business and Management* 6, no. 6 (2014).

Geographic scope and infrastructure

As already mentioned, the petrochemical infrastructure is closely connected to the upstream business of the oil and gas industry that provides access to affordable feedstock and fuel. Most of Saudi Arabia's petrochemical industry is well suited between the two industrial cities Jubail on the Gulf and Yanbu on the Red Sea. Meanwhile, an advanced infrastructure encompassing thousands of square kilometers of pipelines, airports, communication networks, roads, deep-seaports, housing, schools, and commercial support centers have been created between Jubail and Yanbu. Since its inception, Saudi Arabia's petrochemical industry also benefitted from the Kingdom's advantageous geographical position (see chapter 2), linking important markets in Europe Europe and Asia. This central location is not only important for providing incentives for joint ventures to attract capital and technology but also to gain expertise and technology.

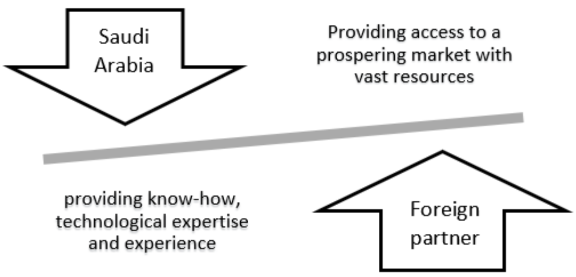

Figure 18: Two-way exchange between the Kingdom of Saudi Arabia and foreign partners[132]

The majority of end-consumers and buyers of petrochemical products are located in the US, Europe and Asia-Pacific countries. Especially over the last decade, the Asian market became more important, in which Saudi Arabia as a leading petrochemical producer plays a crucial role. China has emerged as the most crucial market. Over the last years, several joint ventures were established between Saudi Aramco and Chinese petrochemical companies including the China Petroleum and Chemical Corporation (Sinopec) or Panjin Xicheng Industrial. The partnerships mainly focus on oil refining and cracking processes to produce large-quantities of ethylene and paraxylene.

[132] see also: Al-Ankari, 'Technology Transfer: A Case Study Analysis of the Saudi Oil and Petrochemical Sectors', 17.

In March 2022, it was reported that Aramco intends to buy a 10% stake in Rongsheng Petrochemical.[133] In addition, the role of India is also growing. Various deals have been signed between the Indian Oil Corporation (IOC) and Saudi companies including Saudi Aramco, SABIC and S-Chem.[134] Furthermore, a provisional deal was signed in 2020 between Saudi Aramco and India's Reliance Industries Limited to invest around 20% stake in the Indian behemoth's refining and petrochemicals business.[135] These examples reveal how Saudi Arabia's petrochemical industry is steadily becoming an integral part of the global economy.

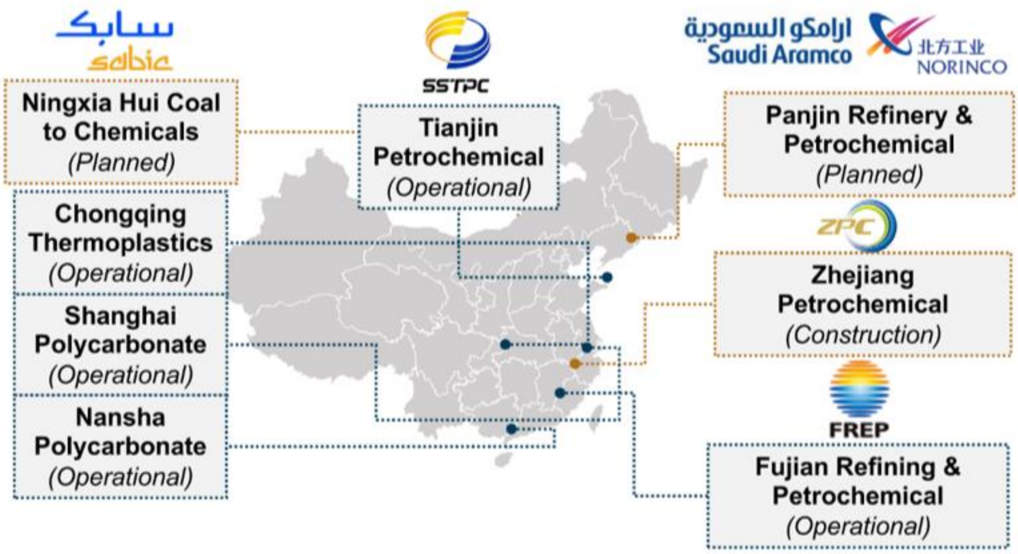

Figure 19: Overview of the growing petrochemical partnerships between Saudi Arabia and China as one leading Asian country[136]

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133 David Blackmon, D. (2023): Rise of Brics challenges oil world order, The Petroleum Economist, https://pemedianetwork.com/petroleum-economist/articles/trading-markets/2023/rise-of-brics-challenges-oil-world-order/

134 The Tribune (2018): Saudi Aramco picks up 50% stake in Ratnagiri refinery, https://www.tribuneindia.com/news/archive/business/news-detail-572470; SABIC (2021): SABIC Collaborates with Indian Oil Corporation Limited to Reduce Emissions from Diesel Engines, https://www.sabic.com/en/news/30682-sabic-collaborates-with-iocl-to-reduce-vehicular-emissions-in-india;

135 Verma, S. (2020): Reliance's $15 billion stake sale deal with Aramco delayed, https://www.reuters.com/article/us-reliance-agm-energy-idUSKCN24G1W6.

136 KAPSARC (King Abdullah Petroleum Studies and Research Center), 'The Future of the Petrochemicals Industry and Sino-Saudi Cooperation' (King Abdullah Petroleum Studies and Research Center, 14 February 2021), 10, https://doi.org/10.30573/KS--2020-WB12.

Technological development and human resource management

As said, Saudi Arabia created its petrochemical sector from scratch, which required technological expertise from abroad and the willingness of external actors to share and transfer their know-how. The transformation of the international joint venture strategy had a deep impact on the successful achievement to become a technological leader in petrochemicals. Long-term technological partnerships and cooperation provided avenues for technological information inflows and technological learning. This was especially important for areas such as "skilled managerial and entrepreneurial expertise[204]:

1. Technical consultancy and services;
2. Machinery and equipment;
3. Marketing of products [137]

Furthermore, the creation of specific units and task forces inside and outside the Kingdom to foster research and development was equally central. For instance, SABIC's research and innovation center has created specific facilities near industrial complexes and business areas such as Riyadh and Jubail but also in other locations including Houston (USA) and Bangalore (India). As of today, around 1,660 full-time employees are working in the SABIC's Corporate Technology and Innovation department in 20 centers around the world.[138] They all help to deliver high-class application solutions and sustainable cost-advantaged process innovation. In close distance of the headquarter in Riyadh is SABIC Academy, which was very important during the pandemic in digital programs and initiatives when many employees had to work remotely.[139]

The central location of the petrochemical sector next to urban centers such as Riyadh, Damman, or Jeddah also provided the required national manpower for a flourishing industry. However, especially throughout the early decades, skilled personal was a limited resource. Over the years, the Saudi petrochemical sector advanced through a better education system. This included the introduction of expanded technical subjects in schools and universities and more exchange with international technical and scientific organizations. Both included also more programs for sending students and researchers to research and technology-oriented institutions of higher education abroad.[140] For the Saudi government, the petrochemical sector is an indispensable key element for the ultimate goals of job creation as part of Saudization efforts (see

137 Masood, 'Petrochemical Industry in Saudi Arabia', 103.
138 SABIC, 'SABIC Annual Report 2021'.
139 SABIC (2021) Sustainability Report 2021 – our workforce. https://www.sabic.com/en/reports/sustainability-2021/collaboration/our-workforce
140 Masood, 'Petrochemical Industry in Saudi Arabia'.

chapter 2).[141] Here, the production of petrochemical products is only the beginning of further processes of industrialization since many manufactured products are further used in other sectors including textiles, automotives, cosmetics, agriculture etc.

4.3 The petrochemical sector and the energy transition

The petrochemical sector is a prime mover for many other branches of industry including food, transportation and electronics. Therefore, it also has specific obligations in terms of ensuring environmental sustainability and comply with the Sustainable Development Agenda, which the Kingdom has ensured in the scope of the Paris Agreement. Petrochemical output relies on non-renewable feedstock such as hydrocarbons and freshwater while also emitting GHG emissions and toxic gases, generating hazardous waste and polluted water. Especially plastic as an important end-product of the sector creates massive waste problems as it decomposes over a long time. It often contains toxic substances such as softeners, solvents and other chemicals, which get into the environment and ecosystem in the form of microplastic particles. If burnt, hazardous air pollutants can create health problems, acid rain or ozone layer depletion.[142] A sustainable transformation of this sector is quite challenging due to its complexity and the broad range of manufacturing goods it produces for various other branches of industry.[143]
Saudi Arabia's petrochemical industry, which experienced continuous growth over the last decades, also triggers severe negative side-effects in terms of its climate footprint. In 2020, the Kingdom's petrochemical industry accounted for around 32.3% of GHG, making it the second most polluting branch of industry after cement (35.5%) and far before the iron and steel industries (16.8%).[144]

[141] Yamada, 'Gulf-Asia Relations as "Post-Rentier" Diversification?'
[142] Ahmed Ghaithan et al., 'Impact of Industry 4.0 and Lean Manufacturing on the Sustainability Performance of Plastic and Petrochemical Organizations in Saudi Arabia', *Sustainability* 13, no. 20 (13 October 2021): 11252, https://doi.org/10.3390/su132011252.
[143] D. Saygin et al., 'Potential of Best Practice Technology to Improve Energy Efficiency in the Global Chemical and Petrochemical Sector', *Energy* 36, no. 9 (September 2011): 5779–90, https://doi.org/10.1016/j.energy.2011.05.019.
[144] Rahman et al., 'Greenhouse Gas Emissions in the Industrial Processes and Product Use Sector of Saudi Arabia—An Emerging Challenge'.

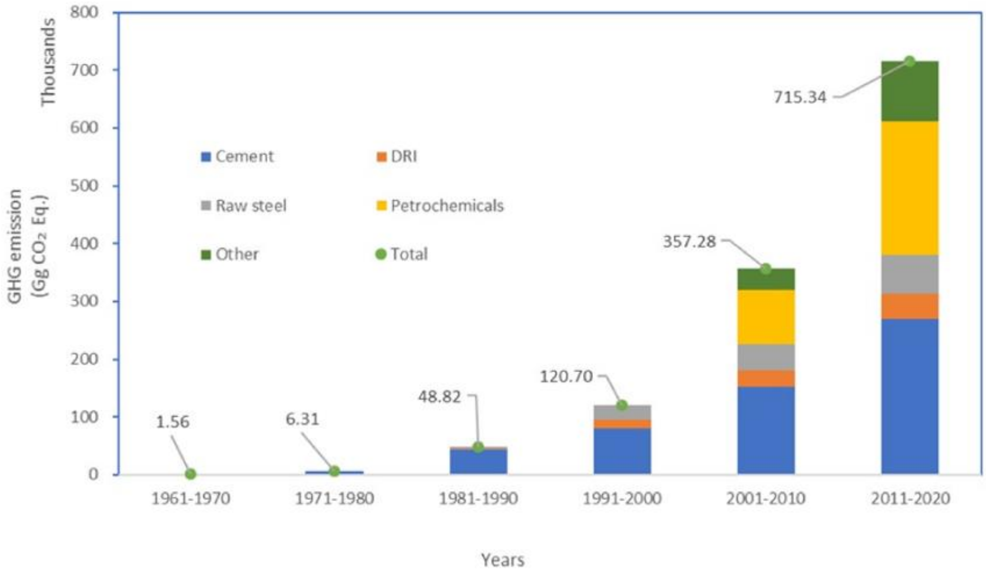


Figure 20: Overview GHGs from different industrial sectors in Saudi Arabia[145]

So far, environmental sustainability has not been a key concern of Saudi Arabia's plastic and petrochemical industries. However, the sectoral stakeholders and the political decisionmakers are well aware of its ecological responsibility and align them with the Kingdom's transition towards a low-carbon economy.[146] Even more important is the growing pressure that stricter national and international concerns on GHG emissions could lower the industrial growth. Mostly in line with the Kingdom's recent climate initiatives, such as the Saudi Vision 2030 and the Saudi Green Initiative[147], the petrochemical sector, and frontrunners such as SABIC in particular, have pushed forward climate change mitigation efforts.

[145] Rahman et al., 7.

[146] Ghaithan et al., 'Impact of Industry 4.0 and Lean Manufacturing on the Sustainability Performance of Plastic and Petrochemical Organizations in Saudi Arabia'.

[147] for an overview, see: Mohammad Asif Salam and Sami A. Khan, 'Transition towards Sustainable Energy Production: A Review of the Progress for Solar Energy in Saudi Arabia', *Energy Exploration & Exploitation* 36, no. 1 (2017): 3–27, https://doi.org/10.1177/0144598717737442; Mohammed A. Al Yousif, 'Renewable Energy Challenges and Opportunities in the Kingdom of Saudi Arabia', *International Journal of Economics and Finance* 12, no. 9 (30 July 2020): 1, https://doi.org/10.5539/ijef.v12n9p1; Tobias Zumbrägel, *Political Power and Environmental Sustainability in Gulf Monarchies* (Singapore: Palgrave Macmillan, 2022); Aisha Al-Sarihi and Noura Mansouri, 'Renewable Energy Development in the Gulf Cooperation Council Countries: Status, Barriers, and Policy Options', *Energies* 15, no. 5 (6 March 2022): 1923, https://doi.org/10.3390/en15051923; Mohammad Al-Saidi, 'Energy Transition in Saudi Arabia: Giant Leap or Necessary Adjustment for a Large Carbon Economy?', *Energy Reports* 8 (June 2022): 312–18, https://doi.org/10.1016/j.egyr.2022.01.015.

Accordingly, SABIC has announced in summer 2021 that all its operations will be carbon neutral by 2050.[148] In 2022, it published the SABIC's Carbon Neutrality Roadmap, which was developed by different segments of the company including the Energy Efficiency and Carbon Management (EECM) body, the Corporate Sustainability unit as well as representatives from all three Strategic Business Units (e.g. petrochemicals, agri-nutrients and specialties).

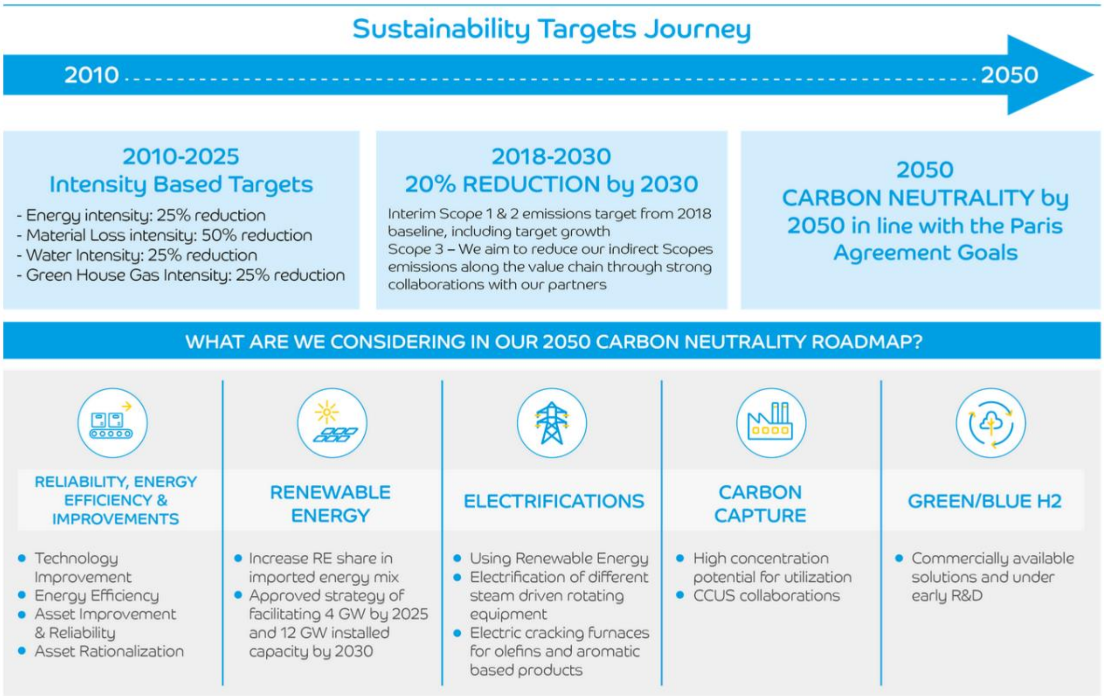


Figure 21: SABIC's Carbon Neutral Roadmap 2050[149]

Energy efficiency

Throughout the whole petrochemical industry´s value chain, several potential measures to save energy are being taken to reduce emissions. In terms of operation, Saudi Arabia has already put much attention in converting its gas-fired power plants and make it more efficient. Over the last two decades, many single-cycle gas turbines have been converted into combined-cycle plants, which generate more electricity by

148 SABIC, 'SABIC Annual Report 2021'.
149 SABIC, 2022, p. 28

extracting heat from exhaust gases and convert it into steam. Furthermore, steam power plants have been upgraded by using supercritical and more energy efficient boilers.[150]
More energy efficient processes are also required for desalination, which provide most of the water to the petrochemical industry as indispensable feedstock. Here, endeavors are in place to install more energy-efficient plants (e.g. using reverse osmosis) and expand the number of desalination plants run with renewable power. Alone in 2020, Saudi Arabia unveiled five new large-scale desalination plants that all use the more energy-efficient reverse osmosis technology.[151]
By introducing key projects and initiatives, Saudi Arabia's petrochemical champion SABIC was also able to increase its energy intensity by 1% from 2020 to 2021 and reduce the overall energy consumption by 4.4.% from 2020 to 2021. According to the company, it has built the world's most energy efficient ethylene glycol plant. Additionally, energy optimization projects included adjustment to the medium pressure steam header pressure, a reconfiguration of boiler conductivity control parameters, improved monitoring systems and adjustment of specific key performance indicators.[152]

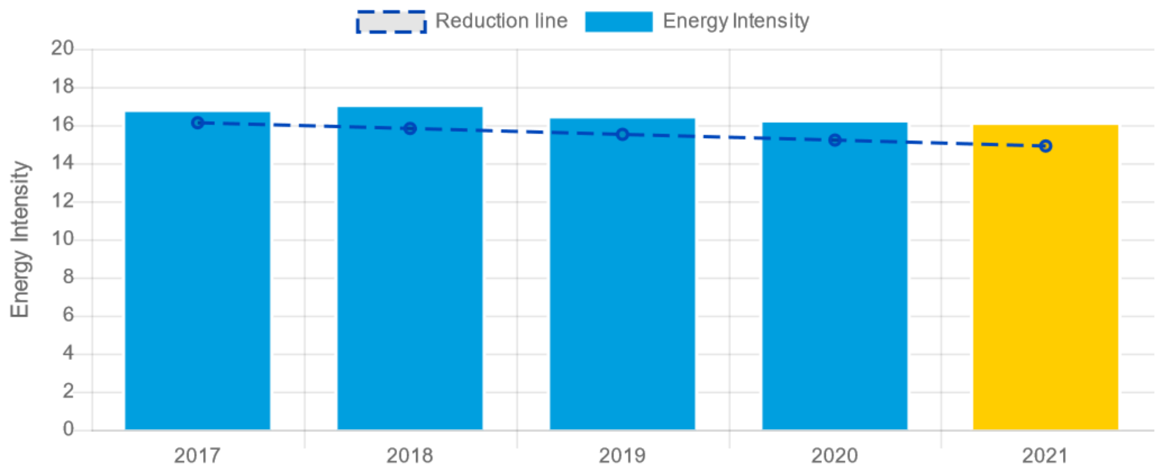
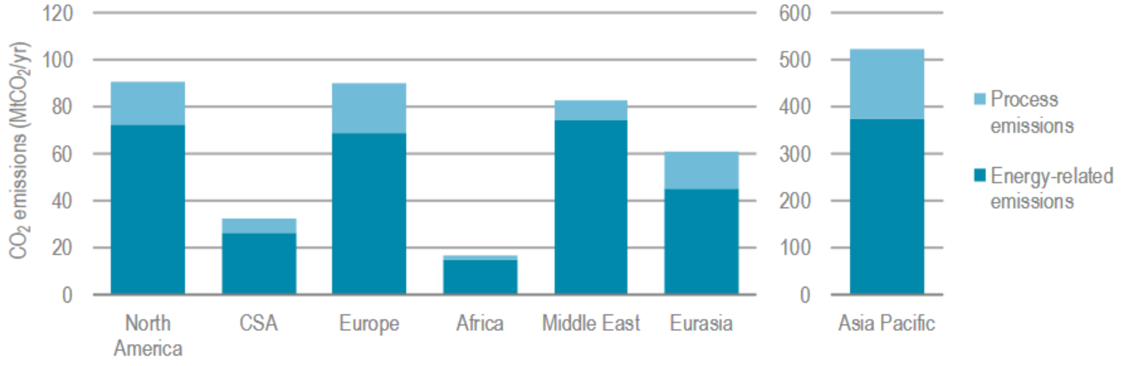


Figure 22: Overview SABIC's Energy Intensity(GJ7t/Product Sales)[153]

[150] Fattouh.
[151] ; see further: Saudi Water Partnership Company, https://www.swpc.sa/en/
[152] SABIC (2021), Sustainability Report 2021 – Energy. https://www.sabic.com/en/reports/sustainability-2021/energy-efficiency/energy
[153] Ibid.

Emission efficiency and decarbonization

While the Saudi government is gradually turning to renewable energy sources (mainly solar and wind – see chapter 3) and attempts to electrify major industrial processes, it is imperative that the petrochemical sector also assesses options of electricity production, in which conventional emission-intensive power sources of gas and oil can be replaced. As mentioned, driving the petrochemical sector's processes, equipment and facilities releases large amounts of CO_2 equivalents. Most of the carbon emissions are created as by-products of the processed feedstock whereas the actual production contributes comparatively little to the negative CO_2 balance.



Note: CSA = Central and South America.

Figure 23: Direct CO2 emissions by primary chemicals by region in 2017[154]

In light of decarbonization, switching from fossil energy as combustion fuel to renewable energy sources such as wind and solar energy can significantly help to achieve low-carbon targets. The electrification of the chemical industry in terms of providing direct heat, steam and power could not only reduce the carbon footprint but also offer "more flexible and compact solutions for heat generation".[155]

Accordingly, SABIC's Carbon Neutral Roadmap also calls for including renewable energy sources into their energy mix. It is planned to secure 4 GW of renewable capacities by 2025 and 12 GW by 2030. One example includes the construction of a polycarbonate plant, which will be fully powered by renewable electricity. It will be based at its facility in Cartagena (Spain) and ready to operate by the end of 2023.[156]

[154] IEA.

[155] L. Mosca et al., 'Hydrogen in Chemical and Petrochemical Industry', in *Current Trends and Future Developments on (Bio-) Membranes* (Elsevier, 2020), 408, https://doi.org/10.1016/B978-0-12-817384-8.00017-0.

[156] SABIC (2021) Sustainability Report 2021 – Our approach and performance https://www.sabic.com/en/reports/sustainability-2021/energy-efficiency/our-approach

Already now, several of SABIC's buildings are powered by small-scale solar installations. In so doing, the company has equipped its facilities in China, Thailand, and the Netherlands with rooftop photovoltaic systems.[157] In January 2022, it has also started supplying 300 gigawatt hours wind power to its site in Geleen, Netherlands.[158] Most recently, in cooperation with Solarge from the Netherlands, SABIC was able to showcase the development of lightweight, circular photovoltaic (PV) panels, which are more energy efficient and have a lower ecological footprint as current glass PV panels.[159] Furthermore, SABIC has signed an MoU with the recently announced NEOM initiative to establish a chemistry hub with the task of identifying potential usage of green energy.[160] Also in 2021, it collaborated with European chemical industrial companies BASF and Linde to develop an electrically powered steam cracker technology aiming at reducing about 90% of carbon emissions.[161] In addition to greening the feedstock, throughout the operation phase, SABIC has also ambitious targets to cut emissions through carbon sequestration. In light of its vision of a Circular Carbon Economy, the company works towards reusing and removing its carbon emissions. As the first of its kind in the Middle East, one of SABIC's joint venture initiatives, namely the National Methanol Company (Ibn Sina), in which SABIC collaborates with Celanese and Duke Energy, it has created a method to produce certified circular methanol from captured and purified CO_2.[162] Instead of being released into the atmosphere, the carbon-containing gases are reused and add value to the supply chain. At the same time, SABIC seeks to find ways to remove carbon emissions, which are inescapable. The company oversees the world's largest carbon dioxide capture and purification plant at its chemical complex in Jubail. The facility that produces ethylene glycol is able to capture 500,000 metric tons (MT) of CO_2 per year.[163] Meanwhile, Saudi Aramco, the biggest shareholder of SABIC, has established a gas plant

[157] SABIC (2021) Sustainability Report 2021 – greenhouse gas. https://www.sabic.com/en/reports/sustainability-2021/energy-efficiency/greenhouse-gas
[158] SABIC (January 2023) Sabic reaffirms commitment to the circular carbon economy with a target of one million metric tons of trucircle Solutions annually by 2030. https://sabic.com/en/news/38517-sabic-reaffirms-commitment-to-the-circular-carbon-economy-with-a-target-of-one-million-metric-tons-of-trucircle-solutions-annually-by-2030
[159] Saudi Gulf Projects (2023): SABIC, Solarge announces the successful development of Photovoltaic (PV) Panels, https://www.saudigulfprojects.com/2023/05/sabic-solarge-announces-the-successful-development-of-photovoltaic-pv-panels/.
[160] SABIC, Annual Report 2021 – future plans and investment. https://www.sabic.com/en/reports/annual-2021/strategic-report/future-plans-and-investment
[161] SABIC, 'SABIC Annual Report 2021'.
[162] SABIC (January 2022) SABIC'S affiliate becomes first Mideast company to get certification for circular methanol production. https://www.sabic.com/en/news/31835-sabics-affiliate-becomes-first-mideast-company-to-get-certification-for-circular-methanol-production
[163] SABIC (n.d.) Creating the world's largest carbon capture and utilization plant https://www.sabic.com/en/newsandmedia/stories/our-world/creating-the-worlds-largest-carbon-capture-and-utilization-plant

at Al Hawiyah that reinjects CO_2 into oil reservoirs for enhanced oil recovery (EOR)[164]. At the end of the value chain, there are also possibilities to reduce emissions: In terms of transportation, monitoring and when necessary fixing leaks at the pipeline system is a crucial element to avoid emissions. SABIC has also created a specific form of foamed pipe insulation that offers protection against pipe fractures while also saving energy. As the previously launched Maersk Integrated Logistics Hub at King Abdullah Port has announced, through more efficient and speedier transportation systems, it is able to safe up to 27% emissions.[165]

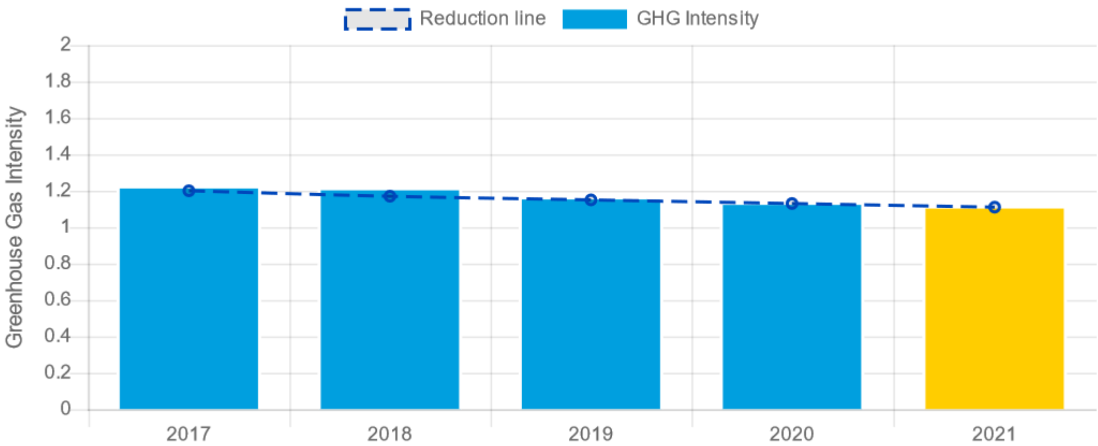


Figure 24: SABIC's Greenhouse Gas Intensity (t CO2 eq/t Product Sales)[166]

Materials and service efficiency

Many petrochemical materials are needed within the energy transition. For instance, transmission lines of wind parks require around 81% of plastic.[167] Oil-derivatives are required for coating purposes and cabling-BoS elements require it for insulation purposes and fire protection. Oil-derivatives offer superior weather-resistance, temperature protection, and strength when compared to other materials. The insulation oil also acts as a buffer in electricity transport and provides heat dissipation.

At the same time, solar PV requires petrochemical materials as well. More than 90% of the components include mono-crystalline silicon and poly-crystalline silicon. Other elements include the PV's solar film. Plastic is used within PV systems for a variety of reasons. It is often used as a protective layer to cover

[164] Al-Saidi, 'Energy Transition in Saudi Arabia'.
[165] Gulf Petrochemical and Chemical Association, 'Sustainability: The New Imperative'.
[166] SABIC (2021) Sustainability Report 2021 – Greenhouse Gas. https://www.sabic.com/en/reports/sustainability-2021/energy-efficiency/greenhouse-gas; the yellow colour depicts the targeted aim.
[167] Kramarz, T. et all. (2021): Governing the dark side of renewable energy: A typology of global displacements, Energy Research & Social Science 74, 2.

and protect exposed electronic components. It also provides a low-cost way to cover connecting wiring, while also preventing the intrusion of dust and debris. Plastic can also help the system to be waterproof and perform in corrosive atmospheres. In addition, plastic helps to reduce any interference from outside sources as well as improve the overall system performance.

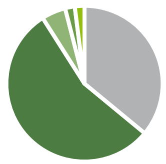


Figure 25: Solar PV technology by global market share[168]

Lately, it was announced that scholars from KAUST have been able to produce more efficient solar cells to conventional ones. Concretely, the perovskite-silicon solar cell achieves a power conversion efficiency of 33.2% making it "the most efficient two-junction solar cell technology under standard illumination conditions".[169]

Until today, there is the widespread disposal practices of incineration and landfilling of post-consumer plastic waste although there is great potential for recycling polymers and plastics. It would decrease feedstock demand as the required raw materials are reused while also leading to energy savings [170]. Dematerialization and growing usage of recycled-products are also key issues in Saudi Arabia's petrochemical sector although the development is still in its infancy. One notable exception includes SABIC's TRUCIRCLE initiative that aims at accelerating efforts towards advanced recycling solutions.[171]

The COVID-19 pandemic and global travel restrictions have also revealed the potential of improving service efficiency and lower the carbon footprint. Less travel activities, remote working opportunities and advanced technological communication systems can remove unnecessary consumption or products, and industrial emissions be reduced. Looking at the Saudi petrochemical sector, one must admit that aspects

[168] Ibid.
[169] Bellini, E. (2023): KAUST claims 33.2% efficiency for perovskite/silicon tandem solar cell, PV Magazine, URL: https://www.pv-magazine.com/2023/04/13/kaust-claims-33-2-efficiency-for-perovskite-silicon-tandem-solar-cell/.
[170] Saygin et al., 'Potential of Best Practice Technology to Improve Energy Efficiency in the Global Chemical and Petrochemical Sector'.
[171] SABIC (n.d.) Trucircle Portfolio and Services, https://www.sabic.com/en/sustainability/circular-economy/trucircle-portfolio-and-services

of material and service efficiency appears lagging behind. Using SABIC as the prime example again, the company announced a decrease of material loss by around 2% from 2020, which, however, was rather a result of a decrease in external sales.[172]

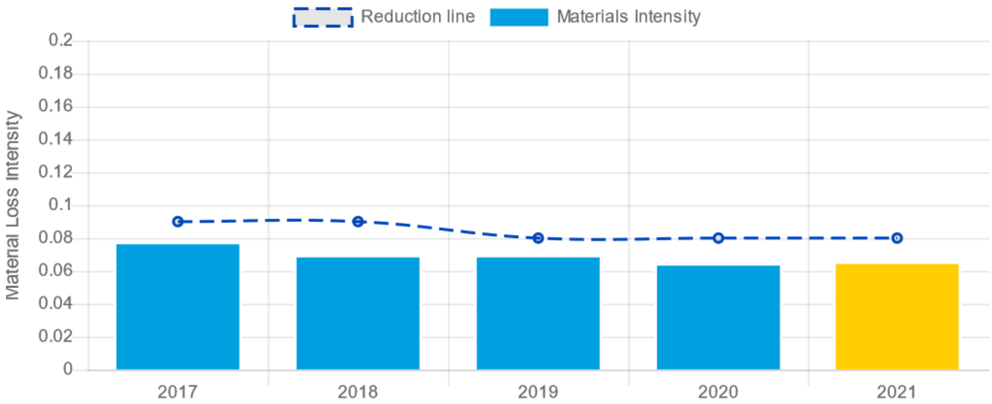


Figure 26: SABIC's Material Loss Intensity (t/t Product Sales) [173]

4.4. The Future of Petrochemicals

Given the various promising opportunities, it can be expected that Saudi Arabia's petrochemical industry will experience growth in the medium to long-term.[174] It can be assumed that the Saudi petrochemical's days of "cheap ethane and producing basic petrochemicals" are counted.[175] Instead, Saudi petrochemicals have to continue their process of upgrading and refining to a higher grade their value chain, moving towards more specialty products as already initiated over the last years. Here oil industry giants such as Saudi Aramco have already announced plans to expand the downstream investments and expand refining and petrochemical facilities.[176] Investing in new technologies for production and carbon sequestration are

[172] SABIC (2021) Sustainability Report 2021 – Material loss. https://www.sabic.com/en/reports/sustainability-2021/energy-efficiency/material-loss
[173] SABIC (2021) Sustainability Report 2021 – Greenhouse Gas. https://www.sabic.com/en/reports/sustainability-2021/energy-efficiency/greenhouse-gas; the yellow colour depicts the targeted aim.

[174] Oxford Business Group (2022): Demand for hydrocarbons, minerals and petrochemicals driving Saudi Arabia's economic growth, https://oxfordbusinessgroup.com/reports/saudi-arabia/2022-report/industry/tapping-potential-increased-global-demand-for-hydrocarbons-petrochemicals-and-minerals-is-driving-growth-and-transformation/.
[175] Fattouh, 'Saudi Oil Policy: Continuity and Change in the Era of the Energy Transition', 14.
[176] IEA, 'The Future of Petrochemicals Towards a More Sustainable Chemical Industry', 2018.

crucial steps. Furthermore, developing strategies and solutions for re-usage and recycling will have a significant role to play in the future of petrochemicals. The latter is not confined to technology and innovation but also includes the provision of more accessibility to facilities and better education to promote sectoral nationalization efforts and awareness campaigns for citizens to recycle more. At the same time, SABIC explores options of producing green hydrogen. According to the company's official website, a proposal for installing a small electrolysis unit is under a feasibility evaluation.[177]

The SWOT-Analysis indicates that there are various aspects that put the petrochemical industry in an advantageous position over others. For instance, the production of polymers is likely to increase as it is needed in the hydrogen sector, in the construction of polymer electrolyte membrane (PEM) electrolysers. SABIC's announcement to construct the world's first "commercial unit to produce certified circular polymers from the advanced recycling of used plastics" can be seen as a promising step if the company is able to advance this technology.[178] The same can be said for the production of methanol, the production of which has rather been on a constant level over the last years. With the increasing demand of hydrogen worldwide, the production levels for methanol are also expected to rise. So far, it plays a key role in the production of hydrogen, as it is the key component used to produce hydrogen gas through a process known as steam methane reforming. So far, this process unleashes large amounts of greenhouse gas emissions. With improved technologies of carbon sequestration (for instance, CCUS), the process of steam methane reforming (SMR) can become low-carbon. As chapter six on the hydrogen economy will show, ammonia is perceived as a promising carrier. Here, Saudi Arabia's fertilizer industry is in an advanced position. Having said that, there are also multiple challenges. Most of them are concerned with aspects of environmental sustainability that could hamper industrial growth. In this regard, it is imperative to seek for more sustainable solutions. The sector's integration into the hydrogen development appears to be a promising pathway as the following chapter examines.

[177] SABIC (2021) Sustainability Report 2021 – our approach and performance. https://www.sabic.com/en/reports/sustainability-2021/energy-efficiency/our-approach

[178] Arab News (January 2023), SABIC pledges to process 1M metric tons trhough circular plastic initiative by 2030, https://www.arabnews.com/node/2235331/business-economy

Info box 1: Turquoise hydrogen and the future petrochemical industry

Another way to produce clean hydrogen is through a specific process known as 'methane pyrolysis' (turquoise hydrogen). Here, in the absence of oxygen, natural gas, and methane in particular, is heated to high temperatures. The result is hydrogen and solid carbon as a byproduct. It is carbon-neutral as no carbon dioxide is produced during the process. At the same time, carbon black as one product of methane pyrolysis can be used for a variety of production processes in the petrochemical industry including plastics, industrial rubber, tires, inks/toners, caotings or paints.

Strengths	Weaknesses	Opportunities	Threats
Cutting-edge technology	Dominance by state-owned industrial leader SABIC and its various affiliates	Governmental support	Environmental contamination and associated penalties/fines on GHGs emissions
Feedstock advantage	Human resources system	Increasing demand from Asia, notably China.	Protective measures imposed in key end-markets, including China and India
Strategic marketing alliances with leading international companies	Policy coordination and evaluation	Educational reforms to promote Saudization and develop local expertise	Significant supply build-up in China
Excellent geographical location and industrial and logistics infrastructure	Innovation management (e.g. recycling)	Influx of international expertise and investments in light of ongoing economic and energy diversification	Loss of value of hydrocarbons
Growing derivatives production capacity	High carbon footprint		Growing water stress
Outstanding expertise of SABIC in the national and international petrochemical sector			

Acceptance of the sector among wide parts of the population			

Table 9: SWOT-Analysis of the petrochemical sector in Saudi Arabia

In conclusion, Saudi Arabia's petrochemical sector has played a pivotal role in the country's economy, marked by its long-standing tradition and status as the second most important sector after conventional hydrocarbons. Key factors contributing to its success include access to competitively priced feedstock and energy resources, technological advancements, and effective marketing capabilities. The sector's diversification efforts have resulted in a wide range of final products, supported by strategic locations and a robust infrastructure. Together with a streamlined governance structures, technological development, human resource management and large investments, it all has propelled the industry's growth. Geographically, the sector's positioning between Jubail and Yanbu, along with extensive infrastructure, has facilitated its growth and access to emerging markets like China and India. The petrochemical sector aligns with Saudi Arabia's climate initiatives, such as the Saudi Vision 2030 and the Saudi Green Initiative, with commitments to carbon neutrality by 2050 and investment in new technologies for production and carbon sequestration. Efforts toward energy efficiency, including the conversion of gas-fired power plants to combined-cycle plants, are notable. Additionally, there is a focus on emissions reduction and decarbonization, with plans to incorporate renewable energy sources and carbon sequestration. In light of these promising developments and commitments, Saudi Arabia's petrochemical industry is poised for growth, with a potential key role for the country's plans towards a hydrogen economy.

5. Saudi Arabia's Mining Sector

5.1 Overview

In "Vision 2030", Saudi Arabia stated its strong interest in drastically developing its mining sector to make it the third pillar of the economy, in an effort to diversify its industrial basis beyond oil and petrochemical production. The energy minister shared in March 2018 that the country has strong interest in increasing revenues from mining while also creating more jobs by 2030.[179] As of 2018, mining accounted for 7% of public investment in Saudi Arabian companies.[180] Since 2016, there have been several key developments:

Date issued	Development	Purpose
2017	Mining Investment Code	Granting mining rights to corporations, individuals, and other personnel with financial/ technical expertise and competence[181]
Oct 2019	Long-term global mining strategy	Creates concrete strategy while integrating sustainability[182]
June 2020	New Mining Law	Attracting new investment, especially foreign[183]

Table 10: Key legislative developments in mining in Saudi Arabia

[179] El Yaakoubi, Aziz. "Saudi Arabia to Auction up to Three Mining Licences in 2022 - Minister." Reuters. January 12, 2022. Accessed March 2, 2023. https://www.reuters.com/world/middle-east/saudi-arabia-auction-up-three-mining-licences-2022-minister-2022-01-12/; U.S. Department of Commerce. "Saudi Arabia New Mining Law." Market Intelligence, International Trade Administration. Last modified June 29, 2020. Accessed March 2, 2023. https://www.trade.gov/market-intelligence/saudi-arabia-new-mining-law; U.S. Department of Commerce. "Saudi Arabia - Mining and Minerals." Export.gov. Last modified October 13, 2021. Accessed March 2, 2023. https://www.export.gov/apex/article2?id=Saudi-Arabia-Mining-and-Minerals.

[180] Grand, Stephen, and Katherine Wolff. "Assessing Saudi Vision 2030: A 2020 Review." In-Depth Research & Reports, June 17, 2020.

[181] USGS. 2019. "Saudi Arabia [Advance Release]." In Minerals Yearbook, vol. 3, pp. 53.1-53.12. U.S. Department of the Interior.

[182] "Saudi Mining Strategy in Spotlight at IMARC." Arab News, 4 Nov. 2019, https://www.arabnews.com/node/1579281/corporate-news.

[183] UNCTAD. "New Mining Law." Investment Policy Monitor, 9 June 2020, https://investmentpolicy.unctad.org/investment-policy-monitor/measures/3540/new-mining-law. Accessed 2 March 2023.

As of 2020, Saudi Ma'aden was the sole mining, majority state-owned, company in the Kingdom. However, this is to change since the New Mining Law of 2020 came into force, and more mining companies have emerged in the market.[184] On January 1st 2021, Saudi Arabia's administrative regulations on mining investments went into effect. These were implemented to enhance governance in mining investment, dispute settlements, and licensing procedures. With an exploitation license, the licensee can export processed minerals for commercial purposes. There is an export limit of 30% of annual production capacity and exporters must pay 10% of the net sales, which is subject to change at any given time according to the minister or his delegates.[185] Saudi Arabia is also developing infrastructure to support the mining sector. For example, a $6 billion investment was made for an electric vehicle battery metals plant and a steel plate mill complex.[186] Other projects under consideration include new steel plate mill complexes, "green" flat steel complexes, and another EV battery metals plant.

5.2. The mining sector's supply and value chain

Input-output Structure

One of the primary inputs is electricity. While Saudi Arabia has been developing renewable energy in recent years, electricity generation is still fossil-based. Saudi Arabia aims to make mining a sector that can be long-term and cost-effective. The country has a range of mineral resources such as gold, copper, and phosphates that have allowed it to produce a range of products. Heavy investment in infrastructure in Saudi Arabia is set to lay the foundation for the mining sector. Mining is overseen by the Ministry of Industry and Mineral Resources, making logistics for mining products seamless. Minerals can be efficiently transported from mining sites to processing facilities and traded to markets all over the world.

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[184] Reuters Staff. "Saudi Arabia Aims to Boost Investment with New Mining Law." Reuters, June 10, 2020. Accessed March 13, 2023. https://www.reuters.com/article/saudi-mining-law/saudi-arabia-aims-to-boost-investment-with-new-mining-law-idUSL8N2DO5Y5.
[185] Arab News. "Saudi Arabia approves new mining law to boost investment." Arab News, June 10, 2020. Accessed March 2, 2023. https://www.arabnews.com/node/1786501/business-economy.
[186] Saba, Yousef. "Saudi Arabia announces $6 billion investments in steel complex, EV metals plant." Reuters, 6 May 2022. https://www.reuters.com/business/saudi-arabia-announces-6-bln-investments-steel-complex-ev-metals-plant-2022-05-06/.

Figure 27: Growth in Mining Production in Saudi Arabia (Monthly Change)[187]

The most profitable and mature mining product is gold. Gold production has increased since the announcement of Vision 2030, and 12.35 thousand kilograms were produced in 2019.[188] The underground gold reserves are estimated at 323.7 tons.[189] From the same mine, Ma'aden also extracts 4,000 tons of zinc, 900 tons of copper, and 280,000 oz of silver annually. In total, the annual output of Ma'aden includes approximately 2,600 tons of zinc and 1,000 tons of copper.[190] Looking forward, phosphate is considered the most promising mineral: The Saudi Geological Survey assumes that Saudi Arabia has the potential to become one of the top 5 global producers of phosphate. Ma'aden currently extracts about 11.6 million tons annually.[191]

187 Trading Economics. (n.d.). Saudi Arabia Mining Production. Retrieved from https://tradingeconomics.com/saudi-arabia/mining-production
188 Leaders Magazine, "Saudi gold production jumps 143% since 2030 Vision." Leaders. July 9, 2020. Accessed July 18, 2023. https://www.leaders-mena.com/?p=6333

189 Kane, Frank. "Saudi Arabia's largest gold mine to begin operations Q1 2022 - Ma'aden CEO." Arab News. January 11, 2022. Accessed July 18, 2023. https://www.arabnews.com/node/1957626/business-economy

190 Leach, Adam. "Feature: A Kingdom of Riches: Saudi Arabia Looks to Strike it Rich with Mining Sector." Mining Technology. August 22, 2014. Accessed March 6, 2023. https://www.mining-technology.com/features/feature-a-kingdom-of-riches-saudi-arabia-looks-to-strike-it-rich-with-mining-sector-4382267/.
191 Leach, Adam. "Feature: A Kingdom of Riches: Saudi Arabia Looks to Strike it Rich with Mining Sector." Mining Technology. August 22, 2014. Accessed March 6, 2023. https://www.mining-technology.com/features/feature-a-kingdom-of-riches-saudi-arabia-looks-to-strike-it-rich-with-mining-sector-4382267/.

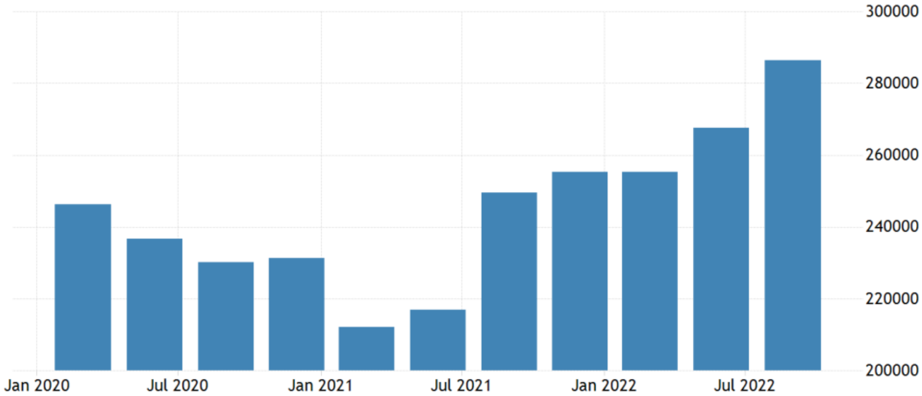

Figure 28: GDP from Mining in Saudi Arabia[192]

The country intends to decrease imports and increase exports of minerals. The following figure shows fluctuation in export for copper, gold, zinc, and nickel. It is interesting to note here that the top producing projects are mostly owned by Ma'aden, with the exception of copper, in which the most producing project is jointly owned by Ma'aden and Barrick of Canada.[193]

[192] Trading Economics. (n.d.). Saudi Arabia GDP from Mining. Retrieved from https://tradingeconomics.com/saudi-arabia/gdp-from-mining
[193] "Kingdom of Saudi Arabia Exploration Licensing Round of Umm Ad Damar Cu/Au (Ag/Zn) and Muhaddad Cu/Zn (Pb) Mineral Exploration Investment Opportunities - 2022." Ministry of Industry and Mineral Resources, 2022.

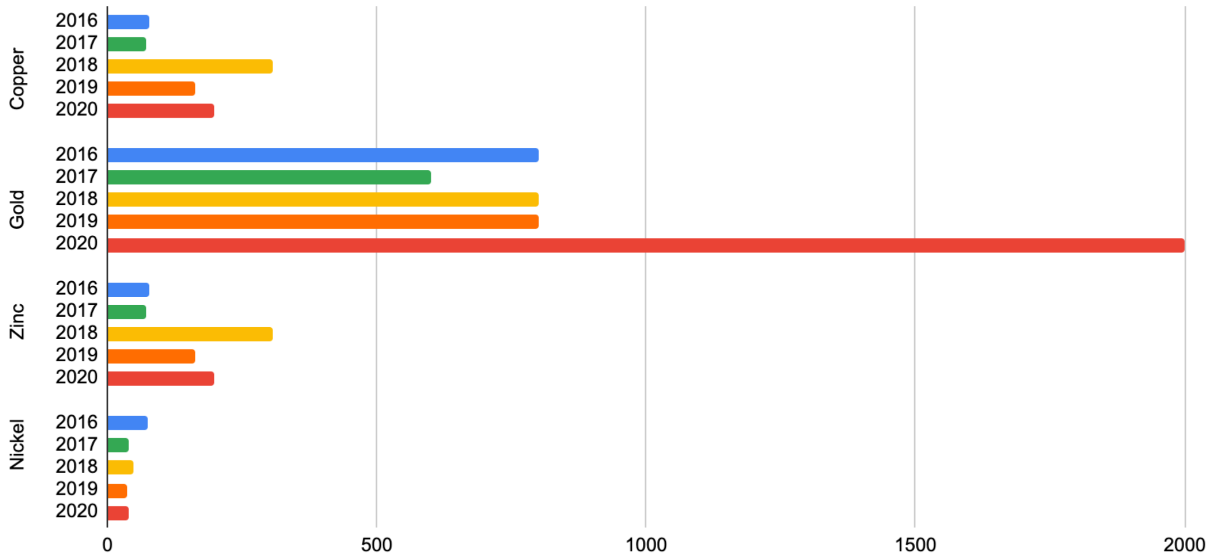

Figure 29: Copper, Gold, Zinc and Nickel exports (in million USD) [194]

Additionally, it is interesting to note that Saudi Arabia is active also in upstream stages of copper and zinc value chain. Most saleable products of copper and zinc can be produced domestically.[195]

Government structure: Lead Firms & Industry Organization and National policies

Despite growing efforts to privatize the mining sector as part of the overarching privatization strategy,[196] the dominant key players are government-run.[197] The following figure shows the governance structure centralized under the Minister of Finance, in which the key players cooperate to develop mining.

[194] "Kingdom of Saudi Arabia Exploration Licensing Round of Umm Ad Damar Cu/Au (Ag/Zn) and Muhaddad Cu/Zn (Pb) Mineral Exploration Investment Opportunities - 2022." Ministry of Industry and Mineral Resources, 2022.

[195] "Kingdom of Saudi Arabia Exploration Licensing Round of Umm Ad Damar Cu/Au (Ag/Zn) and Muhaddad Cu/Zn (Pb) Mineral Exploration Investment Opportunities - 2022." Ministry of Industry and Mineral Resources, 2022.

[196] Zenger News. "Saudi Arabia Looks to Mining as Way to Diversify Its Economy." Forbes, January 3, 2023. Accessed March 1, 2023. https://www.forbes.com/sites/zengernews/2023/01/03/saudi-arabia-looks-to-mining-as-way-to-diversify-its-economy/?sh=752bf6f45eaa.

[197] "Saudi Mining Strategy in Spotlight at IMARC." Arab News, 4 Nov. 2019, https://www.arabnews.com/node/1579281/corporate-news.

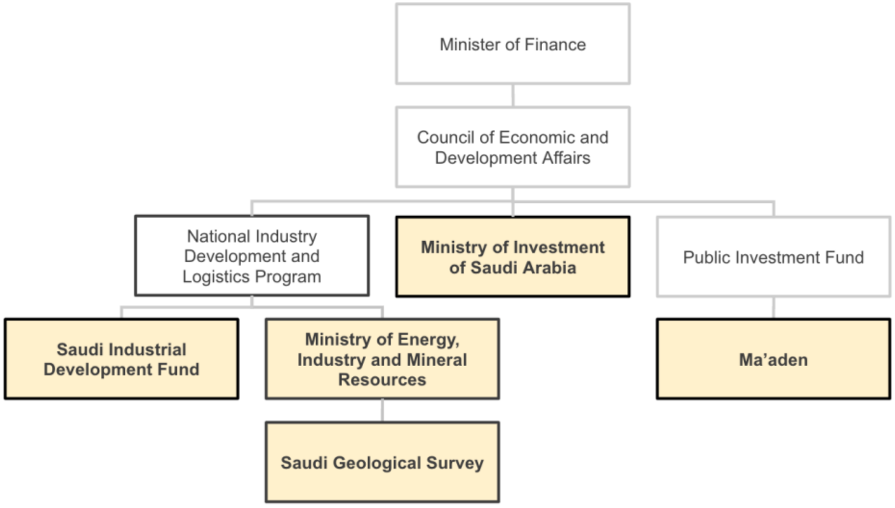

Figure 30: Governance Structure of Key Players in the Mining Industry[198]

First, the (former) Ministry of Energy, Industry and Mineral Resources, part of the National Industrial Development and Logistics Program, developed the Saudi Geological Survey Program in 2020. This was initiated to gather data to act as a foundation for the development of Saudi Arabia's mining sector.[199] The Saudi Arabian General Investment Authority (SAGIA) is in charge of increasing investment in the mining sector, and puts emphasis on gaining foreign investment.[200] Additionally, the Saudi Industrial Development Fund, according to Saudi Vision 2030, has become a key player in funding the National Industry Development and Logistics Program.[201] Established by royal decree in 1997, Ma'aden was entirely owned by the Kingdom until 2008 when 50% of its shares were floated on the Saudi Stock Exchange. In June 2018, however, PIF acquired more shares and the government's ownership increased to 65.44%. Now, it

[198] Ma'aden, "History," accessed April 14, 2023, https://www.maaden.com.sa/en/about/history.; Saudi Arabia. Vision 2030. "National Industrial Development and Logistics Program (NIDLP)." Accessed April 14, 2023. https://www.vision2030.gov.sa/v2030/vrps/nidlp/.; U.S. Department of State. "2022 Investment Climate Statements: Saudi Arabia." Accessed April 14, 2023. https://www.state.gov/reports/2022-investment-climate-statements/saudi-arabia/.; "Board of Directors," Saudi Industrial Development Fund, accessed April 24, 2023, https://www.sidf.gov.sa/en/AboutSIDF/Pages/Board%20Of%20Directors.aspx.
[199] Saudi Press Agency. (2020, October 18). Saudi Arabia Launches Its Massive regional Geological Survey Program in Collarboration with World-Renound Partners. Retrieved from https://www.spa.gov.sa/viewstory.php?lang=en&newsid=2145869
[200] TradeArabia News Service. "Saudi Arabia offers many investment opportunities." TradeArabia, 7 Apr. 2019, http://www.tradearabia.com/news/IND_353167.html.
[201] Oxford Business Group. "Industrial funding increased and extended to mining sector in Saudi Arabia." Oxford Business Group, 27 January 2020, https://oxfordbusinessgroup.com/news/industrial-funding-increased-and-extended-mining-sector-saudi-arabia.

has extended activities beyond sole gold mining to include aluminum, copper concentrate, industrial minerals, and phosphate.[202] It discloses that the PIF is actively involved in the decision-making of regulations in mining.[203] The Ministry of Industry and Mineral Resources, responsible for developing the mining industry, is part of the National Industrial Development Logistics Program to realize the goals cited in Vision 2030:[204]

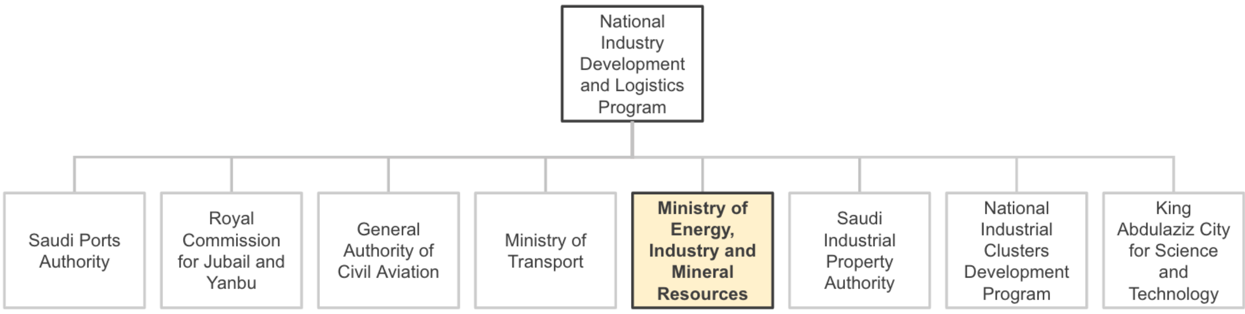

Figure 31: Governance Structure of the Ministry of Industry and Mineral Resources

The Ministry of Industry and Mineral Resources, headed by H.E. Eng Sama Abdulaziz Al-Zamil,[205] is responsible for license issuance and renewal, permitting and easements, compliance and enforcement, and reporting and registrations. Additionally, the Ministry is largely responsible for Ma'aden's operations.[206] According to ZoomInfo, the top 10 metals and mining companies in Saudi Arabia by revenue as of March 2023 are as follows:[207]

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202 Ma'aden - About Us - History." Ma'aden. Accessed March 1, 2023. https://www.maaden.com.sa/en/about/history.
203 Ma'aden. (2021). Ma'aden Annual Report 2021. Retrieved from https://www.maaden.com.sa/download/Ma'aden%20Annual%20Report%202021.pdf
204 Grand, Stephen, and Katherine Wolff. "Assessing Saudi Vision 2030: A 2020 Review." In-Depth Research & Reports, June 17, 2020.
205 The National Industrial Development and Logistics Program. "About NIDLP." Vision 2030, Government of Saudi Arabia, 2021, https://www.vision2030.gov.sa/v2030/vrps/nidlp/.
206 Ministry of Industry and Mineral Resources. "Services." Ministry of Industry and Mineral Resources, Government of Saudi Arabia, 2021, https://mim.gov.sa/services?category=2.
207 ZoomInfo. "Top 10 Companies from Mining and Metals Industry in Saudi Arabia by Revenue." Accessed March 1, 2023. https://www.zoominfo.com/top-lists/top-10-companies-from-mm-industry-in-SA-by-revenue

Company name	Revenue ($)	Employees	Ownership
Saudi Arabian Mining Company (Ma'aden)	8.1B	5.8k	Government (65.44%)
Aluminum International Co	898.5M	2.3k	Closed Joint-stock
Rajhi Steel	564.4M	2.7k	Private
Arabian Geophysical and Surveying	394.6M	918	51% owned by Saudi Aramco's subsidiary
Saudi Geological Survey	326.4M	3.3k	Government
Mitwalli Steel Products	266.1M	894	NA
BEMCO Steel Industries	192.6M	925	NA
AL JAZIRAH	144.2M	709	NA
MAADANIYAH	115.7M	481	NA

Table 11: Overview of key mining companies[208]

Ma'den is by far the most important actor. Yet other players have emerged over the last years, among which many are government-owned. Therefore, while Saudi Arabian officials have announced plans to privatize, it is clear that government-owned entities account for the majority of the mining output. Ma'aden, the longest-operating and largest producing company, is supported by other public services such as the Saudi Geological Survey. Ma'aden also has global and regional partners as seen in the figure below:

[208] Alinco. "About Us." Accessed March 15, 2023. https://alinco.com.sa/about-us/.; Rajihi Steel. "Home." Accessed March 15, 2023. https://www.rajhisteel.com/english/pages/default.aspx.; ARGAS. "Profile." Accessed March 15, 2023. https://www.argas.com/profile/

Company	Headquarters	Project
Alcoa	USA	Fully Integrated High-Efficiency Aluminium Production Complex located in Ras Al Khair Industrial City in the Eastern Province of Saudi Arabia. The Complex includes a Bauxite Mine, a Refinery, a Smelter, and a Casthouse.
Mosaic	USA	Ma'aden Wa'ad Al Shamal Fertilizer Production Complex is located in Wa'ad Al Shamal Minerals Industrial City, in the Northern Province of Saudi Arabia. This Complex extracts phosphate from the north of Saudi Arabia to develop it into fertilizer products for global agriculture customers.
Barrick Gold Corporation	Canada	Joint Venture Partners in the Jabal Sayid underground Copper Mine and Plant in Saudi Arabia.
SABIC	Saudi Arabia	Joint Venture Partners in a $5.6 billion in the Ma'aden's Integrated Fertilizer Production Complex located in Ras Al Khair Industrial City in the Eastern Province of Saudi Arabia. Joint Venture Partners in a USD 8 billion investment in the Ma'aden Wa'ad Al Shamal Fertilizer Production Complex located in Wa'ad Al Shamal Minerals Industrial City, in the Northern Province of Saudi Arabia.
Sahara Petrochemicals Company	Saudi Arabia	Joint Venture Partners in a USD 750 Million in the Caustic Soda & Ethylene DiChloride Production Complex in Jubail Industrial City in the Eastern Province of Saudi Arabia.

Table 12: Overview of Ma'aden's global partnerships[209]

[209] Ma'aden. "About Partnerships." Ma'aden, n.d., https://www.maaden.com.sa/en/about/saf.

Geographic Scope and Infrastructure

In recent years, Saudi Arabia has demonstrated significant advancements in enhancing the efficiency of its mining sector, leading to a notable increase in mining production. These developments have been aligned with the goals set out in Vision 2030, launched in 2016.[210] As part of this vision, Saudi Arabia has embarked on the Geological Survey Program, which has a comprehensive mandate to explore mining prospects across the entire Arabian Shield region. The Kingdom has committed to achieving the substantial milestone of completing 50% of this survey by the year 2035.[211]
Significant mines are located mainly within the Arabian Shield, as shown in figure 31.[212]

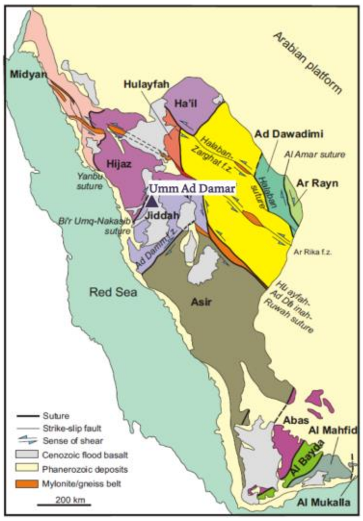

Figure 32: Map of the Arabian Shield[213]

[210] Leaders Magazine, "Saudi gold production jumps 143% since 2030 Vision." Leaders. July 9, 2020. Accessed July 18, 2023. https://www.leaders-mena.com/?p=6333

[211] The National Industrial Development and Logistics Program. "About NIDL." Vision 2030, Government of Saudi Arabia, 2021, https://www.vision2030.gov.sa/v2030/vrps/nidlp/.

[212] "The Diggings." The Diggings. Accessed March 3, 2023. https://thediggings.com/sau/states.
[213] "Kingdom of Saudi Arabia Exploration Licensing Round of Umm Ad Damar Cu/Au (Ag/Zn) and Muhaddad Cu/Zn (Pb) Mineral Exploration Investment Opportunities - 2022." Ministry of Industry and Mineral Resources, 2022.

Location	Total mines	Occurrences	Prospects	Plants	Producers	Top commodities
Medina	8	3	0	1	4	Copper, gold, silver, zinc, magnesite, uranium
Riyadh	5	0	3	0	2	Gold, silver, zinc, copper, lead, iron
Tabuk	5	3	1		1	Lead, zinc, iron
Mecca	4	1	1	1	1	Gold, iron, titanium, pigment, tungsten
Najran	4	2	1		1	Copper, gold, iron, molybdemum, nickel, silver, sulfur, sulfur-pyrite, zinc
Hail	3	1		1	1	Gold, copper, lead, magnesite, silver, zinc
Al Quassim	2	1	1			Gold, silver, tin, tungsten, zinc
Al Bahah			1			Copper

Table 13: Overview of mining locations in Saudi Arabia[214]

Technical and Human Resource Development

Under Vision 2030, there are multiple initiatives such as the National Transformation Program and PIF that intend to develop technological infrastructure. Ma'aden published in its annual report piloting of new technologies to improve its mining operations. First, its Technology R&D and Innovation strategy is considered foundational to the company's 2040 strategy. It intends to leverage technology in the entire

[214] Ibid.

value chain. Piloted technologies in 2021 include the monitoring of biometrics of field workers, detection of irregularities in gold mines, and drones to survey mines.[215] As of 2021, the mining industry employs around 250,000 people[216], and it is set to increase to 470,000 jobs in 2030.[217] Further training is expected to reduce concerns about the lack of skilled labor in developing markets such as mining. In order to overcome the shortage of mining experts and promote nationalization efforts in this sector, governmental entities and companies such as Ma'aden are offering training courses and capacity development schemes for young mining professionals. However, further reforms in the educational curricula are needed to promote future job creation in the mining sector and increase the number of national experts. As a skilling effort, PIF has offered training for its employees by partnering with top international institutions such as Berkley, Harvard Business School, and London Business School.[218] Additionally, Ma'aden provides education in rural areas of the Kingdom.[219]

5.3. The mining sector and the energy transition

The mining sector is relevant for the energy transition as there is an increasing demand for strategic minerals in electronics for renewable and efficient products. The World Bank publishes that "production of minerals, such as graphite, lithium, and cobalt, could increase by nearly 500% by 2050, to meet the growing demand for clean energy technologies. It estimates that over 3 billion tons of minerals and metals will be needed to deploy wind, solar and geothermal power, as well as energy storage, required for achieving a below 2°C future."[220] As Europe takes a leading position in the global energy transition, the Middle East can be a partner to provide cost competitive supplies of raw materials. Saudi Arabia is an interesting partner for its development plans, experience in complex infrastructure projects, and low

[215] Ma'aden. (2021). Ma'aden Annual Report 2021. Retrieved from https://www.maaden.com.sa/download/Ma'aden%20Annual%20Report%202021.pdf
[216] Al Rawashdeh, Rami, and Gary Campbell. "Mineral policy in the Gulf Cooperation Council (GCC) countries: The case of Saudi Arabia." Resources Policy 77 (2022): 102424. doi:10.1016/j.resourpol.2021.102424.
[217] Al-Mudaifer, Khalid Saleh. "Mining: Building the Third Pillar of Industry in Saudi Arabia." Al Arabiya English, June 30, 2021, https://english.alarabiya.net/views/2021/06/30/Mining-Building-the-third-pillar-of-industry-in-Saudi-Arabia; The General Secretariat of the Executive Committee for the Realization of the Kingdom's Vision 2030. "Achievements." Vision 2030, Government of Saudi Arabia, 2021, https://www.vision2030.gov.sa/v2030/achievements/.
[218] "Public Investment Fund Program 2021-2025." Public Investment Fund, n.d. https://www.pif.gov.sa/en/Pages/VRP2021-2025.aspx.
[219] Ma'aden. (2021). Ma'aden Annual Report 2021. Retrieved from https://www.maaden.com.sa/download/Ma'aden%20Annual%20Report%202021.pdf
[220] World Bank, "Climate-Smart Mining: Minerals for Climate Action," last modified May 26, 2019, https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action.

barriers to enter the market.[221] The National Industrial Development and Logistics Program, responsible for realizing Saudi Arabia's potential in energy, mining, industry, and logistics, has 12 key objectives, 5 of which are relevant to mining:

1. Localize promising manufacturing industries
2. Grow and capture maximum value from the mining sector
3. Create and improve the performance of logistics hubs
4. Improve the local, regional, and international connectivity of trade and transport networks
5. Increase the local content in non-oil sectors

Thus far, they have achieved the following:[222] Launched the Geological Survey program to explore mining opportunities that cover the "Arab Shield", an area of more than 600,000 km^2

While the nature of the program requires a holistic approach when mining non-fuel materials, there is no clear policy on energy efficiency or decarbonization in the Vision. However, there has been progress: Applicants who intend to gain an exploration license must submit an environmental impact management plan and a social impact management plan. Environmental impact management plans must comply with the Kingdom's environmental laws and sustainability regulations. As for social impact management plans, applicants must commit to the employment of Saudi nationals and engage with local communities. Once the licenses are given, organizations must follow up on their endeavors through annual reports, which must include their environmental management plan and compliance status.[223]

Emission Efficiency

The emissions efficiency of mining contributes to the sustainability of the global energy transition. The carbon footprint of green energy technologies is directly affected by the carbon footprint of the mined materials used in the product. This is extremely important because the global energy transition, including

[221] Darryn Quayle. "Gulf Sits on Trove of Energy Transition Minerals." Meed, 9 Apr. 2021, https://www.meed.com/gulf-sits-on-trove-of-energy-transition-minerals.
[222] The National Industrial Development and Logistics Program. "About NIDL." Vision 2030, Government of Saudi Arabia, 2021, https://www.vision2030.gov.sa/v2030/vrps/nidlp/.
[223] "Kingdom of Saudi Arabia Exploration Licensing Round of Umm Ad Damar Cu/Au (Ag/Zn) and Muhaddad Cu/Zn (Pb) Mineral Exploration Investment Opportunities - 2022." Ministry of Industry and Mineral Resources, 2022.

the one highlighted in Saudi Vision 2030, requires intense demand for strategic minerals.[224] Devices such as electric vehicles and wind turbines need more minerals for production, as shown in the table below:

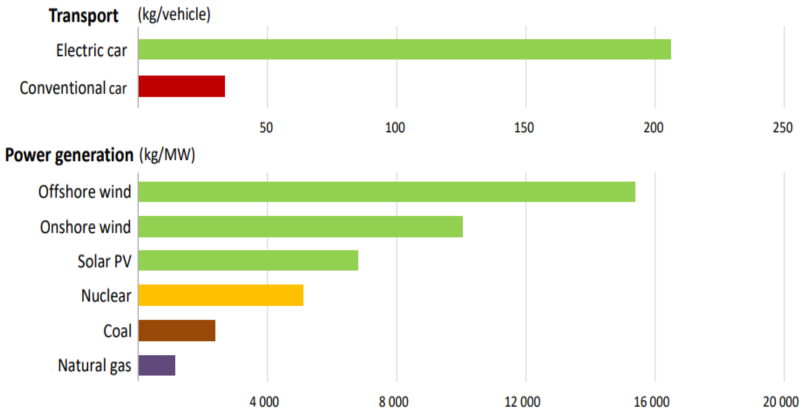

Figure 33: Minerals used in selected energy technologies[225]

If these products are mined in a carbon-intensive way, an electric car could result in having a higher carbon footprint than the lifetime of a conventional car, solely for its production. For example, the electric car Tesla Model 3 would become cleaner than the gasoline car Toyota Corolla only after it runs 13,500 miles. Until then, the Tesla Model 3 has a higher lifetime carbon footprint.[226] Saudi Arabia can harness its solar and wind power potential to make the mining sector less carbon intensive electricity is the main energy-driver of the mining sector.

Materials and resource efficiency

Alike petrochemicals, many minerals are needed within the energy transition. Particularly, minerals such as copper, zinc, lithium, cobalt, graphite, nickel, or manganese constitute important elements for the energy transition and experience a greater demand. The increase in demand has resulted in prices of

224 Saudi Press Agency. "Crown Prince Announces 'Saudi Green Initiative' and 'Green Middle East Initiative'". Saudi Press Agency, 27 March 2021, https://www.spa.gov.sa/viewfullstory.php?lang=en&newsid=2340161#2340161.
225 World Economic Forum. "This Is Why the Energy Transition Will Be Reliant on the Mining Industry." World Economic Forum, 19 May 2021, https://www.weforum.org/agenda/2021/05/energy-transition-reliant-on-mining/.
226 Paul Lienert, "Explainer: Lifetime carbon emissions, electric vehicles vs gasoline cars," Reuters, June 29, 2021, https://www.reuters.com/business/autos-transportation/lifetime-carbon-emissions-electric-vehicles-vs-gasoline-cars-2021-06-29/.

historical heights and could result in a potential bottleneck in future.[227] For instance, copper has increased in value for its importance in all types of current transmission.[228] Furthermore, critical metals are further needed for solar PV technologies and lead-acid and lithium-ion batteries as the following tables highlight:

Metal	Crystalline PV	Cadmium telluride	Copper indium gallium diselenide	Amorphous silicon
Aluminum	X			
Copper		X	X	
Indium		X		
Iron	X			
Lead	X			
Nickel	X			
Silver	X			
Zinc			X	X

Table 14: Metal content of the main solar PV technologies[229]

Metal	Battery type	
	Lead-acid	Lithium-ion
Aluminum		X
Cobalt		X
Lead	X	
Lithium		X
Managenese		X
Nickel		X
Steel	X	X

Table 15: Metal content of lead-acid and lithium-ion batteries[230]

Currently, however, Saudi Arabia has still to become a significant producer of most of these high-demand commodities, excluding copper and manganese. In order to become a reliable future supplier of key minerals for the energy transition, Saudi Arabia should implement a sustainable and efficient resource management strategy of minerals. This should include a conscious approach of to extracting, using, and

[227] Russell, Clyde. "Mining is Key to Energy Transition, But It's Still Unloved." Reuters, 11 May 2022, https://www.reuters.com/business/energy/mining-is-key-energy-transition-its-still-unloved-russell-2022-05-11/.
[228] Kramarz et al. (2021): Governing the dark side of renewable energy: A typology of global displacements
[229] Ibid.
[230] Ibid.

conserving mineral resources in a way that ensures their availability for current and future generations while minimizing negative environmental and social impacts.

Mineral	Saudi Arabia	World
	Total production (tons)	Production (tons)
Copper	75,400 (2020)	880,000,000 (2020)
Manganese	21,000 (2022)	49,500,000 (2020)

Table 16: Key Minerals in Saudi Arabia[231]

5.4 The future of the mining sector

The chapter has outlined Saudi Arabia's great mining potential. In addition to its abundant oil and gas resources, the country is rich in a number of elements that are crucial for the global energy transition. As

[231] Statista. "Saudi Arabia: annual copper production 2020." Accessed March 7, 2023. https://www.statista.com/statistics/709543/saudi-arabia-annual-copper-production/.; Statista. "Copper - Statistics & Facts." Accessed March 7, 2023. https://www.statista.com/topics/1409/copper/.; U.S. Geological Survey. "Mineral Industry Surveys: Manganese in December 2022." Reston, VA: U.S. Geological Survey, 2022. Accessed March 7, 2023. https://www.usgs.gov/centers/national-minerals-information-center/mineral-industry-surveys.; "Statista. (2021). Global manganese production volume from 2012 to 2020. Retrieved from https://www.statista.com/statistics/1003518/global-manganese-production-volume/"; Observatory of Economic Complexity. (n.d.). Saudi Arabia: Cobalt - Exporting Countries ($). Retrieved March 7, 2023, from https://oec.world/en/profile/bilateral-product/cobalt/reporter/sau; BASF. (n.d.). BASF Cobalt Initiative. Retrieved March 7, 2023, from https://www.basf.com/sa/en/who-we-are/sustainability/we-source-responsibly/cobalt-initiative.html; Observatory of Economic Complexity. (n.d.). Saudi Arabia: Graphite - Exporting Countries ($). Retrieved March 7, 2023, from https://oec.world/en/profile/bilateral-product/graphite/reporter/sau; Tsevatana Praraskova (2021, October 27). Saudi Arabia Targets Battery Metals Mining With "Huge" Investment. Retrieved March 7, 2023, from https://oilprice.com/Latest-Energy-News/World-News/Saudi-Arabia-Targets-Battery-Metals-Mining-With-Huge-Investment.html.; Michelle Lewis. (2021, June 4). Scientists have cost-effectively harvested lithium from seawater. Retrieved March 7, 2023, from https://electrek.co/2021/06/04/scientists-have-cost-effectively-harvested-lithium-from-seawater/.; Mining Technology. (2022, November 29). Saudi Arabia plans to build world's largest EV metals and minerals plants. Retrieved March 7, 2023, from https://www.mining-technology.com/news/ev-metals-minerals-plants-saudi-arabia/.; Saadi, Dania. "Interview: Saudi Arabia to Auction Mining Licenses in 2022 to Woo Foreign Investors." S&P Global Market Intelligence, June 16, 2021. Accessed March 7, 2023. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/061621-interview-saudi-arabia-to-auction-mining-licenses-in-2022-to-woo-foreign-investors.

environmental, social, and governance (ESG) issues become more prevalent, there has been an increase in demand for mined materials as well as an increase in demand for transparency and high-quality engagement. According to KPMG, the top 5 risks for the mining industry as illustrated in the following graphic.

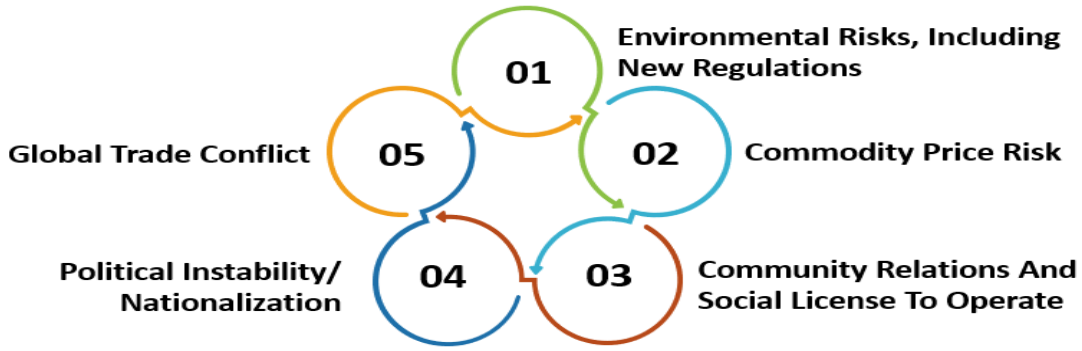

Figure 34: Overview of risk factors in the mining industry (own compilation)

Environmental risks became a more prominent risk since the previous year when commodity price risks were ranked the first most relevant risk.[232]

Info box 2: Lithium as a game changer in Saudi Arabia's mining industry?
It is believed that Saudi Arabia possesses substantial lithium reserves, primarily located in the Al-Qasim region. With the help of external partners, investments in the development of lithium mining operations have been increased lately. Lithium is a critical component used in lithium-ion batteries, which power most modern EVs, portable electronics, and renewable energy storage systems. With the rise in demand for EVs and renewable energy, securing lithium resources has become strategically important for countries aiming to play a significant role in the green energy transition.

[232] KPMG. (2022). Global Mining Outlook 2022: Extracting key insights for mining leaders. Retrieved from https://assets.kpmg/content/dam/kpmg/xx/pdf/2022/04/global-mining-outlook-2022.pdf

Strengths	Weaknesses	Opportunities	Threats
Abundance of natural resources	Lack of expertise and technology on mining	Increasing demand for minerals and metals	Political and regional instability and potential terror attacks
Strong government support for mining	Low investor confidence due to lack of information and transparency	Interest in sustainable mining operations	Global competition from more mature markets such as Australia
Increasing focus on sustainability	Majority of market share owned by Ma'aden (Saudi Arabia)	Saudi Geological Survey found essential new materials such as cobalt and lithium[233]	Volatility caused by sustainability-related regulations
low crime rate, low utility cost, limited employment costs (no minimum wage)[234]	Small domestic labor force, lack of female workers, focus on domestic labor[235]		
quality transportation network and trade networks with			

[233] Gibon, Clément. "Saudi Arabia's Expanding Mining Sector Moves it Closer to its 2030 Vision." Inside Arabia, February 15, 2022, https://insidearabia.com/saudi-arabias-expanding-mining-sector-moves-it-closer-to-its-2030-vision/.
[234] U.S. Department of Commerce. "Saudi Arabia - Mining and Minerals." Export.gov. Last modified October 13, 2021. Accessed March 2, 2023. https://www.export.gov/apex/article2?id=Saudi-Arabia-Mining-and-Minerals.
[235] U.S. Department of Commerce. "Saudi Arabia - Mining and Minerals." Export.gov. Last modified October 13, 2021. Accessed March 2, 2023. https://www.export.gov/apex/article2?id=Saudi-Arabia-Mining-and-Minerals.

Europe, Asia, and Africa to trade minerals and metals			

Table 17: SWOT analysis of the mining sector in Saudi Arabia

In conclusion, Saudi Arabia's ambitious Vision 2030 aims to develop the mining sector into a significant contributor to the country's economy. This includes investments in infrastructure to support mining activities and leverage the nation's abundant mineral resources, with gold, zinc, copper, nickel, and phosphates being among the key focus areas. While there is a push towards privatization in the mining sector, government entities continue to play crucial roles in attracting foreign investments and funding industry development programs, with Ma'aden leading the sector's implementation.

Efforts are also underway to address the shortage of skilled labor by providing training and capacity development programs. However, reforms in educational curricula are essential to ensure the sustainable growth of the sector and the development of a skilled workforce. In alignment with global sustainability goals, environmental and social impact management plans are required for exploration licenses in the mining sector, emphasizing compliance with environmental laws, sustainability regulations, and local employment engagement.

Overall, Saudi Arabia's commitment to the development of its mining sector demonstrates its dedication to diversifying the economy and achieving long-term sustainability. It all will be crucial for the plans for transforming Saudi Arabia into a hydrogen economy.

6. Saudi Arabia industry's potential for the hydrogen development

6.1 The hydrogen supply and value chain

An overview on the supply and value chain of hydrogen from production to transport up to end-use consumption already discloses the various integral components such an industry requires. It is expected to become even more complex with the ramp up of a global hydrogen economy as it is associated with many uncertainties regarding supply (raw material prices and availability), demand-side, transportation constraints and safety measures, lack of investment and production costs. Typically, the supply and value chain can be divided into three core parts, namely (a) production (upstream), (b) storage and distribution (midstream) and (c) application and utilization (downstream).

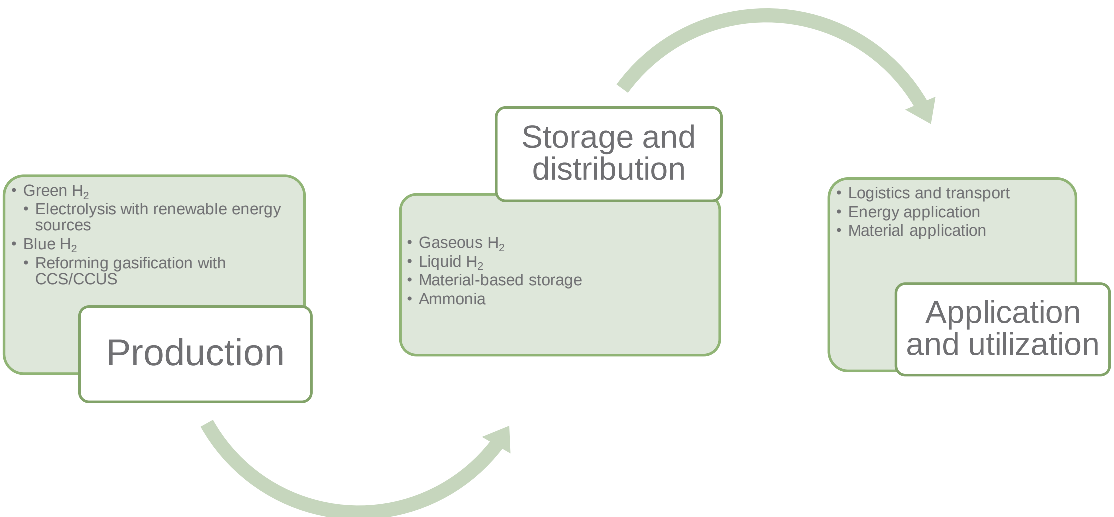

Figure 35: Overview of the supply and value chain of hydrogen (own compilation)

Both the petrochemical and mineral industries are large producers and consumers of hydrogen. Hence, they play an integral part throughout the entire hydrogen cycle. In the following, we address and estimate the different advantages of both industries for blue (fossil fuel with CCS/CCUS) and green (renewable energy powered electrolysis) H2 supply chains. Also the analysis considers both local use as well as export of H2. However, currently there are still uncertainties in all parts of the hydrogen supply chain.

Supply chain of green hydrogen:

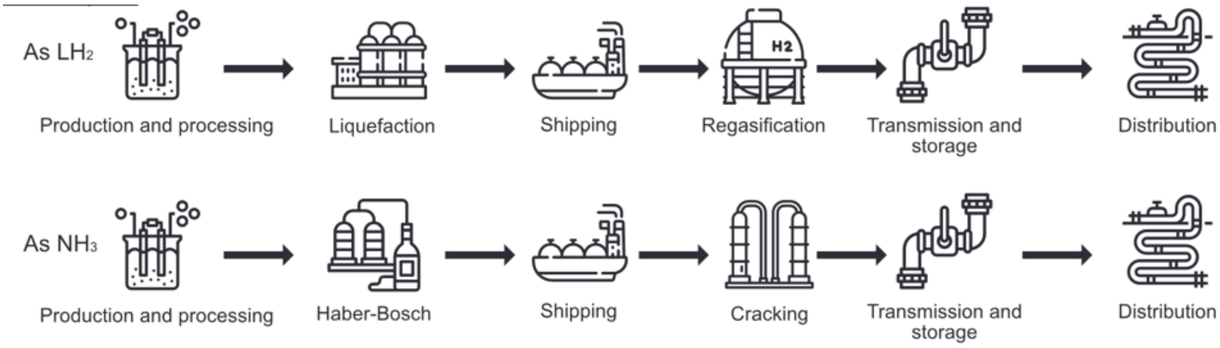

Figure 36: Different value and supply chains of hydrogen[236]

Supply chain of blue hydrogen

Production

The efficient fuel can be obtained both from renewable sources, such as water or biomass, and from hydrocarbons. As elaborated previously, the first stage of production can differ tremendously when considering the different colors of hydrogen. In terms of green hydrogen, Saudi Arabia will remain dependent on the import of critical minerals for building its H_2 economy. To produce green hydrogen, both

[236] Cooper et al 2022: Hydrogen emissions from the hydrogen value chain-emissions profile and impact to global warming, Science of The Total Environment 830

present electrolysis technologies, namely alkaline electrolysers (AEL) units, and polymer electrolyte membrane (PEM) electrolysers,[237] need raw materials and components from outside the Kingdom.

The relatively simple electrolyser design of AEL units does not require rare metals but nickel and (nickel-plated) stainless steel. The global key suppliers of nickel include Australia (22%), Indonesia (22%), Brazil (17%), Russia (8%) and the Philippines (5%). Additionally, China is a global player of smelting and refining operations. Having said this, as previously mentioned, Saudi Arabia continues to expand its domestic nickel production so that the mining industry can fill this demand. There are also projections that the Saudi Kingdom exports nickel, making it a valuable partner for other countries in their development of a hydrogen economy.[238] For PEM electrolysers units, which offer a more flexible adjunction to fluctuating electricity production, iridium and platinum are required. Both are “are among the most scarce, carbon-intense, and expensive metals”.[239] Additionally, there are no deposits of both metals in Saudi Arabia. Instead, with over 90% of reserves, South Africa has by far the largest endowments of iridium and platinum, followed by Russia (6%), Zimbabwe (1,7%), the USA (1,3%) and Canada (0,4%).[240]

When taking a step back to the energy sources that are needed to fuel the electrolysers, Saudi Arabia’s mining industry has further advantages that should be used. As outlined in the empirical chapters, both the petrochemical and mining sectors are critical for a low-carbon development and the use of clean energy technologies such as wind turbines and transmission lines, solar PV and different battery types. Furthermore, in terms of the ‘electrification’ as key element, more copper will be needed as more wires will be built that require copper. Another abundant and mature element is zinc, which is needed for onshore and offshore wind parks. Already licensed and exploited in larger quantities, demand is expected to grow. The same applies for other minerals found in Saudi Arabia such as lithium, aluminum and cobalt, which are all needed for low-carbon technologies.

It is not only the mining sector that is important for the production parts of the supply chain. Petrochemicals are also key drivers as petrochemical end-products provide necessary materials for renewable energies. Petrochemicals are found in solar panels, wind turbine blades or batteries, all important components for providing the clean electrons for green hydrogen’s production. For instance, ethylene vinyl acetate (EVA) is used for photovoltaic panels. In this sense, Saudi Arabia has already started to explore this promising industrial branch and aims to further localize parts of its nascent PV industry. In the north, the Saudi

[237] There is also a third option, namely Solid Oxide Electrolysis (SOEL). However, as it is still considered to be in the research stage of development, it is not included here.
[238] Trading Economics 2023: Saudi Arabia Exports of nickel, https://tradingeconomics.com/saudi-arabia/exports/nickel; ReporterLink 2022: Saudi Arabia Nickel Industry Outlook 2022 – 2026, https://www.reportlinker.com/clp/country/7010/726409
[239] Ansari et al. 2022, Electrolysers for the hydrogen revolution: challenges, dependencies, and solutions, p. 4.
[240] Ansari et al. 2022, Electrolysers for the hydrogen revolution: challenges, dependencies, and solutions; IEA (2022): Critical Minerals Policy Tracker.

International Petrochemical Company (Sipchem) has constructed a new EVA production facility. Once established, it can meet the demand of demand of 700MW-yearly PV-production capacity[241].

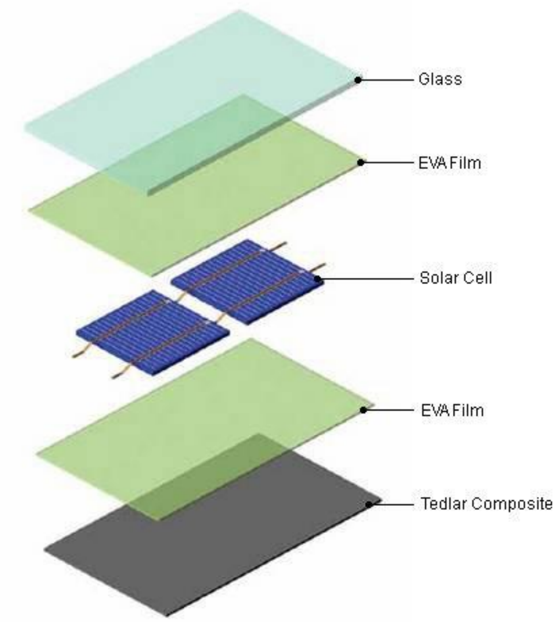

Figure 37: EVA Film application in solar panels[242]

Storage and distribution

Hydrogen is relatively difficult to store. It is very flammable and must be stored safely in special tanks, usually at low pressure. There are currently two storage options. On the one hand, physical storage in the form of energy-intensive cryogenically freezing or liquifying as well as chemical storage that connects hydrogen with metal and chemical elements to create hydrides or store it in sorbent materials, as illustrated here:

[241] Al-Saidi, 'Energy Transition in Saudi Arabia'; Zaid S. AlOtaibi et al., 'Current Status and Future Perspectives for Localizing the Solar Photovoltaic Industry in the Kingdom of Saudi Arabia', *Energy Transitions* 4, no. 1 (June 2020): 1–9, https://doi.org/10.1007/s41825-019-00020-y.
[242] EVA (ethylene vinyl acetate) Film: composition and application, URL: https://sinovoltaics.com/learning-center/materials/ethylene-vinyl-acetate-eva-film-composition-and-application/

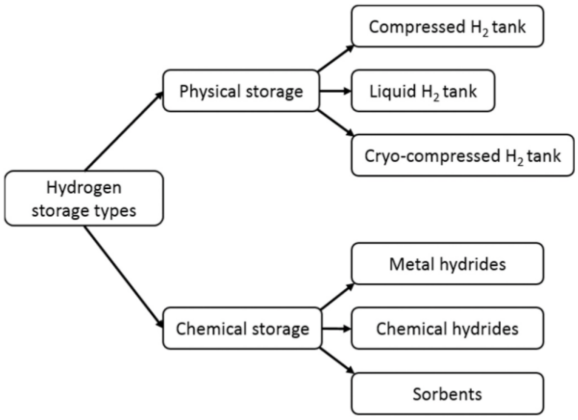

Figure 38: Different H2 storage types[243]

Presently, physical storage, especially cryogenically liquified hydrogen and compressed hydrogen gas, are the more mature and common applications. In this way, it is then further transported in cylinders, pipelines, and cryogenic tanks. Whereas liquefaction of hydrogen is useful to store large quantities and/or transport it over long distances, it is a very energy-intensive process and has a relatively low efficiency rate. In order to liquify hydrogen, it must be cooled down to a temperature below -253°C.[244] Furthermore, the energy-intensive processes can also lead to unintentional emissions, so-called fugitive emissions, because of leaks in equipment (e.g. pipelines or compressors) and faulty equipment emissions. It was noted, however, that various plastic such as polyvinyl chloride, PVC, and polyethylene, which are also produced in Saudi Arabia, can help minimize leaks and embrittlement.[245]

In terms of chemical storage, there are several promising avenues that circumvent the energy-intensive liquefaction of hydrogen. More viable options include carbon-based fuels such as methane/natural gas, methanol or methylcyclohexane.[246] Another entry point for the petrochemical sector and more promising way, because it is 'carbon neutral' and has a higher H_2 density than the above-mentioned carbon-based fuels, is the production of ammonia. Its compounds consist of three parts hydrogen and one part nitrogen, which makes it a viable carrier for hydrogen or fuel (e.g. in the maritime sector). Being technically the more viable option (in terms of conversion, storage, transport) as well as considering established markets,

243 Burton et al. 2021
244 Yin, L., Ju, Y., 2020. Review on the design and optimization of hydrogen liquefaction processes. Front. Energy 14, 530–544. https://doi.org/10.1007/s11708-019-0657-4
245 Cooper et al. 2022
246 Chatterjee et al. 2021, Limitations of Ammonia as a Hydrogen Energy Carrier for the Transportation Sector

production facilities and infrastructure, ammonia is considered an ideal element of the hydrogen development in the eyes of many. Saudi Arabia is already a key producer and exporter of natural gas-based grey ammonia and could expand this sector towards green and blue ammonia.

Accordingly, CO_2 emissions from (SMR)-based ammonia production could be captured. In this regard, the country has already managed to dispatch several tons of high-grad blue ammonia to Japan. The successful demonstration was part of a joint venture between Saudi Aramco, SABIC and the Japanese Institute of Energy Economics. Additionally, SABIC is currently experimenting the convertion of some of its conventional steam cracker at its petrochemical facilities to blue hydrogen.[247] Meanwhile, the tech-oriented campus at KAUST is working on projects such as ammonia cracking and conversion of plastics to hydrogen and energy. As the International Energy Agency (IEA) forecasts, the production of ammonia will experience a surge, particularly in the Middle East with leading countries such as Saudi Arabia.[248] Especially for the Kingdom's hydrogen ambitions, on the one hand, and various plans to further specialize and upgrade the value chain of its petrochemical industry, on the other hand, ammonia offers various opportunities.

247 SABIC, 'SABIC Annual Report 2021'.
248 IEA, 'The Future of Petrochemicals Towards a More Sustainable Chemical Industry'.

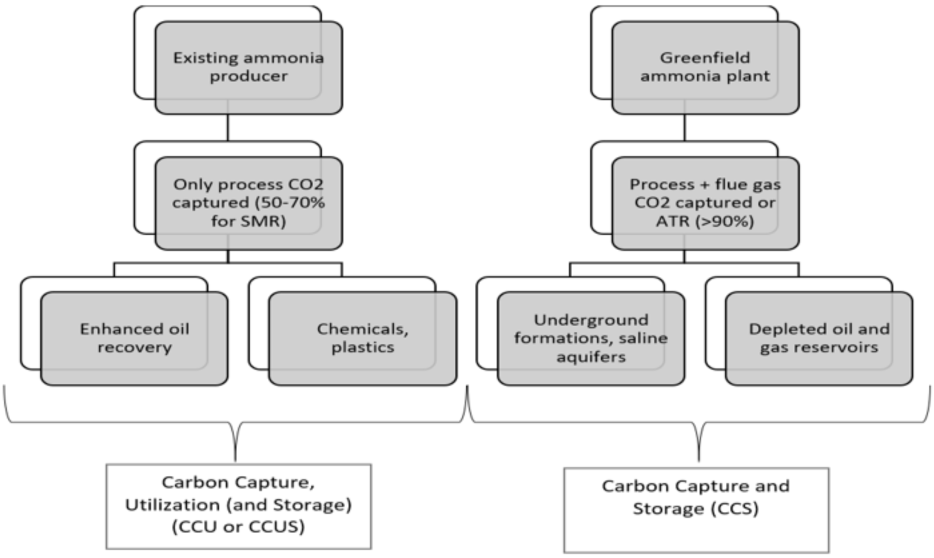

Figure 39: Potential application of Ammonia in the petrochemical sector[249]

Application and utilization

As already mentioned, hydrogen can enable many processes in the energy industry. While it is currently used in different sectors such as petroleum refining, fertilizers, chemicals, and food, its relevance is likely to grow and expand to other fields.

[249] Gulf Petrochemicals and Chemicals Association (September 2021), GPCA Insight, https://www.gpca.org.ae/wp-content/uploads/2021/10/Insight-Newsletter_September2021-1.pdf

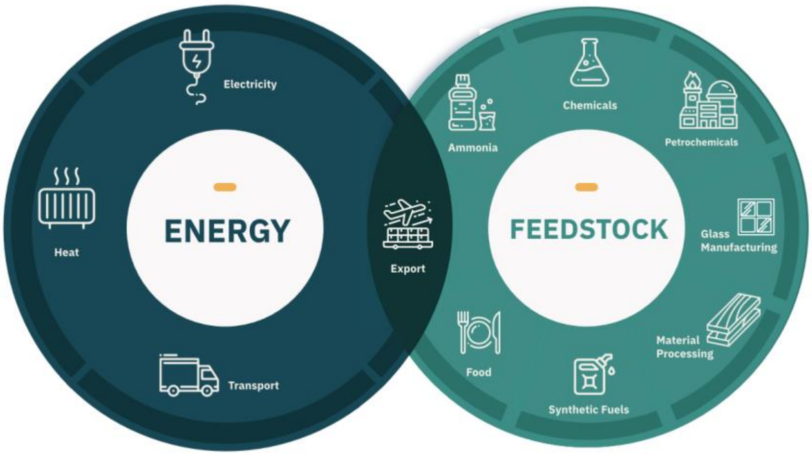

Figure 40: Overview of H2 application and usage[250]

In this regard, hydrogen can decarbonize many existing industrial processes. One of them is iron and steel production. Recently, the Saudi Ministry of Investment has declared that the Kingdom is eager to prepare these industries for the green transition. Here, hydrogen can be used as an alternative to hydrocarbons (usually coal) in the direct reduction process.

250 Rashid Manna and Omar Saffouri, 'POWER-TO-[X] Green Hydrogen Opportunities In Jordan' (Friedrich-Ebert-Stiftung (FES), 2022), https://library.fes.de/pdf-files/bueros/amman/19061.pdf.

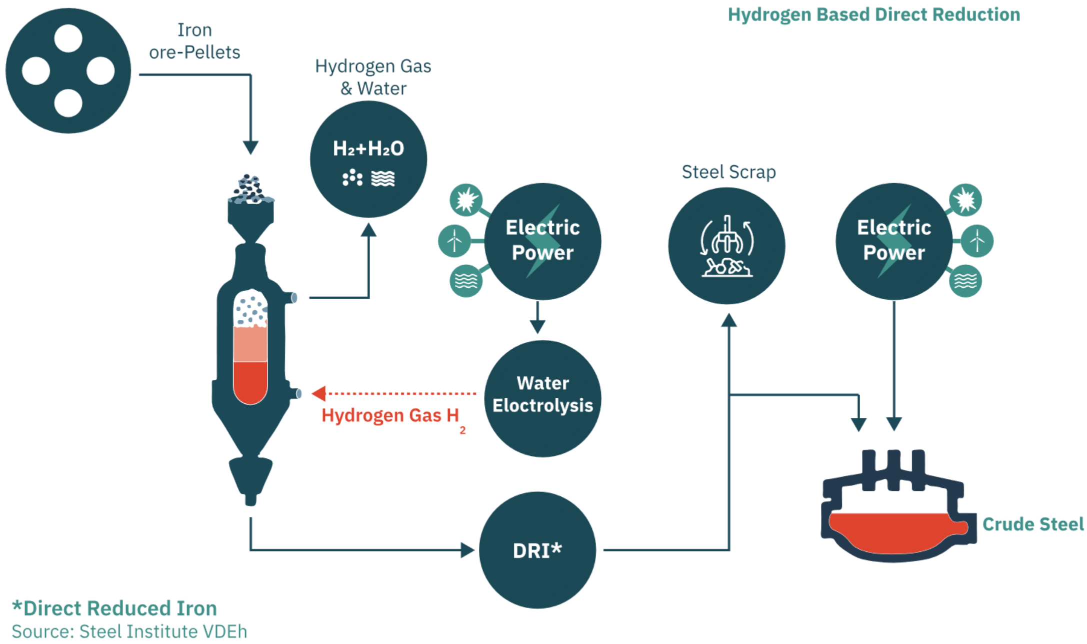

Figure 41: Direct-Reduced-Iron Production from Hydrogen as an Alternative to Carbon (Coal)[251]

Food production is another end-use. Here, hydrogen can be used to produce saturated and unsaturated fats.

[251] Ebd.

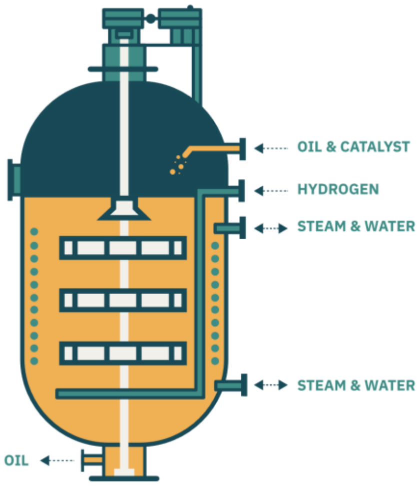

Figure 42: Hydrogen Usage in the Production of Hydrogenated Fats[252]

Already today, refineries and petrochemical plants are the largest consumers of hydrogen. However, since these processes are almost completely fossil-based, they emit large quantities of CO2-emissions that are equal to the entire aviation industry worldwide.[253]

Hydrogen uses	Consumption (Billion m³)	Percentage
Ammonia production	250	50%
Petrochemistry	185	37%
Production of other chemical products	65	13%
Total	500	100%

Table 18: Overview of hydrogen within different chemical applications[254]

The production of green and blue hydrogen at large scale can decarbonize these processes. Additionally, hydrogen can be used as a reactant to any chemical process. In this vein, electrolysis-derived hydrogen

[252] Ibid.
[253] Future Cleantech Architects, Hydrogen Factsheet: https://fcarchitects.org/basics-gaps/
[254] Burton et al. 2021

can be used as a building block for all primary chemicals. It can be used directly in combination with other elements such as nitrogen, carbon and oxygen to produce methanol and ammonia, as well as indirectly (via methanol-to-olefins/aromatics).[255] More concrete examples include, for instance, hydro cracking to refine petrochemicals, hydro processing to produce sulphur and nitrogen-based compounds as well as the production of petrochemicals such as methanol and polypropylene. At the same time, hydrogen can also act as a catalyst in recycling processes. For instance, heavier plastics can be "hydrogenated and cracked to produce lighter plastics for reuse".[256]

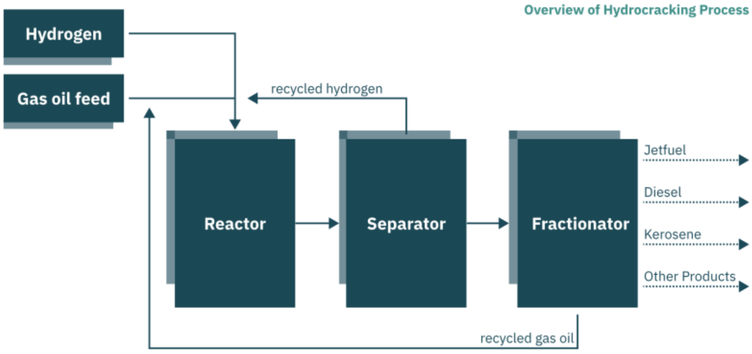

Figure 43: Hydrogen Usage in Transformation of Heavy Oils to Lighter Oils[257]

[255] IEA, 'The Future of Petrochemicals Towards a More Sustainable Chemical Industry'.
[256] Burton et al. 2021, p. 2.
[257] Manna and Saffouri, 'POWER-TO-[X] Green Hydrogen Opportunities In Jordan'.

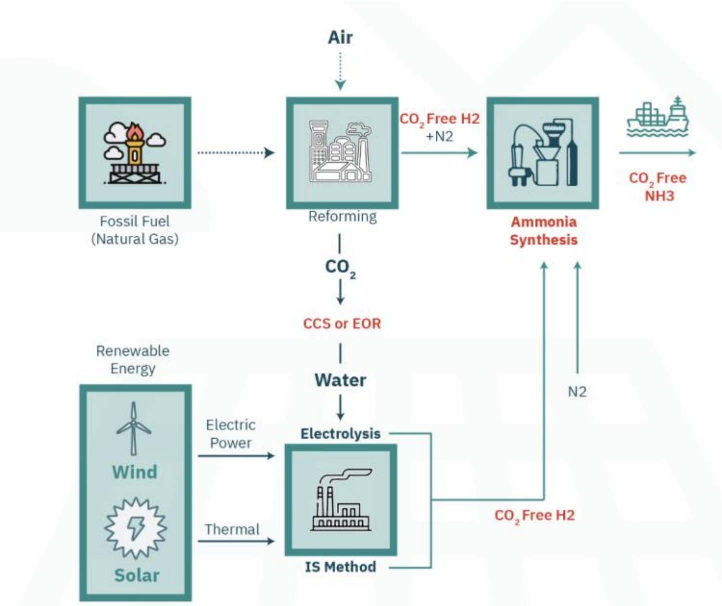

Figure 44: Ammonia Production from Hydrogen as a Main Reactant[258]

Also in the mineral sector, green/blue hydrogen can be used as an alternative feedstock. At least two aspects can be considered here. This relates to a direct energy and greenhouse gas reduction impact of the sector itself on the one hand; on the other hand, more indirect potentials of implementing hydrogen technologies on minerals operations and markets. Especially transportation and mobility are key target areas. For instance, hydrogen can be used for heavy trucks or ships involved in the mining business for transportation purposes. Furthermore, the mining sector is heavily dependent on very energy intensive machines. Hydrogen-fueled haulers or excavators, where first prototypes have been already presented, could represent a further potential application.[259] Finally, hydrogen will play a key role in powering production processes (e.g. exploiting minerals or high quality heat generation).

[258] Manna and Saffouri.
[259] Liebherr (October 2022), Liebherr hydrogen excavator receives Bauma Innovation Award, https://www.liebherr.com/en/deu/latest-news/news-press-releases/detail/liebherr-hydrogen-excavator-receives-bauma-innovation-award.html

6.2 Saudi Arabia's untapped industrial potential

After looking into the value-chain of hydrogen and the role of the mining and petrochemical industry, we look at the untapped potential of Saudi Arabia within the energy transition's supply chains. As has been already noticed, the country has great opportunities to ramp up its efforts and become an integral part of the global transition towards a low-carbon development. Until today, major components for renewable energy are imported from Western countries and China. The latter is the major provider of solar technology and equipment worldwide and a major investor, financier and technology provider for local renewable energy projects. Saudi Arabia has the potential to localize parts of the clean energy production processes as it is able to independently provide key components of it.

Metals such as aluminium, copper, indium, iron, lead, nickel, silver and zinc are needed in main solar PV technologies. Simultaneously, petrochemical endproducts such as plastics play an essential role in increasing the efficiency and reliability of renewable energy. Plastics are being used to construct the components of solar panels, build rotor blades, and sheath electrical wiring that helps harness renewable energy sources. The plastics used for these components are usually lightweight, flexible, and price-competitive, helping to make renewable energy solutions more efficient and cost-effective. In the case of solar panels, plastics are used to help guide and support the large glass sheets that are often used to capture sunlight. By using a lightweight yet durable plastic material, the panels are able to support the great weight of the glass while also remaining light enough to be mounted on the tops of buildings. Additionally, the sun's rays are able to travel through the plastic and glass sheets in order to realize the photovoltaic effect and produce electricity.. As mentioned before, SABIC is already working in this direction to produce solar panels made in Saudi Arabia.[260]

For harnessing wind energy, plastics are also used in the construction of turbine blades. In traditional turbine blades, plastic is developed with a specific airfoil shape that helps maximize wind energy capture and efficiency. These blades can be adjusted to increase their efficiency as needed, with different weights and sizes of plastic being used for different conditions. The required BoS (balance of system, i.e. components and equipment in a renewable energy system) can partially be developed in Saudi Arabia. This refers particularly to the electrical wiring and cabling that are necessary to connect the energy generation or storage system to the electrical load or the grid. A prominent Saudi Arabian company

[260] Further local companies to develop solar panels include Desert Technologies near Jeddah, Masdar in Tabuk and Masdar in Khobar.

specializing in the production of electrical cables and related products is Riyadh Cables Group, which was already founded in 1984.

To move a step further, the clean energy produced can be used for clean hydrogen – either surpluses or dedicated capacities. In this regard, additional petrochemical endproducts, plastic in particular, are further needed along the entire hydrogen value chain. It is needed for the construction of electrolysis as electrolyzers contain polymer membranes and plastic components, which separates the hydrogen and oxygen gases during the electrolysis process. In terms of hydrogen storage, polyethylene can be used for composite cylinders that store high-pressure hydrogen gas. It ensures gas impermeability and maintains the structural integrity of the cylinder. The same applies to the transportation of hydrogen: Plastic pipelines made from high-density polyethylene (HDPE) or polyamide (nylon) are used to transport gaseous hydrogen from production facilities to storage facilities or end-users.

Still on the storage note, next to hydrogen as potential electricity storage, the clean energy can be stored in batteries. With its unfolding development of a lithium mining industry, Saudi Arabia is well suited to become a key player of renewable energy storage solutions, which is so far lacking across the whole Middle East. In so doing, the country needs to upgrade the mid- and upstream segments, which are still in their early stages. The announcement of the first lithium hydroxide refinery between an Australian and Saudi joint venture is a promsing step in this direction.[261] Ramping up the lithium-ion batteries production will enable Saudi Arabia to position itself as a key supplier for electric vehicles´ battery technology. Already now the Saudi leadership cooperates with various stakeholders to manufacture EV.[262] In general, e-mobility is a crucial element for the clean energy transition taking place globally, and Saudi Arabia is well-suited to play an integral part in it. However, so far, a great deal of emissions are associated with the production of lithium.

[261] https://source.benchmarkminerals.com/article/from-oil-to-lithium-how-saudi-arabia-is-building-a-battery-supply-chain?utm_content=buffer30165&utm_medium=social&utm_source=linkedin.com&utm_campaign=buffer

[262] Ibid.

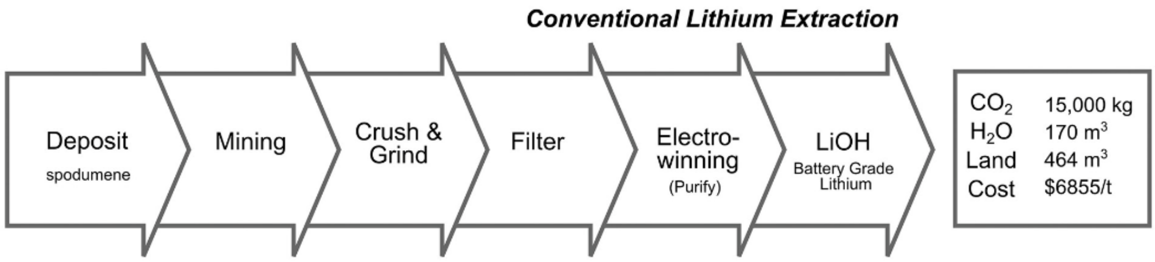

Figure 45: Overview of supply chain of lithium extraction[263]

Another opportunity for cleaner transportation is a greater focus on hydrogen fuel cells. Hereby, petrochemical materials are also used for the manufacturing of hydrogen fuel cells and fueling stations as they offer excellent resistance to corrosion, are lightweight, and are relatively easy to install. Batteries and hydrogen can complement each other in certain scenarios. On the one hand, batteries are well-suited for short-duration, high-power applications like electric vehicles and grid stabilization, where their quick response and high efficiency are advantageous. On the other hand, hydrogen can be helpful for long-duration energy storage and high-energy applications, where its ability to store large amounts of energy over extended periods is valuable. Additionally, hydrogen fuel cells can provide continuous power for certain applications where battery life is limited. Greater research in hybrid energy storage systems that combine batteries and hydrogen technologies are another avenue for Saudi Arabia's untapped potential. These systems aim to leverage the benefits of both technologies by integrating them into a single solution, offering enhanced flexibility, scalability, and efficiency.

6.3. Future steps to consider in order to spur the development of a hydrogen economy

So far there is still much uncertainty how a global hydrogen economy will look like in the future. There is much consensus that it is needed as a crucial element for the energy transition and to meet the net-zero targets as part of the global climate commitments. However, the specific scale, scope and speed of this transformation remain unclear today. It is barely foreseeable how quickly technological innovations will

[263] https://geoscientist.online/sections/features/mining-the-brine/

expand and how much countries are willing to invest in these developments. Both elements are crucial to secure future needs and availability of raw materials and drive production costs down. Moreover, hydrogen is a difficult element to handle. While it has been known and used for more than two centuries, it has not been an integral part of our energy systems, so far. In the words of the historian Matthias Heymann:

> *"No other chemical substance had in the twentieth century resulted in the emergence of so extensive and enthusiastic a scientific movement. And yet, as we see today, that enthusiasm had its roots in a serious underestimation of the complexity of the problems."*[264]

The complexity of the entire value chain including demand, production, storage and distribution needs to be closely evaluated and perceived as a whole, where every part is closely linked to one another.[265] This study is an attempt to consider the whole value chain and how two of Saudi Arabia's key industries are important parts of it. However, there are also limitations in such a way that many more sectors, components and variables need to be considered. In the following, we would like to draw attention to several aspects, which we found crucial when imaging a future hydrogen economy. Certainly, all these aspects are closely interconnected with each other and should be tackled in a comprehensive manner.

Economic and technical considerations

Until now, hydrogen is still very expensive. The cost of green hydrogen production varies depending on the source of power used, with the cost typically ranging from $2.30 to $3.50 per kilogram. Blue hydrogen production is generally less expensive than green hydrogen production, typically ranging from $1.30 to $1.80 per kilogram. In 2022, it was reported that green hydrogen is cheaper than blue hydrogen in the Middle East. For instance, it was stressed that Qatar with $2.62/kg is the cheapest location for renewable H2, followed by Saudi Arabia ($3.23/kg), Oman ($3.58/kg) and UAE ($4.51/kg) when using alkaline electrolysers, with prices for PEM electrolysers roughly $1/kg higher. In contrast, blue hydrogen was estimated to cost between $4.66-$4.80/kg in those nations.[266]

In the Middle East, the costs for grey hydrogen are also significantly lower than in other parts of the world given the low cost-competitive abundance of fossil fuels.[267] Consequently, large scale financing and investment schemes are needed to provide climate-friendly hydrogen at the lowest possible cost. Closely

[264] Heymann 2009, Scientists, pioneers and visionaries: Hydrogen as energy carrier, Piper-Verlag, p. 185
[265] Mac Dowell et al., 2021
[266] Collins, L. (2022). Green hydrogen now cheaper than blue in Middle East, but still way more expensive in Europe, https://www.rechargenews.com/energy-transition/green-hydrogen-now-cheaper-than-blue-in-middle-east-but-still-way-more-expensive-in-europe/2-1-1173423.
[267] Mac Dowell et al., 2021.

related to this is the challenge of fuel poverty. Required processes such as liquefaction of hydrogen or ammonia cracking processes require either very low or very high temperature that demands much more energy than currently available and cost-efficient.[268] The expansion of energy systems, especially renewable energy with solar and wind, must be scaled up to satisfy this growing demand.
At the same time, hydrogen technology is still immature and inefficient. The high decomposition temperature leads to immense efficiency losses. For instance, for liquification, hydrogen must be cooled down to -252.87°C. Also, the commercially viable electrolysers' efficiency is still to be improved. Reasons include "over-potential caused by the build-up of bubbles on and between the electrodes, heat losses within the system as well as excess power consumption within the control unit and operational features".[269] There are technical solutions to these shortcomings including improved coupling between PV panels and electrolysers. Also, the over-potential from the build-up bubbles can be reduced through innovative applications of magnetic, light energy, ultrasonic or pulsating electric fields.[270] However, there is a lack of large-scale application so far as they are not economically viable for both large- and small-scale hydrogen production.[271] More investments, broader research and development in these technologies and improved configuration of the hydrogen components are needed.

Environmental considerations and sustainable resource management

Hydrogen is an indirect greenhouse gas as "it interferes with the sink of other non-CO_2 GHG, most importantly methane".[272] A greater oxidization of hydrogen in the atmosphere would inevitably mean a higher concentration of GHG emissions. So far, there are not many studies that analyze the growing risk of global warming through hydrogen as there are inconsistencies over the exact metrics and measurement.[273] However, the few that exist are rather pessimistic. For instance, Ilissa B. Ocko and Steven P. Hamburg estimate that emissions derived from hydrogen could be "200 times that of carbon dioxide and larger than that of methane".[274] Notably, even if green hydrogen is not as climate-damaging as currently assumed by some, it is not a net-zero product as the supply chain is not decarbonized (yet). Emissions are created across the production and installation of wind turbines, solar panels, batteries, electrolyzers, and hydrogen storage. Considering this, more research is required to understand the emissions associated with hydrogen production and use. Furthermore, the entire value chain of hydrogen

[268] Jinwoo et al. 2022; Yin & Lu 2020; Chatterjee et al. 2021.
[269] Burton et al. 2021, p. 8.
[270] Burton 2021.
[271] Ibid.
[272] Cooper et al. 2020, p. 5.
[273] Ibid.
[274] Ilissa B. Ocko and Steven P. Hamburg, "Climate Consequences of Hydrogen Emissions," *Atmospheric Chemistry and Physics* 22 (2022): 9350, https://doi.org/10.5194/acp-22-9349-2022 .

must become clean in order to label green hydrogen as a climate-friendly practice.[275] Full life-cycle assessments and more environmental analysis are needed here.

Also, blue hydrogen comes with an environmental burden. Many of those problems relate to carbon sequestration as a prerequisite for producing it. Until today, the most efficient CCS plants can capture 90-95%, while others have a lower rate of only 60% or slightly higher.[276] Consequently, it is not a carbon-neutral technology in its current stage and plays no large part in achieving the net-zero targets. Next, GHG emissions can be emitted along the entire value chain through leakages, venting and purging if not managed properly. A bigger issue comes to the question whether CCS or CCUS is at play. As Natalie Koch notes:

> *“CCS and CCUS are often used interchangeably in energy discussion, but they refer to different activities. The sole goal of CCS is storage – storing CO_2 underground so that it remains there forever. CCUS, by contrast, is a broader term that extends the CCS idea to include processes that ‘upcycle’ captured carbon.”*[277]

Using CCUS in terms of EOR is a favored practice in the oil- and gas-exporting Gulf countries as it is today “the only form of large-scale, permanent carbon sequestration that is profitable.”[278] In this regard, the captured carbon is reinjected to extract more oil or gas. However, in contrast to CCS, the carbon dioxide (CO_2) is not stored deep underground with the aim of permanently remaining there but closer to the surface. This can result in higher probabilities that the stored CO_2 enters the surface again, making the whole process of carbon sequestration useless.[279] Furthermore, there are other ecological risks of soil erosion, toxicity, eutrophication, and acidification. In some cases, it might even “infiltrate groundwater aquifers and contaminate freshwater resources with dangerous uranium and barium”.[280] In order to avoid these problems, industrial and political stakeholders have to prioritize supply chain efficiencies and apply high environmental and labor standards. Additionally, natural-based solutions of carbon removal should

[275] Cooper et al. 2021; Mac Dowell et al., 2021.
[276] Zumbraegel 2022; Schimmel et. al., Hydrogen Cooperation Potential between Saudi Arabia and Germany. A Joint Study by the Saudi-German Energy Dialogue.
[277] Koch, N. (2022). Gulf Hydrogen Horizons. Why are Gulf oil and gas producers so keen on hydrogen?, p. 6.
[278] Zumbraegel 2022; David Roberts, “Could Squeezing More Oil out of the Ground Help Fight Climate Change?” Vox, December 6, 2019, http://bitly.ws/vnQ5.
[279] Ilissa B. Ocko and Steven P. Hamburg, “Climate Consequences of Hydrogen Emissions,” *Atmospheric Chemistry and Physics* 22 (2022): 9350, https://doi.org/10.5194/acp-22-9349-2022 .
[280] Zumbraegel 2022; Further: Pieter Roefs, Michele Moretti, Kris Welkenhuysen et. al., “CO2-enhanced Oil Recovery and CO2 Capture and Storage: An Environmental Economic Trade-off Analysis,” *Journal of Environmental Management* 239 (2019): 167-177, https://doi.org/10.1016/j.jenvman.2019.03.007 .

be prioritized in a same way as technological solutions of CCS and CCUS. This include afforestation but especially the expanding of mangroves that can absorb huge amounts of CO2 emissions and do not need additional freshwater as feedstock.

Another uncertainty includes the question of sustainable resource management regarding the feedstock to produce hydrogen. Whereas countries like Saudi Arabia enjoy many advantages or producing renewable energy in large quantities (e.g. abundance of land, high solar radiation and one of the lowest costs for solar electricity), the installed capacity remains low and not nearly meeting the expected demand that is required. Many of the installed solar PV panels further face challenges as they are not fully operational at all times. Temperature rises above 25°C significantly lower their efficiency.[281] Furthermore, sand and dust storms often impair the power production.[282] Oftentimes, they have to be cleaned regularly by using freshwater. This adds to the chronic water problem in the region. It further increases the water demand of green hydrogen. In Saudi Arabia, as elsewhere in the Gulf states, the majority of freshwater is produced through desalination, which is costly, energy-intensive and ecologically harmful. So far, most of the desalination plants are fossil-fueled making the feedstock of green hydrogen once again not carbon-neutral. Additionally, by-products such as the brine and other chemicals are often released into the seas. Overall, desalination is not a sustainable practice under current circumstances. Hence, more research and development are needed to make desalination cleaner and more efficient. Accordingly, Khan and colleagues from KAUST see several potential opportunities to reduce the cost and environmental impact of desalination, ranging from improving pre-treatment and brine post-treatment technologies.[283] At the same time, Saudi Arabia has large improvement potential in terms of waste-water management, collecting rain-water (where and when meaningful and possible) and increase efficiency in usage. Currently, Saudi Arabia reuses only 10% of its domestic wastewater.[284]

Also in terms of solar PV, there are potential improvements. One example includes the NO Water Mechanical Automated Dusting Device (NOMADD) technology, which has been already applied in Saudi Arabia.[285] Floating solar farms are another example to avoid the malfunction of solar PV when temperature rises. The concept foresees to construct an array of PV panels on floating structures in artificial or natural water bodies.[286]

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[281] Pouran 2023, https://www.mei.edu/publications/how-floating-solar-farms-can-help-middle-east-deal-water-and-power-challenges
[282] Koch 2022.
[283] Khan et al. 2021, Seawater electrolysis for hydrogen production: a solution looking for a problem?
[284] Dawoud, M. et al. (2022): The future of wastewater treatment and reuse in Kingdom of Saudi Arabia, Desalination and Water Treatment 263, 127–138.
[285] https://www.nomaddesertsolar.com/
[286] Pouran 2023.

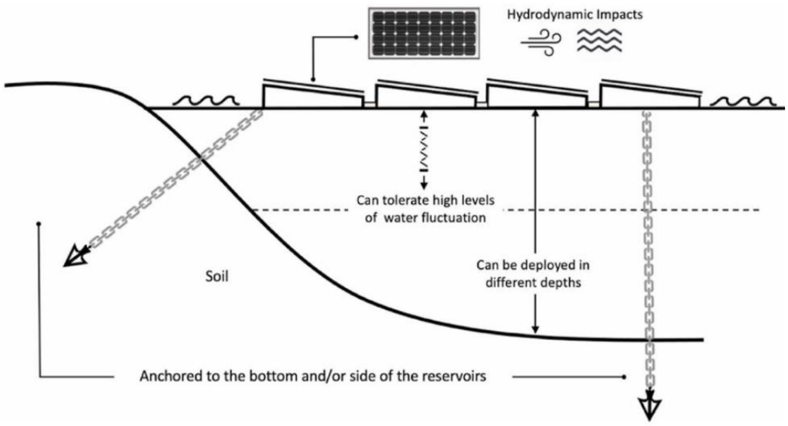

Figure 46: Illustration of floating solar farms[287]

Geopolitical considerations

Despite its advantageous geopolitical location bordering the three markets of Asia, Europe and Africa, most of the hydrogen produced in Saudi Arabia is considered to be long-distance transport. This is costly and more complicated in terms of safety measures and technologization. At the same time, Saudi Arabia has a local infrastructure that is advantageous for spurring the development of a hydrogen economy. With "more than 10 thousand kilometers of natural gas pipelines […], the natural gas infrastructure provides an accelerator for the hydrogen economy."[288]

[287] Ibid.
[288] Abdulaziz AlTurki, https://www.linkedin.com/feed/update/urn:li:activity:7047272430519611392/

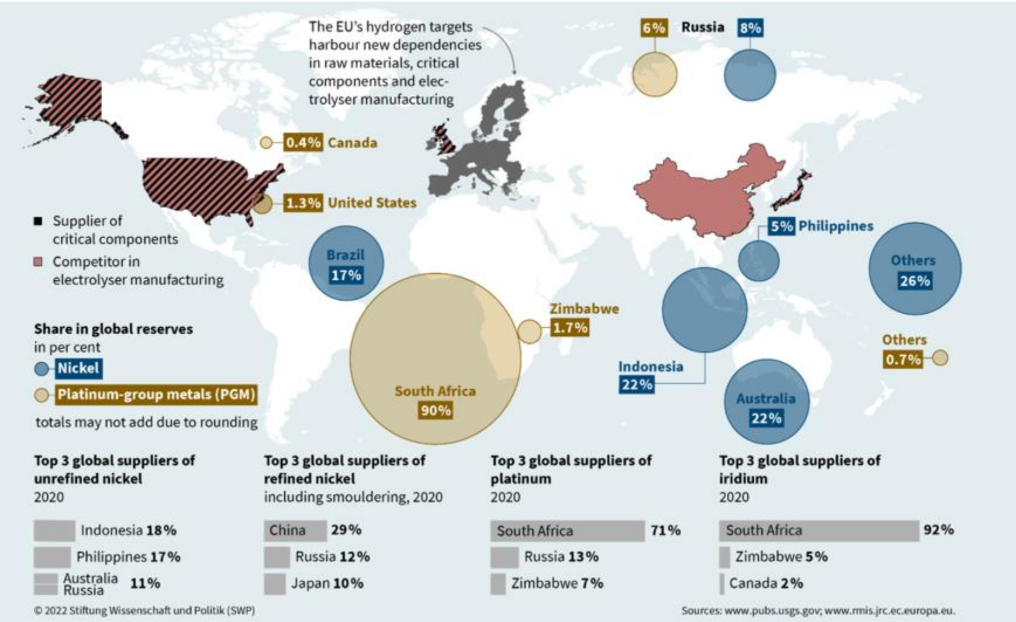

Figure 47: Overview of global competitors in electrolysis manufacturing and raw materials supply[289]

Saudi Arabia´s location benefits the country when it comes to secure the supply of critical minerals and raw materials, which are not domestically available. Already now, Saudi Arabia is seeking more strategic partnerships with these suppliers. In autumn 2022, a Saudi delegation visited South Africa "to explore investment opportunities to become a global supplier of hydrogen and emerge as a hub for green mineral and highly competitive manufacturing."[290] In future, Saudi policymakers should expand these partnerships as well as further developing their own mineral sector and capacities to become a key supplier and exporter of critical elements. Here, the Saudi government should focus on a sustainable resource management strategy including the extraction, usage and conservation of its own mineral resources. When considering the geopolitics of hydrogen, further security and safety aspects must be mentioned as well because hydrogen is highly flammable and explosive. Many still remember the massive explosion of the hydrogen-filled zeppelin Hindenburg in 1937 that led to an abrupt end of Germany's zeppelin economy.[291] While

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[289] Ansari et al. 2022
[290] Arab News 2022, Saudi Arabia explores opportunities in South Africa to become global supplier of hydrogen https://www.arabnews.com/node/2174921/business-economy; **further**: https://solarquarter.com/2023/03/20/acwa-power-signs-agreements-for-1-4-gw-solar-pv-and-1-5-gwh-battery-storage-capacity-projects-in-uzbekistan/ **further**: https://hydrogen-central.com/al-mudaifer-saudi-arabia-become-global-supplier-hydrogen-center-green-minerals/
[291] Heymann 2009.

ammonia is not flammable in air as hydrogen, it has other security problems as it is highly toxic and corrosive. Potential leakages of ammonia can also cause acid rain. It is said that liquid ammonia and its 'apparent toxicity', meaning "the vapor pressure relative to the toxicity, at room temperature", is three times higher than that of gasoline and methanol.[292] Consequently, there must be debates about who takes responsibility of ensuring safe transport routes? Is it the producer or consumer side, or both? So far, no adequate answers have been provided to those questions. This is even more needed when considering that the broader region of the Arabian Peninsula and several countries, including Saudi Arabia, have been subject to attacks on oil facilities and ships. At the same time, in light of the current war in Ukraine, also Europe has experienced acts of sabotage against its energy infrastructure with the blasting of the North Stream pipeline. This kind of high vulnerability in light of a global hydrogen economy must be carefully considered.[293]

Human capacity and labor market dimension

"Vision 2030"'s Human Capability Development Program (HCDP) outlines ambitious goals to reform the educational system to empower Saudi nationals in competing globally in terms of skills and values. Upskilling and supporting innovation and entrepreneurship culture have been defined as key pillars of Saudi Arabia's educational reforms to prepare the young generation for the future local and global labor market. In doing so, the government aims to overcome traditional shortages in the educational system that was dominated mainly by religious studies and social sciences but was lacking competitive training in engineering, natural sciences, technology, mathematics, foreign languages, arts, and vocational skills. The strategy thus explicitly outlines remaining challenges as "traditional and non-renewable educational methods and curriculum continue to be used in the Kingdom's educational system" and defines the system as non-flexible and compulsory. Hence, nationalization efforts and educational reforms seem to promote so-called "good jobs" that are influencing the way in which work affects family life, social integration and health and are influenced by contextual social factors such as socioeconomic and/or educational background, class, and gender.[294] By taking this definition into consideration, "good jobs" provide basic needs, the ability to save, and the opportunity to lead a productive and healthy life.[295] Against this backdrop,

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[292] Klerke et al. 2008, p. 2305.
[293] Zumbraegel 2022, Hydrogen partnerships between Germany and the Gulf: Too fast and too soon?, TRENDS, https://trendsresearch.org/insight/hydrogen-partnerships-between-germany-and-the-gulf-too-fast-and-too-soon/
[294] Almoaibed, H. Thompson, M. (April 2023), Better Jobs Tomorrow: The Appeal and Increasing Relevance of Alternative Credentials in Saudi Arabia. King Faisal Center for Research and Islamic Studies. https://www.kfcris.com/en/view/post/407.
[295] Almoaibed, H. Thompson, M. (July 2021), "Good Jobs and Bad Jobs": Employment Attitudes, Perceptions, and Priorities in Saudi Arabia. King Faisal Center for Research and Islamic Studies. https://www.kfcris.com/en/view/post/350

the educational reforms in Saudi Arabia also intend to prepare the youth for "better jobs tomorrow"[296] that do not only aim to generate income but also incorporate values such as green environmentalism or sustainability. In HCDP, renewable energy and engineering are mentioned among four main fields of knowledge on which the educational reforms aim to focus on.

Against this backdrop, the hydrogen economy provides an excellent opportunity to create direct and indirect "good jobs" along the supply chain.[297] This will include renewables (mainly solar and wind), electrolysis systems producing hydrogen, from up-, mid- and downstream in addition to innovative demand-side processes. New decision-makers seem to follow an output-oriented and pragmatic hands-on approach to transform the educational system and make it globally more competitive.[298] Furthermore, the hydrogen economy requires substantial infrastructure development, initital R&D[299], transmission, and transportation, technology development and support, operation services and maintenance.[300] Along the supply chain, additional direct and indirect jobs in the petrochemical and chemical industry, mobility, mining, or further industries such as steel, cement, food and beverage or agriculture are expected to be created. Studies estimate that about two-thirds of the hydrogen used in 2050 would be for energy (not industrial feedstock) and about one-third of that would flow to end uses in transport, storage (reinforced pipelines and tanks to resist hydrogen corrosiveness) and mobility (railways, road construction, marine and aviation), buildings and agriculture (rather than industry).[301] Furthermore, demand in jobs varies from the different types of hydrogen: Jobs related to green hydrogen could be created in road transport and heating for buildings. On a global level, green hydrogen is expected to create 30 million jobs by 2050 and generate USD 2.5 trillion of annual revenues worldwide.[302]

[296] Almoaibed, H. Thompson, M. (April 2023), Better Jobs Tomorrow: The Appeal and Increasing Relevance of Alternative Credentials in Saudi Arabia. King Faisal Center for Research and Islamic Studies. https://www.kfcris.com/en/view/post/407.
[297] Interview with Saudi energy expert, Riyadh, May 24, 2023.
[298] Interview with international expert on the Saudi educational and training system, Riyadh, May 24, 2023.
[299] Bachhaus, A. Jongsma, C. Leguijt, C. van den Toorn, E. (April 2021) Jobs from investment in green hydrogen. Update and extension. CE Delft. https://cedelft.eu/wp-content/uploads/sites/2/2021/04/CE_Delft_200427_Jobs_from_investment_in_green_hydrogen_Def.pdf.
[300] Rodríguez, P. (January 2023) Betting on green hydrogen to fulfil employment growth. https://cicenergigune.com/en/blog/green-hydrogen-employment-growth.
[301] Van Renssen, S. (May 2021) Hydrogen tests climate policymakers with its job potential. https://www.energymonitor.ai/tech/hydrogen/hydrogen-tests-climate-policymakers-with-its-job-potential/.
[302] Rodríguez, P. (January 2023) Betting on green hydrogen to fulfil employment growth. https://cicenergigune.com/en/blog/green-hydrogen-employment-growth.

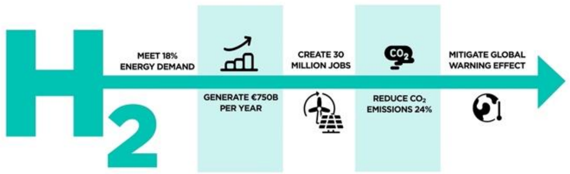

Figure 48: Global green hydrogen potentials[303]

For the GCC region, regarding the educational skills, the hydrogen sector offers huge potential for job creation as outlined below.

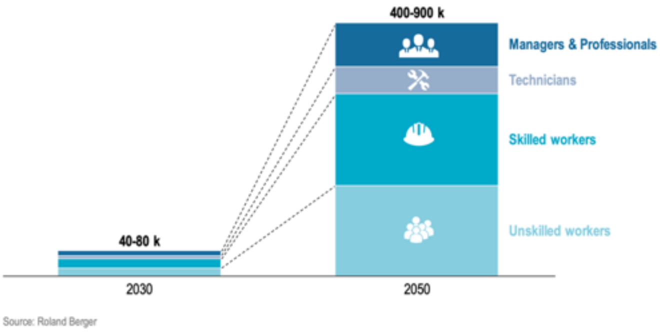

Figure 49: Potential job creation by educational skills in the GCC hydrogen sector[304]

Again in the GCC region, the bulk of jobs per category is provided within the hydrogen sector.[305] No specific data for Saudi Arabia is available.[306] Nonetheless, as the country has the largest population across the region and considers localization a top priority, we expect to see the majority of those jobs created in the Saudi hydrogen economy followed by Oman and the UAE that also promote their local hydrogen industries.

[303] Ibid.
[304] Roland Berger Middle East W.L.L and Dii Desert Energy (n.D.) The potential for green hydrogen in the GCC region. https://www.menaenergymeet.com/wp-content/uploads/the-potential-for-green-hydrogen-in-the-gcc-region.pdf.
[305] Ibid.
[306] Interview with international expert on the Saudi educational and training system, Riyadh, May 24, 2023.

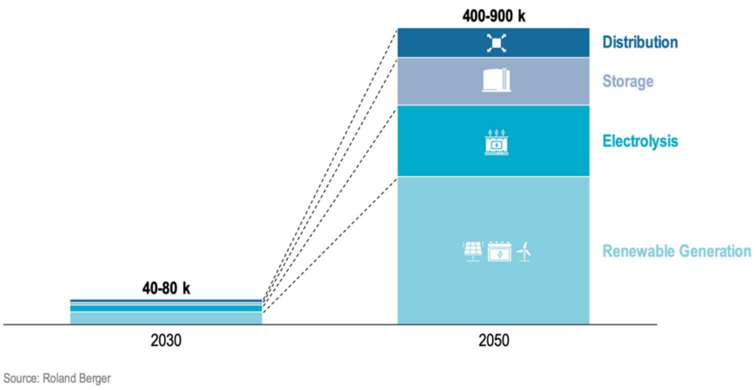

Figure 50: Potential job creation in the GCC hydrogen sector[307]

Localization offers the most potential for job creation. Here, Saudi Arabia is investing in R&D activities and needs human capital in transport, storage, services, maintenance, or management. Specific sectors are of utmost priority: Manufacturing of non-complex PV components (e.g., mounting structures, cabling), wind energy components, and electrolysers is expected to be localized in the short-term, leveraging the current Saudi capabilities.[308] As Saudi Arabia aims to localize its automotive industry by producing EV in partnership with Lucid as outlined above, this sector could also emerge as a driver for national job creation. As the EV mobility features prominently in the Kingdom's diversification and localization efforts, the educational system should prepare for a growing demand in EV-related jobs. In the mining sector, the extraction of cobalt, copper, lithium, nickel and zinc is highly capital-intensive but large-scale high-skilled employment opportunities are limited as a bulk of the jobs is needed in the construction of new mine sites and related infrastructure.[309] As a consequence, new academic and corporate programmes for education, acreditation and vocational training, upskilling or reskilling of the existing workforce need to be developed. As already outlined before, the long-term experiences in education and vocational training in the oil, petrochemicals and mining sector provide Saudi Arabia an excellent opportunity to enhance learning mechanisms for hydrogen-related education as part of the "good jobs" narrative on an academic, vocational training, and community-based level. As compatibility in skills exist between the oil and

[307] Roland Berger Middle East W.L.L and Dii Desert Energy (n.D.) The potential for green hydrogen in the GCC region. https://www.menaenergymeet.com/wp-content/uploads/the-potential-for-green-hydrogen-in-the-gcc-region.pdf.

[308] Roland Berger Middle East W.L.L and Dii Desert Energy (n.D.) The potential for green hydrogen in the GCC region. https://www.menaenergymeet.com/wp-content/uploads/the-potential-for-green-hydrogen-in-the-gcc-region.pdf.

[309] International Renewable Energy Agency (2022) Renewable Energy and Jobs. Annual Review 2022) https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Sep/IRENA_Renewable_energy_and_jobs_2022.pdf.

hydrogen industries, requirements to start developing an educational system from scratch are reduced. On a social level, more awareness for "good jobs" in hydrogen is emerging, as young nationals consider the sector as a promising opportunity to work in the green energy field.

However, expectations need to be managed properly. Based on international data, jobs in the hydrogen construction sector are mainly for semi- and non-skilled migrant laborers from Asia and Africa rather than for Saudi nationals. In fact, job creation during the operation stage is less than a tenth of the early years during the construction of the project.[310] Most of the jobs are linked to hydrogen application, transport, or storage and not production, which also needs to be taken into consideration. Next, R&D jobs needed in the inauguration phase of the hydrogen economy could be replaced with a growing number of jobs in the construction and operation of green hydrogen production plants and the required infrastructure for hydrogen.

So far, data on graduates in hydrogen-related disciplines and vocational training seminars is lacking. Also, no comprehensive overview on academic and technical, governmental and private institutions exists that would provide more detailed information on extisting academic programs in hydrogen engineering or capacity development measures provided by energy companies. Definitely, a growing number of concerned entities has included hydrogen training into their portfolio and curricula, and started to educate and empower young engineers in hydrogen technologies. So far, the sector relies heavily on expertise from abroad but several entities in Saudi Arabia are developing special curricula to train hydrogen experts along the supply chains. It is further intended to develop upskilling training schemes including on-the-job trainings for the workforce to gain first-hand experience.

Research

On an academic level, some Saudi universities habe established hydrogen courses and training schemes.

- The most outstanding example is the **King Saud University (KSU)** which has developed a Master of Science in Renewable Energy including its three specialization tracks (1) solar energy technology, (2) wind energy technology, and (3) hydrogen energy technology. Out of 24 courses, four are dedicated to hydrogen.
- Furthermore, the **Hydrogen Energy Group** at KSU's Sustainable Energy Technologies Center (SETC) aims to design first generation prototype devices, which can generate hydrogen from catalytic water splitting based on solar energy and focuses on hydrogen production, storage, and

[310] Gielen, D. Lopez Rocha, S. Lathwal, P. (January 2026). Make Hydrogen in developing nations: share prosperity shile meeting our climate goals. https://energypost.eu/make-hydrogen-in-developing-nations-share-prosperity-while-meeting-our-climate-goals/.

utilization.[311] SETC also provides Graduate Studies & Training courses and cooperates with international partners such as KACARE, KACST, Électricité de France (EDF), the German national aeronautics and space research center (DLR), Tokyo University from Japan, and the Massachusetts Institute of Technology (MIT) to only mention a few.[312]

- **King Fahd University of Petroleum and Minerals (KFUPM)** has launced its interdisciplinary research center for hydrogen and energy storage (IRC-HES) in May 2021 which aims to explore multiple promising fields in applied sciences with a special focus on production of blue and green hydrogen, hydrogen separation and storage, and hydrogen utilization. The center has also inaugurated the Carbon Capture and Conversion program which focuses on sorbents for CO_2 capture, oxy-fuel combustion for cost effective CO_2 capture, electrochemical CO_2 conversion, and thermo-catalytic CO_2 conversion. It further aims to establish industrial partnerships with relevant companies and national entities and promote innovation and entrepreneurship, and develops teaching graduate programs in the field of Hydrogen and Energy Storage. [313]
- The **KAUST Solar Center (KSC)** serves as a platform for experts in materials science, chemistry and physics to explore innovative solutions for the harvesting and conversion of solar energy.[314] No detailed information on hydrogen-specific R&D is available but KSC offers excellent potential to include such component into its research portfolio.
- (CREPS) at **King Abdulaziz University (KAU)** provides consultation and solutions to utilities, companies and governmental bodies in the field of renewable energy and electrical power systems as well as the necessary training for technicians, engineers and researchers.

Business

- On a business level, hydrogen education and training is mainly conceptualized and organized by private companies and service providers cooperating with state-owned entities such as **Aramco**, **NEOM** and **ACWA Power** that have developed internal centers of excellence to train and empower their own staff in hydrogen topics. Those companies established training centers and facilities and also develop own curricula in different areas related to energy production including hydrogen.[315] The motivations behind such educational efforts to promote hydrogen are business-oriented as job creation is the top priority. For instanced, ACWA Power provides diploma programs for water and

311 King Saud University (February 2023). Hydrogen Energy. https://set.ksu.edu.sa/en/hydrogen-energy.
312 King Saud University (February 2023). About SET. Moving Towards a Green Environment. https://set.ksu.edu.sa/en/about-set.
313 KFUPM Interdisciplinary research center for hydrogen and energy storage. https://ri.kfupm.edu.sa/irc-hes.
314 KAUST Research Centers https://www.kaust.edu.sa/en/research/centers.
315 Interview with Saudi energy expert, Riyadh, May 24, 2023.

energy technicians and discusses plans to include hydrogen into such initiatives. As outlined by ACWA Powe representatives, those efforts aim to overcome the urban-rural divide and educate experts across the country. So far, the academic programs are mainly concentrated on urban centers which neglect other parts of the population.[316] External consultants are giving free trainings for employees to develop the own institutional knowledge. Here, hydrogen has become a new topic of interest.

- The already mentioned **SABIC Research and Innovation Center** engages in petrochemicals education and could thus provide a future platform for hydrogen education. For instance, programs such as NUSANED are promoting localization efforts and SME's. In addition, Sabic has launched Saudi HR Think Tank (SHRTT) in 2018 in partnership with the Ministry of Human Resources and Social Development to support capacity development in the Kingdom.[317] Other Sabic initiatives include scholarship programs for chemical engineering, industrial engineering, and mechanical engineering, and investment in MADAC Academy to train students in educational issues such as environmental and climate action.[318] In general, those programs could also incorporate hydrogen training courses into their future portfolio.
- Furthermore, the **Saudi Arabian Drilling Academy (SADA)** located in the Eastern province is engaged in drilling operations and training for drillers and engineers but does not explicitly offer hydrogen training courses. Its foundation in 2019 was part of a joint partnership between Saudi Aramco and Technical and Vocational Training Corporation (TVTC).
- In the mining sector, **Ma'aden** has also initiated a number of training courses but no concrete project deals with hydrogen-related topics.

So far, the main focus of such activities and programs is on hydrogen engineering whereas an interdisciplinary approach including other disciplines such as social sciences is lacking. As a consequence, Saudi interlocutors express a strong solution-oriented commitment on KPI and reports on ESG. However, environmental education does not seem to be a priority in the academic hydrogen programs.[319] As no comprehensive national hydrogen strategy exists, the landscape of hydrogen education providers is fragmented and coordination improvable.[320] Still, cross-institutional and multi-disciplinary cooperation

316 Interview with ACWA Power representative, Riyadh, May 25, 2023.
317 SABIC (n.d.) the role of the petrochemical sector in supporting high skill job creation and driving. https://www.sabic.com/en/newsandmedia/stories/our-business/the-role-of-the-petrochemical-sector-in-supporting-high-skill-job.
318 SABIC (n.d.) Sustainable Growth for a better world. Sustainability report 2022. https://www.sabic.com/en/Images/SABIC_Sustainability_Report_2022_EN_tcm1010-40888.pdf.
319 Interview with Saudi educational expert, Riyadh, May 25, 2023.
320 Interview with ACWA Power representative, Riyadh, May 25, 2023.

networks are limited between companies and universities and know-how transfer depends mainly on individuals. As external consultants are oftentimes highly involved in the development of training schemes, local expertise needs more promotion and empowerment to realize localization efforts.[321]

[321] Interview with international expert on the Saudi educational and training system, Riyadh, May 24, 2023.

Conclusion

The study provides a comprehensive overview on Saudi Arabia's ambitious efforts to develop a sustainable hydrogen economy as a driver for energy transition and economic diversification. It thus argues that the Kingdom is undergoing a substantial transformation period and aims to position itself as a regional and global hub for the growing hydrogen economy.

Against this backdrop, Saudi stakeholders consider the integration of hydrogen into the current energy transition as a holistic and cross-sectoral approach that includes a variety of sectors in order to develop domestic and regional supply chains: From construction, business and project development, R&D, logistics to education and vocational training as well as job creation – the hydrogen economy provides an excellent chance for economic diversification. Hence, the study follows a multidimensional concept that defines energy transition as a long-term and multi-faceted way to identify value chain activities in Saudi Arabia, determine these activities according to Saudi Arabia's energy transition targets. Eventually, it evaluates future activities and identify opportunities for competitive advantage towards a hydrogen development.

Given the potential role of the mining and petrochemicals sectors, the Kingdom intends to acquire first-mover advantages that are also crucial for the ambitious goals to develop a competitive hydrogen economy. National champions such as SABIC or Ma'aden are main drivers of the petrochemicals and mining sectors that are heavily investing in the production of ethylene glycol, methanol as well as polyethylene and polypropylene, and the extraction of gold, zinc, copper, or for instance nickel. Both sectors are highly diversified, provide the necessary infrastructure and investment incentives for both national and international stakeholders. They possess the industrial quality and skilled managerial and entrepreneurial expertise in technical consultancy and services, engineering, machinery and equipment, and marketing of products.

Both the petrochemical and mineral industries are also large producers and consumers of hydrogen: As petrochemicals are integral parts of the renewable technologies, Saudi Arabia is highly interested to develop its hydrogen industry building upon its petrochemical sector. In addition, hydrogen energy could promote the extraction and import of critical minerals such as nickel, zinc, iridium, and platinum. Saudi Arabia is also a key producer and exporter of natural gas-based grey ammonia and could expand this sector towards green and blue ammonia. Relevant infrastructure is already existing in terms of pipelines, ports, and logistical facilities or under construction.

Hence, both sectors play an integral part throughout the entire hydrogen cycle. Building on those state-of-the-art industries, the hydrogen sector could benefit from outstanding R&D capacities and facilities, a well-equipped industry that provides regional networks and enhanced infrastructure, training and educational schemes for young talents and a growing industrial sector that is driven by localization, diversification, and nationalization. Definitely, hydrogen can enable many processes in the energy industry. While it is currently used in different sectors such as petroleum, fertilizers, chemicals, and food, its relevance is likely to grow and expand to other fields. In this regard, hydrogen can decarbonize many existing industrial processes. One of them is iron and steel production. Other sectors include the local EV industry, recycling based on hydrogen, hydro cracking to refine petrochemicals, hydro processing to produce sulphur and nitrogen-based compounds as well as the production of petrochemicals such as methanol and polypropylene.

By promoting industrial diversification, the Saudi government does not only want to generate additional non-hydrocarbon revenues from the hydrogen economy but also to create jobs. Despite significant progress on the job market, youth unemployment remains a challenge. Therefore, the hydrogen economy provides an excellent window of opportunity for a Saudi work force to find new jobs in production, construction of industrial facilities, R&D, logistics and services, business development, marketing, and processing. Localization of industries and nationalization of the work force are defined as “Vision 2030”'s key pillars which are the main drivers for the Kingdom’s current educational reforms. As part of those efforts, new university programs and courses focusing on hydrogen education have developed, complemented by special training and skills initiatives introduced by companies such as ACWA Power or SABIC. In doing so, local expertise on the hydrogen economy is growing by educating a rising number of young female and male talents. In particular, the empowerment of women is a great opportunity for Saudi Arabia’s efforts to develop a sustainable and competitive hydrogen industry. Besides the petrochemicals and mining sectors, the number of jobs is expected to grow in the manufacturing of electrolysers, EVs and related fuel cells, in the aviation and railway, design and installation-related activities, the operation and maintenance sector, and the hydrogen storage if the educational system is continuing to adapt to new needs and demands of the job market. Hence, academic and business institutions are interested to further promote training skills and integrate hydrogen education into their curricula.

Regarding international cooperation, Saudi Arabia has entered a variety of partnerships to promote its hydrogen economy. As political and business networks have been established and research collaboration is also of utmost relevance, the potential to advance multilateral and international cooperation in the fields of skills training, young talents’ empowerment, and know-how transfer is excellent. Here, a growing number of technical and vocational training centers, SME’s and entrepreneurial initiatives, research institutions and universities focus on hydrogen economy and future opportunities for employment.

Facilitators such as GIZ H2diplo are excellent door openers to initiate such partnerships in the fields of hydrogen education and job creation.

Annexes

Annex 1: Selected infrastructural and industrial projects in planning[1]

Project	Volume in million USD	Implementing company
Yanbu Crude Oil To Chemicals (COTC): Refinery Package	20,000	Saudi Aramco/Sabic
3,5 GW Gas Fired Power Plants in Al-Qassim and Taiba	8,000	Saudi Power Procurement Company
Jeddah Islamic Port Expansion	7,000	Saudi Ports Authority (Mawani)
Hydrogen Production Plant	6,500	PIF
Nuclear Power Reactor: Package 1	6,000	King Abdullah City for Atomic & Renewable Energy
Renewable Energy Program: Round 4 (Wind and Solar; 3,3 GW; 5 Projects)	4,600	Renewable Energy Project Development Office
Riyadh Dammam High-Speed Rail	4,500	Saudi Railway Company
Integrated Flat Steel Complex in Ras Al- Khair	4,000	Essar
Upgrade of Sewage Treatment Plants: 5 Packages	2,150	National Water Company
NEOM City: The Line: High Speed Rail: Signalling and Rolling Stock	2,000	NEOM

Annex 2: Selected Economic Indicators, 2020-23[2]

	2020	2021	2022 (proj.)	2023 (proj.)
Real GDP growth	-4.1%	3.2	7.6	3.7
Non-oil GDP growth	-2.5	4.9	4.2	3.8

CPI Inflation (avg, %)	3.4	3.1	2.8	2.2
Revenue (% GDP)	29.6	30.9	31.8	32.0
Expenditure (% GDP)	40.8	33.2	26.4	27.1

Annex 3: Strategic investments of the Public Investment Fund (PIF)

	Strategic domestic investments		
Name	Location	PIF stake / Investment volume	Sector
AMAALA Company	Red Sea region	100%	Developing tourist resorts, rehabilitation, health and treatment
King Abdullah Financial District (KAFD) Development & Management Company	Riyadh	100%	Financial services, residential and commercial area
Elm Information Security Company	Riyadh	100%	Digital services and AI
ACWA Power	Riyadh	50%	Power generation, renewable energy, water
Saudi Arabian Investment Company (SAIC)	Riyadh	100%	Cross-sectoral national and international investment
National Unified Procurement Company (NUPC)	Riyadh	100%	procurement and logistics services to secure pharmaceutical supplies and medical devices
Saudi Agricultural and Livestock Investment Company (SALIC)	Riyadh	100%	local and foreign investments in food security
noon Company	Dubai, UAE	50%	e-commerce

Saudi Information Technology Company (SITC)	Riyadh	100%	digital and cyber services and solutions
Saudi Arabian Military Industries (SAMI)	Riyadh	100%	Defense and military services
Saudi Real Estate Refinance Company	Riyadh	100%	Real estate and housing
National Energy Services Company	Riyadh	100%	Energy efficiency
Saudi Investment Recycling Company	Riyadh		Waste management and recycling
The Helicopter Company (THC)	Riyadh	100%	First national helicopter company, aviation and air services, Emergency Medical Services (EMS), tourism
Saudi Entertainment Ventures Company (SEVEN)	Riyadh	100%	entertainment
Selected international strategic investment			
SoftBank Vision Fund	London, England	USD 45 billion	as Internet of Things (IoT), Artificial Intelligence, Healthtech and Fintech
US Infrastructure Investment Program	United States	USD 20 billion	infrastructure projects
Russian Direct Investment Fund	Russia	USD 10 billion	infrastructure, manufacturing, logistics and retail sector
Investment program in Brazil	Brazil	USD 10 billion	private equity and infrastructure
Uber	United States	USD 3.5 billion	Car sharing, transportation
Amazon	United States	USD 432 million	e-commerce
Blackrock	United States	USD 451 million	
French Private Equity Investment	France	USD 2 billion	private equity, credit, and infrastructure

Jio Platforms	India	USD 1.5 billion	telecommunication and digital services
Reliance Retail	India	USD 1.3 billion	Physical retailer
Lucid Motors	United States	USD 1.5 billion	Electric car production
AccorInvest	France	USD 4.6 billion in a consortium together with GIC, institutional investors Colony NorthStar, Crédit Agricole Assurances and Amundi, and other private investors.	Hotels operations
Babylon Health	UK	USD 500 million	Telemedicine
Electronic Arts	United States	USD 3.3 billion	Gaming
JPMorgan Chase	United States	USD 433 million	Financing and equity
Meta	United States	USD 474 million	Digital services
Microsoft	United States	USD 473 million	Digital services, AI, communication
PayPal	United States	USD 492 million	Digital financing services
Starbucks	United States	USD 482 million	Beverages and food

Annex 4: **KSU training courses with a special focus on hydrogen**[322]

Name of the course	Details
Renewable Energy 2: Wind, hydrogen and other energies	Wind energy distribution, Wind power, Wind turbines, Wind farms and energy generation, Hydrogen: Energy generation, Hydrogen energy transfer, Hydrogen: Fuel cells, Types of fuel cells, Hydropower, Ocean thermal energy conversion, Biomass: Energy feedstock, Biomass: Municipal solid waste, Biomass: Liquid and gaseous fuels, Geothermal energy, Tidal energy, Wave energy, Renewable energy contribution and

[322] King Saud University (January 2023) Master of Science in Renewable Energy. https://engineering.ksu.edu.sa/en/node/3464.

	energy balance, Typical projects: Renewable energy and the environmental issues.
Hydrogen Production	Chemical Production of hydrogen, Partial Oxidation, Steam Reforming, Thermal Decomposition, Syngas, Shift reaction, Methanation, Hydrogen Purification, Desulfurization, CO2 Removal, Electrolytic Hydrogen, Liquid Electrolyte Electrolyzers, Solid Polymer Electrolyte Electrolyzer, Ceramic Electrolyte Electrolyzer, Photolytic Hydrogen, Solar Photolysis.
Hydrogen Storage	Compressed Gas, Cryogenic Hydrogen, Storage of Hydrogen by Adsorption, Storage of Hydrogen in Chemical Compound, Metal Hydrides, Hydrogen Storage Materials, Graphite Nanofibres, Sponge Iron, Glass Microspheres, Carbon nanotubes, Aerogels.
Selected Topics in Hydrogen Technology	Materials selection, Catalyst Preparation including nano catalysts, Characterization of catalysts, Infrastructure and distribution of hydrogen, Economic aspects of using hydrogen, Innovation in hydrogen technology