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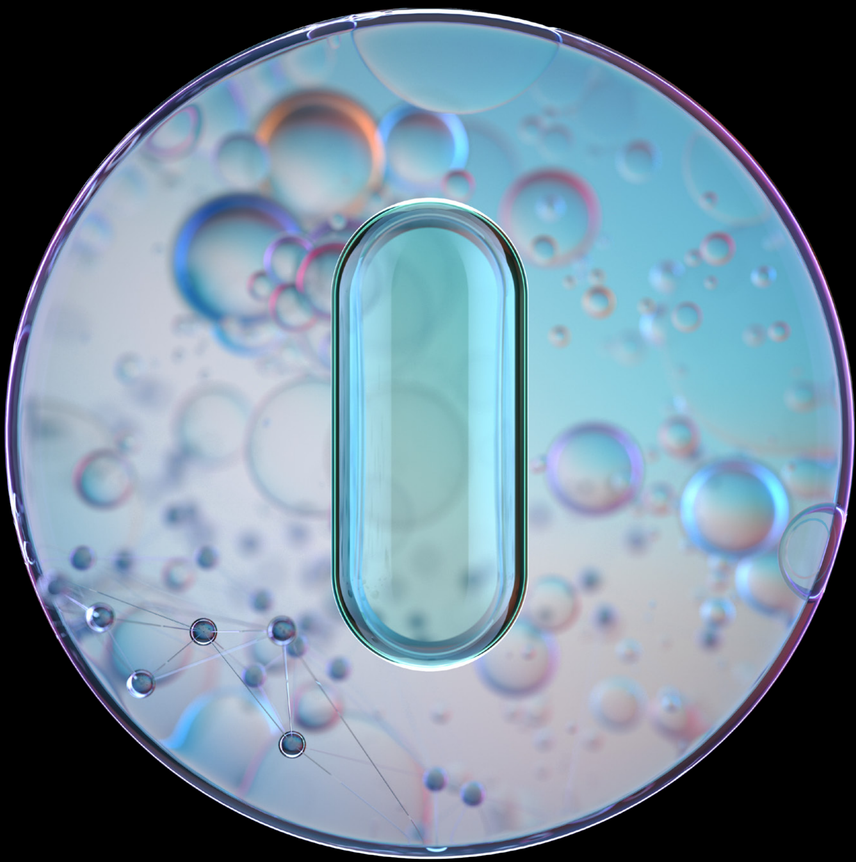


Unfolding the Hydrogen system map

The formula to establish the Hydrogen ecosystem

MAKING AN IMPACT THAT MATTERS since 1845

Contents

Introduction

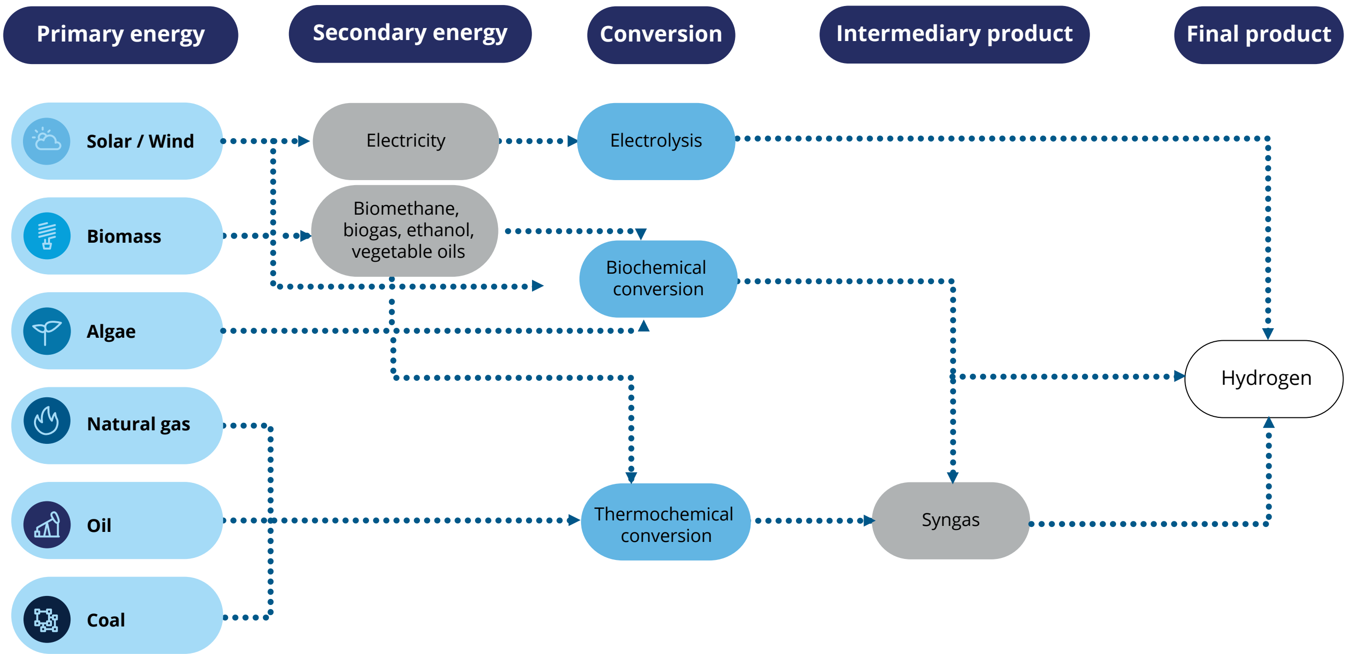
Toward a hydrogen future

Climate change has forced nations and supranational organizations to define new, stringent rules to combat its negative impacts on ecosystems. Specifically, the COP26 climate change conference[1], held in Glasgow in autumn 2021, has set new objectives for countries' agendas to minimize greenhouse gas emissions, which are recognized as the most harmful element to the environment, and to keep the global warming of the post-industrial era to no more than 1.5° Celsius[2]. Decarbonization has been identified as a key lever to combat the rising temperatures, spurring countries to find new, alternative energy sources to support the energy transition. Countries across the globe, led by major energy-producing nations, such as those of the GCC, have committed to new strategies to support the decarbonization process and have identified hydrogen as the most environmentally sustainable alternative to other forms of polluting fuels due to its inherent properties.

Green hydrogen is recognized as an alternative way to decarbonize energy use, as the energy is stored through renewable processes (e.g., photovoltaic panels to capture solar energy) and then converted into hydrogen through the electrolysis of water. Its combustion releases water vapor into the air instead of carbon dioxide, making it by definition a viable sustainable product. For this reason, the green form of hydrogen is a candidate to lead the hydrogen economy in the long term as its properties have a negligible impact on the planet and the environment. Furthermore, some of hydrogen's intrinsic characteristics, such as its very low volumetric density compared to natural gas, make it feasible to convert into different states (e.g., liquefaction to transport as liquid hydrogen) that allow distribution over long distances.

Hydrogen can be produced in different ways depending on the primary energy source utilized, as shown in Figure 1[3], and its production process minimizes or even eliminates carbon emissions, as in the case of green hydrogen.

Figure 1 - Hydrogen production methods



Advantages and opportunities for the GCC

Although hydrogen features key properties that make it one of the best possible alternatives for hydrocarbon energy carriers in the hard-to-abate sectors, not all countries possess the value propositions required to become leaders in this new period of energy transition. Using green hydrogen as the access to renewable energy sources is a key element to enable its production at competitive costs vis-à-vis other energy carriers such as natural gas. In this regard, net export countries such as those of the GCC have a major advantage over other potential producers, due to the key value propositions shown in Figure 2[4].

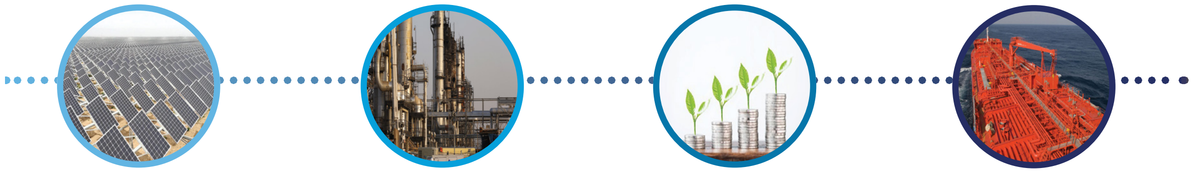
The main attributes at the disposal of GCC countries that can enable them to lead in the post-carbon era are the abundant availability of different renewable energy sources, advanced infrastructure, and solid proven shipping routes representing a strategic asset to export hydrogen to high-demand energy countries such as some of those within Europe and Asia-Pacific.

From another perspective, hydrogen represents an unleashed opportunity for GCC countries to significantly diversify revenues for their national budgets, which are currently characterized by a heavy reliance on oil and gas sales. As the energy transition implies a gradual decline in demand for fossil fuels from global markets, GCC countries cannot continue exposing themselves to the risk of not being fully equipped to be a key supplier of one of the future major clean energy carriers.

The coming years will shape the future of hydrogen and will clearly define each country's role in the global energy market. As this market develops, it is vital to strategically accelerate investment in hydrogen projects to maintain a position as a key supplier in the future energy market, and to finally meet the compelling need to diversify national economies away from non-climate-friendly fossil fuel revenues.

The coming years will shape the future of hydrogen

Figure 2 - GCC countries' key advantages



1 Abundance of high-yield solar energy

2 Potential to retrofit current fossil infrastructure

3 Solid availability of funding

4 Central location to ship to key energy demand markets

Key elements for the GCC to create a successful hydrogen economy

Having affirmed the relevance of becoming a key player in the clean hydrogen market, GCC countries need to be aware of the fundamental elements to successfully set up a hydrogen economy. Monitor Deloitte has identified three key factors which are critical for establishing a leading position as a clean hydrogen player worldwide. These key factors are: technological advancement, governmental push and dedicated investments.

Introduction:

Technological advancement:

Different technologies are used to produce clean hydrogen, but in the new era of green opportunities one stands out:, water electrolysis, which is the conversion of renewable energy resources using water as a feedstock into hydrogen through the electrolysis of water.
To enable significant cost reductions and improve production efficiency, the technologies used in two main stages of the value chain (i.e., primary energy sources creation and conversion both to hydrogen and byproducts such as ammonia) still have significant room for improvements. Such improvements are the key required element to consolidate an integrated ecosystem that is able to create value at low cost, in parallel to further improvements in infrastructure installation methods, foundation designs, logistics, and the digitalization of the industry.

Case study 1

The case of offshore wind turbine technology leadership in Denmark

To understand the advantages that can be delivered by technological advancement, the case of offshore wind turbine development in Denmark offers many lessons. Offshore wind energy harvesting is more expensive than onshore, due to upfront costs, such as foundation installation and components logistics, as well as more elaborate safety procedures and higher maintenance costs. However, the financial burden is significantly reduced by the supply of more consistent wind resources, as well as fewer concerns related to the physical surroundings.

Denmark was a market pioneer in offshore wind energy, establishing the world's first offshore wind farm in 1991, and the Danish value chain now encompasses a wide range of technology and services aimed at all phases of offshore wind energy projects. The country is on course to increase from today's 20 gigawatts (GW) installed capacity to 400-450 GW by 2050[5] – a substantial rise.

Offshore wind plays a crucial role in the decarbonization strategy for countries rich in wind resources, such as Denmark, Ireland and the UK. Denmark will concentrate its efforts in the future on carefully developing smarter solutions that will assure cost-competitiveness and minimize the country's reliance on imported fossil fuels. To achieve its ambitions, Denmark has established a best-in-class offshore wind ecosystem, with manufacturers having production and research and development (R&D) facilities within driving distance of one another, as well as wind turbine testing facilities to expedite the rollout of innovative solutions. Hundreds of enterprises in Denmark's wind industry make up a significant technological cluster. All types of expertise and services are readily available, making collaboration simpler and more agile. Furthermore, suppliers have streamlined access to participate in research, development, and testing, which provides the wind sector with accelerated competitive know-how and innovations, in addition to employment prospects to create value within the country.

Many multinational enterprises have been convinced of the benefits of establishing in Denmark over the years due to the closely collaborative ecosystem. As a result, the best-in-class offshore wind ecosystem makes Denmark the undisputed leader in the wind market, and this is mostly in light of the ongoing pioneering research in the field as well as the exhaustive wind competencies in close proximity to one another.

Figure 3: Offshore wind turbine value chain and relevant stakeholders[6]

Key takeaway

The GCC has the opportunity to leverage a similar approach early on for developing the hydrogen economy through geographically localizing an ecosystem which, thanks to the existing commitment to developing hydrogen-related R&D, will attract foreign talents and investments. Moreover, this will allow both leading and newly-established hydrogen companies to be located close to one another and leverage their synergies for a future hydrogen hub, enabling a significant competitive advantage in both the short and longer-term for the region, through both providing prospective projects with their needs and exporting to projects internationally.

Introduction:

Governmental push:

Government intervention is considered a key prerequisite to push the development of the hydrogen market and hydrogen adoption. The success of any new technology or ecosystem is strictly dependent on collaboration between private and public institutions, backed by solid governmental support substantiated by a set of relevant planet-friendly policies.

Case study 2

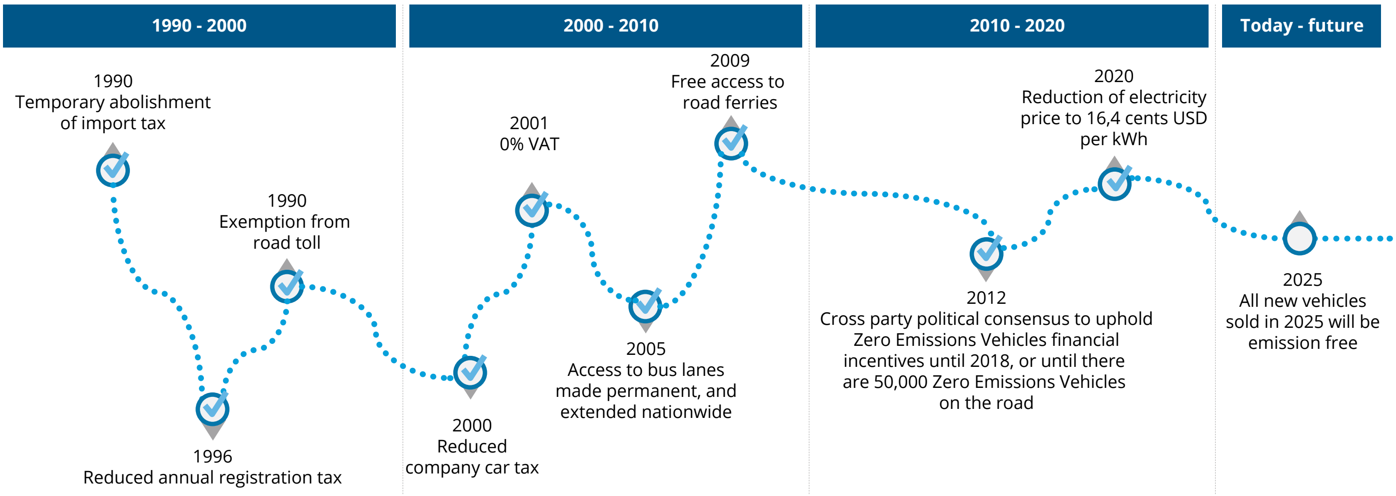
Norway EV policy-driven market creation

Norway leads the way in terms of electric vehicle (EV) adoption on a national scale. The country has been creating extensive and comprehensive EV incentive programs since the early 1990s and this foresight has paid off: a world record 69 percent of automobiles sold in Norway in 2020 were plug-in hybrids (with over 330,000 registered battery electric vehicles - BEVs)[7].

But what has been Norway's strategy to achieve such a remarkable result? Instead of providing big grants and subsidies to individuals (which has been a strategy pursued by the majority of EU countries), Norway offers considerable tax breaks to EV drivers to save money. Indeed, Norwegian taxes on high-emission vehicles are higher, whereas taxes on low and zero-emission vehicles are substantially lower. The higher taxes on polluting vehicles are used to fund zero-emission vehicle incentives without causing a revenue loss.

The Norwegian Parliament has set a target for all new automobiles sold in Norway to be zero-emission (battery electric or hydrogen) by 2025. Although this is a highly ambitious target, instead of leveraging a form of prohibition, the Parliament will achieve its aim by strengthening the green tax system: all new automobiles are subject to a purchase tax based on their weight, CO2 emissions, and NOx emissions. The fee is progressive, making large automobiles that emit a lot of polluting gases quite costly. The purchase tax has been steadily modified in recent years to provide more focus on vehicle emissions and less on weight. Although the import prices for EVs are higher, the progressive tax system makes it more affordable to buy EVs versus similar petrol models (e.g., the retail price of a Volkswagen Golf is €34,076 vs. €33,286 for a Volkswagen E-Golf). As a result, Norway's commitment has led not only to critical environmental benefits but also to solid cost savings for both private and public actors.

Figure 4: Norway EV roadmap



Key takeaway

Overall, governmental policies represent a game-changing element, regardless of the area of development. In the clean hydrogen economy scenario, an integrated governmental commitment built on a common strategy while taking into consideration the specificities for each of the GCC countries would also, if phased successfully, generate equally remarkable environmental, social, and economic benefits.

Introduction:

Dedicated investments:

The last key factor to trigger and accelerate the hydrogen economy is related to the investment component. Investments are certainly one of the most delicate and risky tools, but they have the power to catalyze any economic, sectorial or business development.

Figure 5: Morocco NOOR investments

Project components	NOOR I and NOOR II wind farms	Financing support mechanism
Project costs	$2723 M	$300 M
African Development Bank financing	$123 M	-
The International Bank for Reconstruction and Development	$100 M	$300 M
Clean Technology Fund financing	$238 M	-

Case study 3

Morocco investment value proposition to enable solar energy market advancement

When considering the importance of investments, it is worth learning from Morocco's use of them to develop a renewable solar-dominated sector. In 2006, 94% of the total energy in Morocco was produced from fossil fuels. During this prime time of fossil fuel consumption, Morocco was not wedded to any single technology related to renewables generation. However, it was determined to reduce its reliance on foreign fossil fuels and combat climate change[8]. To achieve this aim, the country established a target of achieving 42% of its power generation capacity demands through renewables by 2020, which was boosted to 52% by 2030 at last year's climate conference in Paris, France. Concentrated solar power (CSP) was selected as a solution to fulfill the country's present and future energy demands under this national strategy, substantiated by the abundant sunshine within its territories. The key lesson learned to achieve its goals was the significance of concessional financing in addressing the higher capital expenses of CSP in the short and medium-term. The Climate Investment Funds (CIF) provided US$435 million in concessional finance, which was used to raise more than US$3 billion from the World Bank Group, the African Development Bank, and other European lenders. The funding for solar projects in Morocco was an opportunity for international financial institutions to finance the development of a new technology that may be essential in the worldwide transition to renewable energy – thereby potentially delivering a global public benefit.

Technology investment, notably in the Middle East and North Africa (MENA), will make a significant contribution to lowering the cost of CSP locally, regionally and internationally through incorporating lesson-learned, technological and operational advancements in current and new developments. New CSP projects could generate new technological advances which, in turn, would lead to a drop in costs and an increase in energy efficiency. While concessional financing is still required to realize expectations, the entry of private investors within the Moroccan CSP market has led to a scaling up of investments in technology and attracted other resources of financing.

Morocco has taken the first step in demonstrating the technology's worth. The cost of technology has progressively decreased in the four years since the NOOR initiative, the first solar power plant in Morocco, was announced, while the technology has continually advanced. The CIF, the World Bank and other organizations continue to show willingness to provide nations and supernations with much needed concessional financing and technical assistance in order to start a green revolution and invest in renewable energy which is as reliable as the fossil fuels it will replace.

The entry of private investors within the Moroccan CSP market has led to a scaling up of investments in technology

Key takeaway

Investments are a fundamental component to enable economic transformation. Indeed, if designed correctly, investments will ultimately lead to the discovery of new technologies which, in turn, concurrently generate greater efficiency and cost reductions. The GCC could leverage an integrated investment strategy to develop a clean hydrogen economy and accelerate a project pipeline with the ambition to reduce costs for projects and technology development and to attract foreign private investors through providing attractive financial returns.

Technologies, governmental commitment, and investments combined represent the key elements to enable excelling in the hydrogen economy. It is therefore also valid that in any GCC clean hydrogen landscape these three elements would play an integral role in the creation of an ecosystem that would provide the following benefits:

- Localizing core technologies for supplying both domestic and global hydrogen markets
- Expediting the development of positive policies required by the different hydrogen ecosystem stakeholders
- Attracting local and foreign direct investments through providing a solid financial proposition

Clearly, the GCC countries should consider an integrated strategy that will encompass these key factors to both enable and accelerate the development of a clean hydrogen economy.

Models for growth and acceleration

The potential of hydrogen is now clear to the key energy players, who are developing strategies to create hydrogen ecosystems. Adhering to the standards dictated by the landmark Paris Agreement and which were revisited during COP26 is just one side of the coin; investing in what is considered the primary energy source of the future will dictate whether players take a leader or a follower position in the future global energy market, and define how countries are able to foster sustainable growth and support their own recovery from the fallout of the Covid-19 pandemic. The hydrogen value chain serving various industrial sectors will create substantial and new types of jobs that in the long term may accelerate a reduction in unemployment rates in those countries that take a leading role in the future of energy.

To fully develop new, integrated energy systems, several countries worldwide have both redesigned their national energy agendas and forged strategic sovereign alliances to capture the synergies required to reduce investment costs, create economies of scale, and speed up the entire development process.

This is the case of the European Union, which created the European Clean Hydrogen Alliance as part of the European Commission's ambitious 'New Industrial Strategy for Europe'. The Alliance's role will be to further facilitate and implement actions to increase the production and demand for renewable low-carbon hydrogen, in addition to the strategies designed at a national level by individual European countries.

The Alliance will also have the mandate to oversee and support the development at each stage of the entire value chain for clean hydrogen, from the procurement of primary energy sources to the distribution of the finished product, as well as researching new industrial applications.

Moreover, the Alliance will be central to facilitating interactions among various actors to provide the necessary public support and to attract much-needed private investment; it will also establish a dialogue with regional and national public authorities, public investors, private funders, and the political sector to identify a clear pipeline of feasible investment projects, facilitate investments, and help define the policies required to support the development of hydrogen projects across the value chain.

Figure 6 - How to foster the development of hydrogen

Indeed, a strong investment program to secure public support from the various EU and European Investment Bank (EIB) funds is needed to achieve the deployment targets set for 2024-2030 in the strategic roadmap. This investment program covers all the factors necessary for the development of the entire hydrogen value chain, starting with investments estimated at between €24bn and €42bn, from today until 2030, to produce electrolyzers at the desired scale. To supply renewable electricity to the electrolyzers, €220-340 billion is required to scale up and directly connect 80-120 gigawatts (GW) of solar and wind power generation capacity over the same period. The plan budgets for circa €11bn of investment to retrofit half of the already existing carbon capture and storage plants. In addition, investments of €65bn are estimated for hydrogen transport, distribution, storage and refueling stations. By 2050, the sum of the investments related to production capacity would reach €180-470bn in the EU, which is the amount needed to support the adaptation of end-use sectors to hydrogen and its derivatives consumption and fuels.

While the European Union Alliance is an outstanding example of effective sovereign intervention, the Australian Energy Council provides another model that countries could leverage when defining their economic visions for hydrogen.

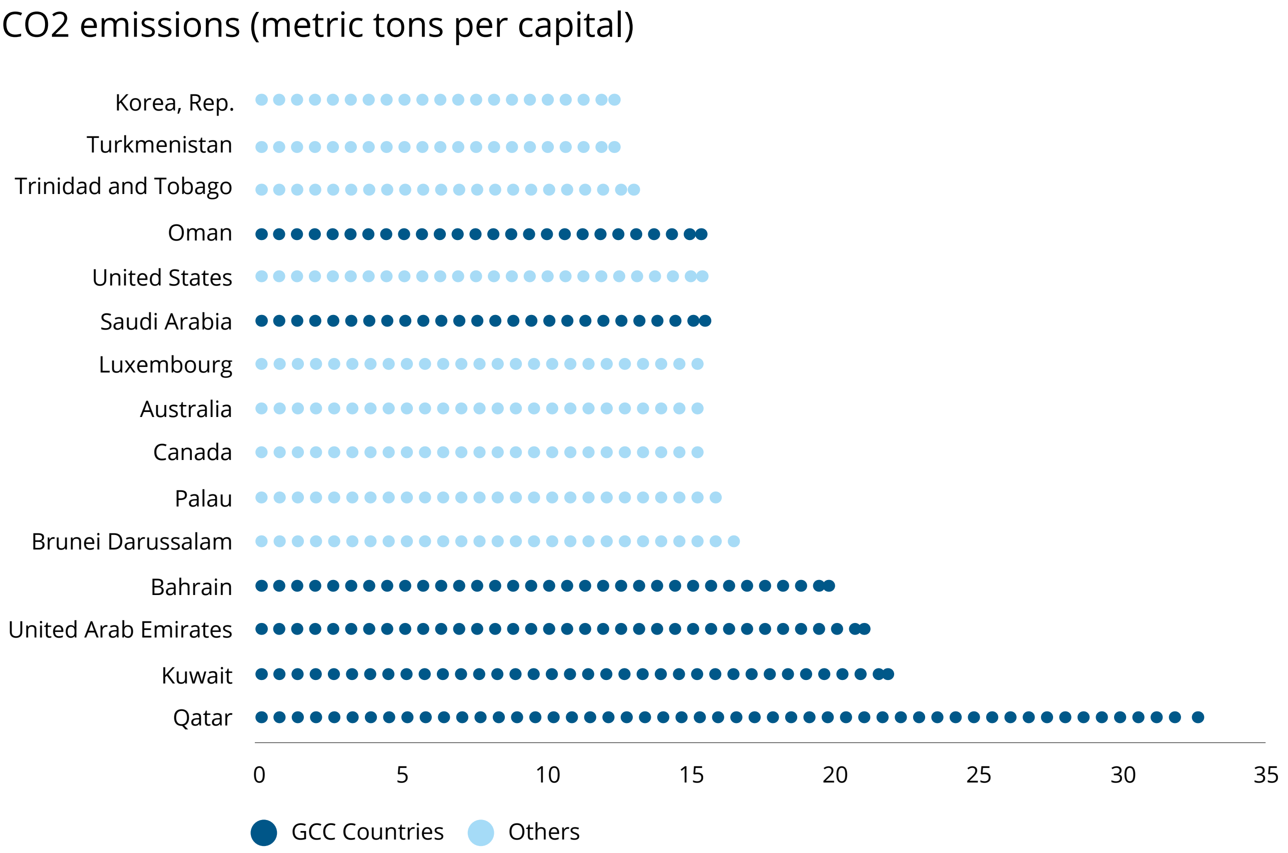
Four years ago, the Council of Australian Governments (COAG) Energy Council set out a vision for a clean, innovative, and competitive hydrogen industry that would make the country a major global player by 2030. The rollout of the national strategy will ultimately enable Australia to maximize the use of its resources and expertise to become a major energy producer and exporter. The country's enormous hydrogen potential was recognized as being capable of generating billions of dollars of economic growth by 2050, and of creating thousands of direct and indirect jobs.

With the Australian model, the benefits would not only relate to limiting the negative carbon footprint but also to significantly reducing the current dependence on imported fuels. Australia's strategic model will follow an adaptive approach, focusing initially on actions that remove market barriers, to build supply and demand and accelerate global competitiveness. To reduce costs at an international level, a key element will be the creation of hydrogen hubs to make infrastructure development more cost-effective, enable economies of scale, and promote synergies. The creation of the hubs will be accompanied by a longer list of strategic actions, 57 in total, to extend the use of hydrogen in transport, industry, and gas distribution networks, integrating it into the country's entire ecosystem.

At the heart of the Australian strategy stands the importance of national coordination of all the different actors to work cooperatively towards enabling the type of best-in-class environment required to unlock investment in hydrogen locally. Early on, Australia recognized how crucial it was to have a shared vision among the various stakeholders and considered it as a primary factor to becoming a major player in the post-carbon era.

The potential of hydrogen is also clear in most of the Middle East, where GCC countries have begun considering it as a top-priority sector for development in their national long-term visions. In the GCC, where the energy sector accounts for a significant portion of greenhouse gas (GHG) emissions per capita compared to the global benchmark as shown in Figure 7[9], efforts are being made to integrate hydrogen as a major energy carrier, as the outcome of being anchored to fossil fuels and declining energy sources could be devastating, not only for the environment but also to welfare nationally.

Figure 7: The GCC countries rank in the top 15 countries in CO2 emissions (metric tons per capita in 2018)



In addition to safeguarding socio-economic commitments to their residents, given the unique socioeconomic circumstances of GCC countries, green hydrogen provides these countries with an opportunity to both transition the economy and address climate targets as reflected at the national agendas shown in Table 1.

The potential of hydrogen is also clear in most of the Middle East, where GCC countries have begun considering it as a top-priority sector for development in their national long-term visions

Table 1: Energy transition agenda extract in the GCC

The Kingdom of Saudi Arabia seeks to become the de-facto supplier of hydrogen, with a target of producing and exporting 4 million tons of hydrogen by 2030[10].

Qatar plans to combat climate change and reduce GHG emissions to achieve a 25% reduction by 2030[11].

The United Arab Emirates reinforced its commitments to net-zero by 2050 through the Hydrogen Leadership Roadmap, which targets a 25% market share in the key export markets.[12] .

Kuwait has pledged to cut its emissions by 7.4% below business-as-usual levels by 2035 in its revised Nationally Determined Contributions[13].

Bahrain aims to reach net-zero carbon emissions by 2060. To help tackle climate change and protect the environment[14].

Oman has also established Oman's Hydrogen Alliance with the mission to diversify its fossil-heavy energy mix to realize climate change commitments through shifting toward green hydrogen[15].

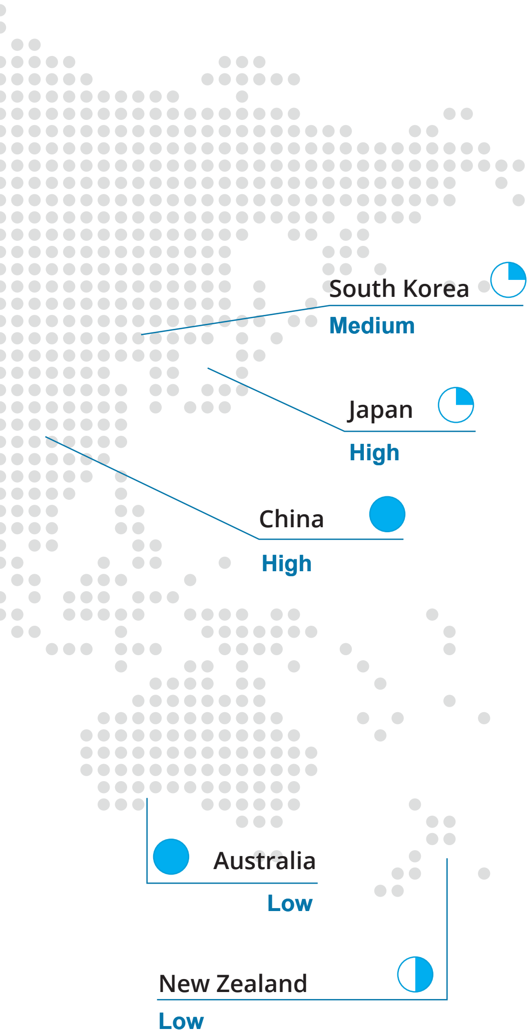
It is no secret that the GCC countries are privileged with accessibility to low-cost renewable energy, which in recent years has been ranked as the cheapest solar power, with the cost per kWh having dramatically dropped by ca. 75% in five years.

The low cost of energy sources combined with the winning factors are the key ingredients required to become major producers and exporters of hydrogen, as in many countries local consumption will be significantly higher than production capacity, as shown in Figure 8[16], giving GCC countries the opportunity to fill the gap.

In this global context, clearly most of the related economic benefits will depend on being able to export hydrogen to the international market rather than purely serving domestic consumption. Revenues that can be generated by exports are mainly driven by the presence of strong infrastructure development programs, the upskilling of talent, an unmatched focus on research and development (R&D), and the localization of technologies. Therefore, the ability of GCC countries to adapt their positional advantages to the specific needs of the emerging hydrogen energy economy will be crucial.

Mutually beneficial relationships among GCC producers and energy importing countries such as Japan, the development of unified policies, and the design of a comprehensive strategy at the sovereign level, just as the European Union did to create synergies, may foster the creation of a hydrogen ecosystem.In this case, GCC countries need to leverage their already existing capabilities to create local hydrogen usage within different sectors and in parallel start to export to the international market. The prioritization of investments in hydrogen and partnerships with first-class international actors to develop an advanced infrastructure featuring the latest technologies may unlock the potential that leads to a fully-fledged set of differentiated capabilities in the hydrogen economy of the future.

Figure 8: Hydrogen roadmap for key players



Integrated system dynamics for GCC governments to adopt

There are many papers, approaches and frameworks that have attempted to describe the evolving topic of the future of energy in general, and hydrogen specifically. Some have focused on the stakeholder landscape of the energy market, while others have examined the diversification of energy sources required to achieve carbon neutrality. Most race to respond to the cardinal question of 'how fast is the momentum of hydrogen adoption?

While these are valid angles and questions to explore, we are more concerned with the way hydrogen ecosystems are changing and the way that relevant private and public players respond to those changes. Therefore, in the following section we will explore 'systems thinking' and how it can be used to provide an integrated view of the future of hydrogen.

Systems thinking is an approach to understanding the non-linear behavior of complex systems by identifying and analyzing the dynamic, interlocking elements within it. It is a framing technique that can be used by the relevant private and public players to diagnose and identify solutions to kickstart a new sector by doing the following:

- Providing policy-makers with a holistic perspective of their hydrogen ecosystem that enables them to grasp the "bigger picture" of what is happening in the system, and what the actors are trying to achieve
- Helping navigate the private and public investment enablers in hydrogen to trigger and accelerate greater funding for hydrogen projects and supporting infrastructure
- Identifying the different dimensions for setting up the hydrogen research, development and innovation programs for success across the sector value chain
- Helping private and public actors see and understand the complexities of a problem to identify impactful points of leverage for long-term change
- Highlighting the dynamic interaction between individual elements within the system, helping private and public actors to identify processes of change which over time reveal patterns of behavior

Systems thinking is an analytical tool that can assist the way private and public decision-makers understand the causes of hydrogen market behaviors and structure the required coordinated responses to produce sustained results over time. Moreover, it can help decision-makers analyze the future of hydrogen, prepare for its impact and capitalize on the opportunities it presents.

How do you develop a systems approach?

A systems approach to the future of hydrogen considers the wider system of interlinked supply, demand and market factors. These factors, also known as elements, can be mapped according to their impact and interconnections. The mapping process requires decision-makers to gradually peel away layers of the hydrogen system to uncover more granularity and complexity.

At its top layer, the hydrogen market system comprises five pivot elements:

- Pro-renewables demand for hydrogen
- Certainty of hydrogen supply
- Pro-renewables governmental policy
- Private and public investment in hydrogen
- Hydrogen production technology and knowledge

Pivot elements represent the dynamic forces that exist among hydrogen market sub-systems. Below them lie five sub-systems that work together within the larger hydrogen system to drive adoption and progress. These sub-systems are supply, demand, technology, investment and policy, as shown in Table 2. The sub-systems comprise a number of elements. Each element represents a key actor, institution, process, activity or resource central to the functioning of a hydrogen ecosystem. They also comprise separate elements that represent catalysts, barriers and gaps in relation to the adoption of hydrogen. The elements within a system are connected using 'feedback loops,' which portray the behavioral outcomes of these elements and the timeframe within which they produce these.

"Sub-system"
Demand

Description

The Demand sub-system captures the elements driving the demand for hydrogen. Firstly, the price of hydrogen is inversely related to its demand, especially as higher hydrogen prices motivate stakeholders to look to other fuels to meet their energy needs. Nevertheless, as substitutability is not only dependent on pricing, but also on the capital expenditure required to make use of alternative fuels, the map depicts energy switching costs as a catalyst/barrier to the Demand sub-system. Additionally, the demand for hydrogen is linked to advancements in technology. As more use cases emerge, more hydrogen is demanded. At the same time, greater availability of hydrogen utilization infrastructure (i.e., charging stations, hydrogen appliances, etc.) drives further hydrogen demand by lowering the barriers to its use; however, the development of the infrastructure itself depends on the demand for hydrogen, so the sub-system contains a feedback loop between both these elements. Lastly, the adoption of hydrogen depends on the trade-offs made between opting for electrification or hydrogen-based energy. Indeed, investment in electrification can 'crowd out' the opportunity for hydrogen. As such, the extent of electrification decreases the demand for hydrogen. Nevertheless, the intermittency of renewable generation drives demand for other means of transporting energy, which places positive pressure on the demand for hydrogen. However, electrification cannot take place across the board and hard-to-abate sectors must look elsewhere to decarbonize, creating use cases for hydrogen to plug this need. As a result, the concentration of hard-to-abate sectors is represented as a catalyst/barrier to the extent of electrification. Lastly, the demand for hydrogen is also driven by industrial uses of hydrogen, such as hydrocracking and hydrotreating of fossil fuels, as well as by the depth and breadth of regulations for decarbonization and carbon pricing that further motivate stakeholders to make use of renewable fuels.

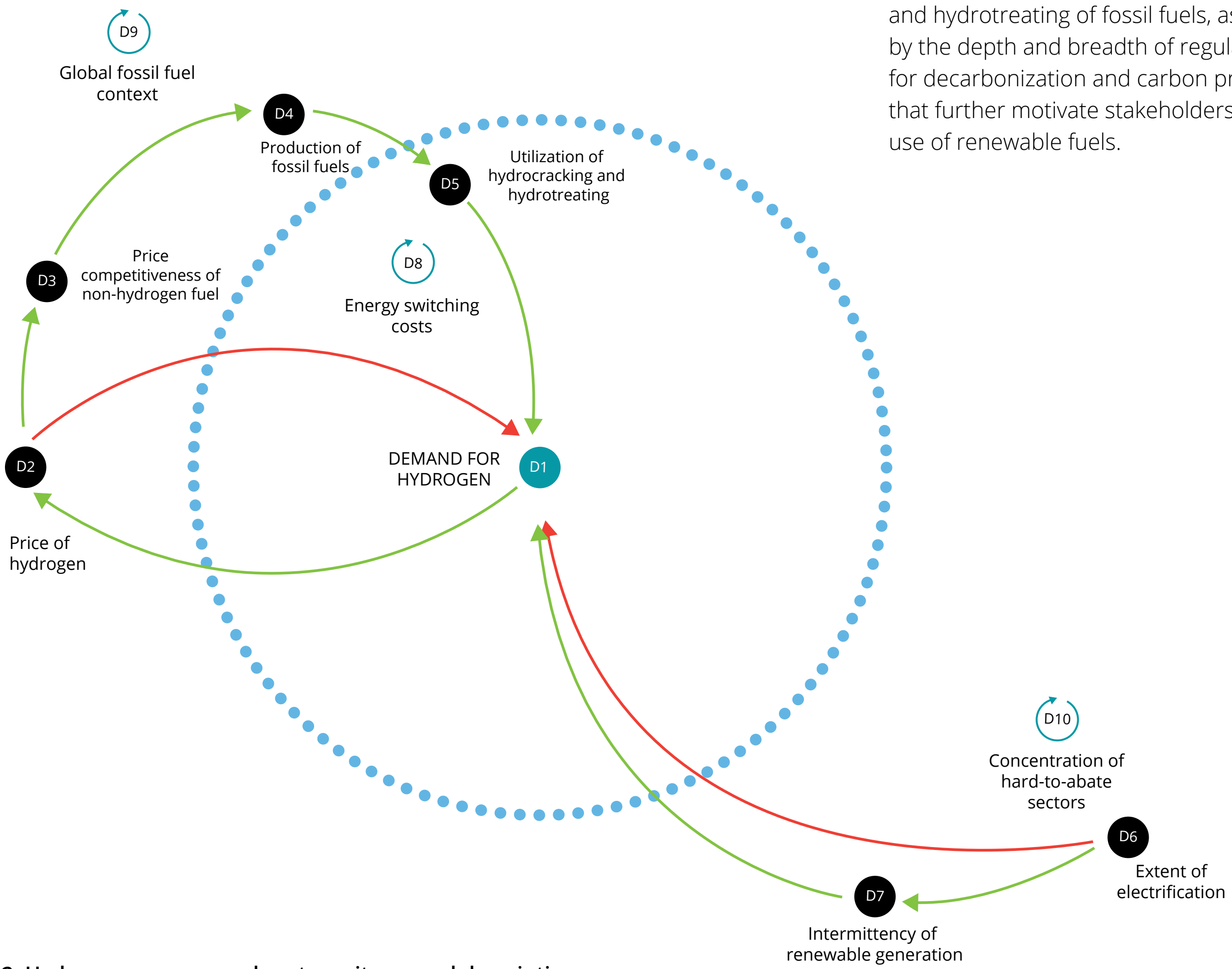
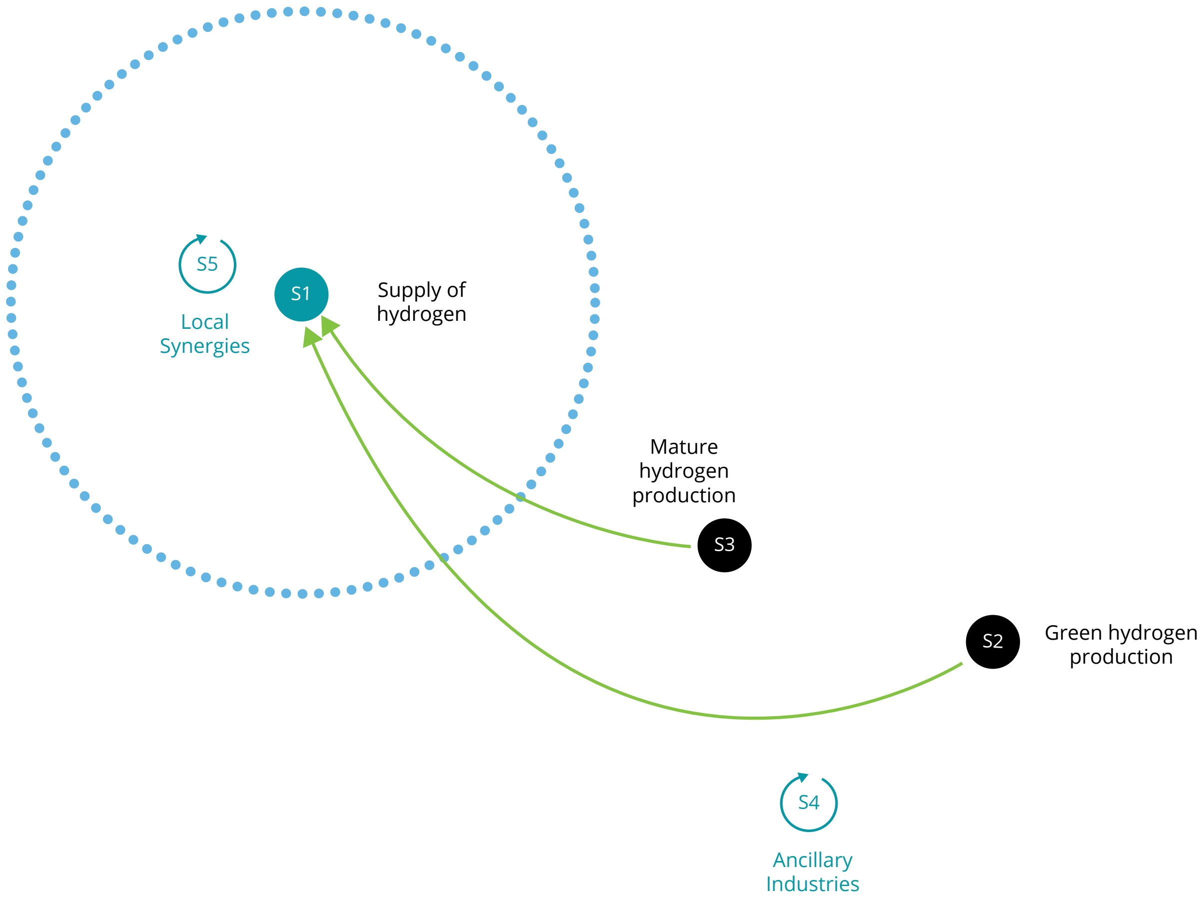


Table 2: Hydrogen economy subsystems items and description

"Sub-system"
Supply

Description

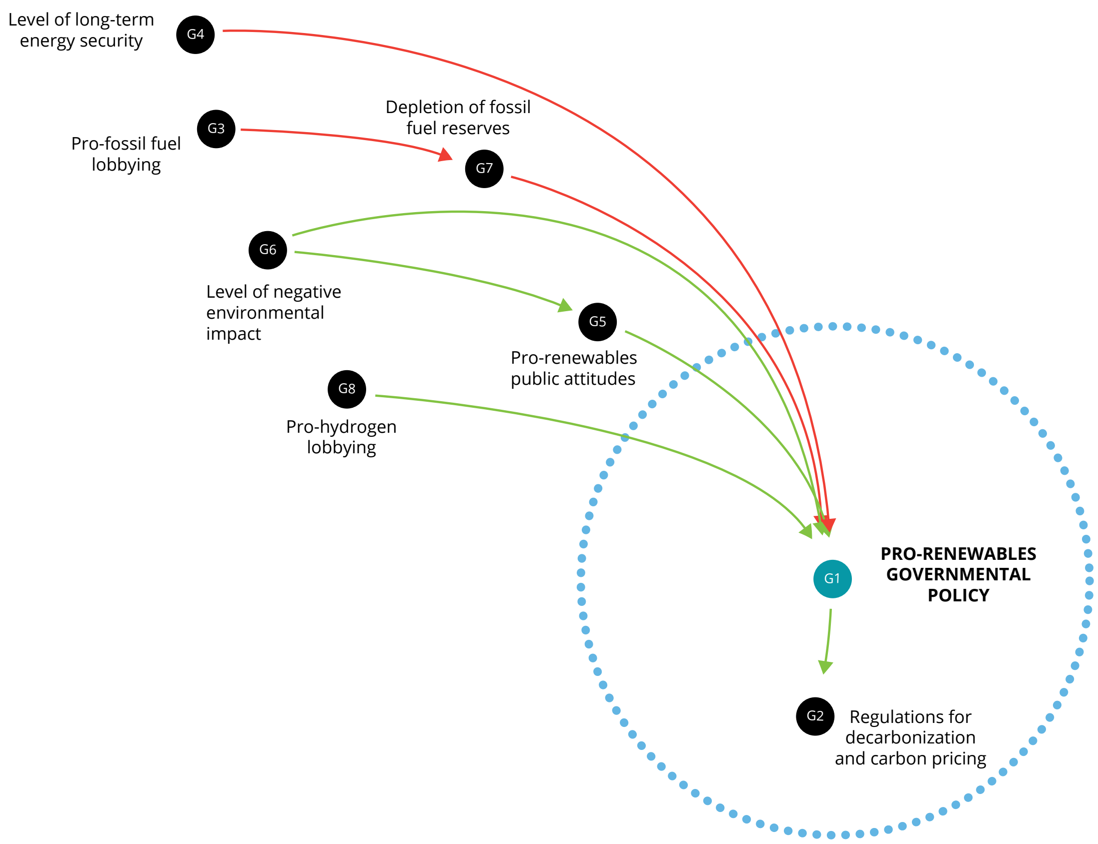
The Supply sub system captures the elements driving the supply of hydrogen. The supply of hydrogen is illustrated as the outcome of green and 'mature' hydrogen production. Green hydrogen production refers to the production of hydrogen by using renewable energy for the process of electrolysis, which separates water molecules into hydrogen and oxygen as a by-product. On the other hand, 'mature' hydrogen refers to the processes of producing hydrogen that do not use electrolysis, such as separating natural gas molecules into hydrogen and carbon dioxide. They are designated as 'mature' methods due to them being the most predominant and well-established methods of producing hydrogen in current use[16]. In the systems map, these two production methods are linked to the level of hydrogen production technology, which determines the realm of possibilities for hydrogen production and their economic feasibility. Additionally, these production processes are tied to the demand for hydrogen, which drives production of both types. Moreover, local synergies (including geography and proximity to assets) and ancillary industries providing support to the production of hydrogen are designated as catalysts/ barriers, as they can serve to further enable the Supply sub-system.



"Sub-system"
Government

Description

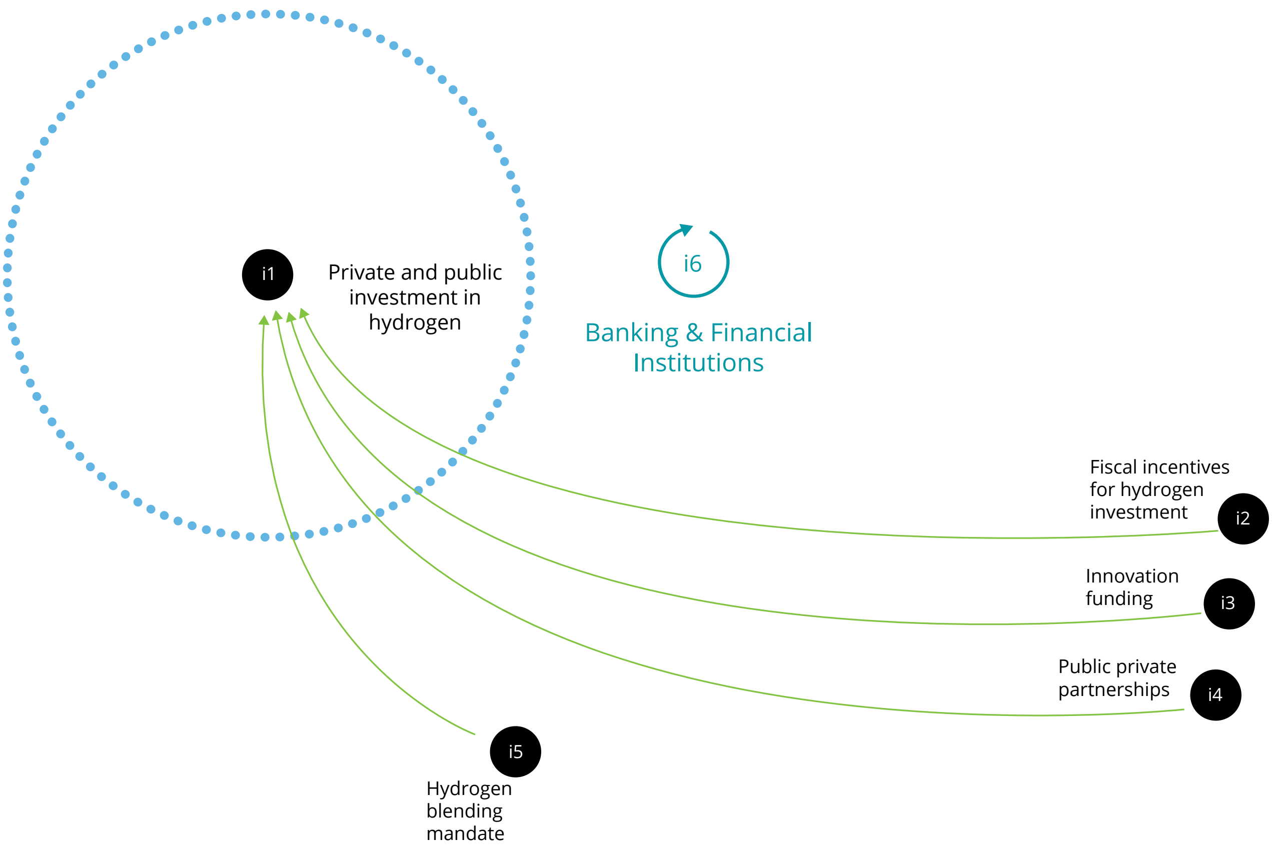
The Government sub-system captures the elements driving pro-renewables governmental policy. Firstly, pro-renewables governmental policy is positively influenced by pro-renewables public attitudes, which are conceptualized in the map as being a response to the level of negative environmental impact from fossil fuels. Additionally, negative environmental impact not only affects governmental policy through public attitudes, but it also exerts an independent, motivating influence for the government to take heed of its environmental impact. Secondly, pro-hydrogen lobbying from the private sector places positive pressure on the government to pursue a pro-renewables policy. On the other hand, there are two elements that dampen the government's motivation to pursue a pro-renewables policy. Indeed, the extent of pro-fossil fuel lobbying in the system will be a negative influence on the formulation of pro-renewables policy. Further, if the government perceives itself to have long-term energy security – for example, through the reliable availability of fossil-fuels in the present and in the future – then it will be less motivated to pursue a pro-renewables policy. To the extent that all these drivers result in a net positive influence on the government conducting a pro-renewables policy, this will manifest itself in greater depth and breadth of regulations for decarbonization and carbon pricing as well as avenues for hydrogen investment, which are captured in the Investment sub-system.



"Sub-system"
Investment

Description

The Investment sub-system captures the elements that drive private and public investment in hydrogen. First and foremost, private and public investment in hydrogen is driven by the demand for hydrogen. As the demand for hydrogen rises, the private and public sectors respond by increasing investment. In addition to this, private sector investment in hydrogen is further catalyzed by its interaction with governmental policy. Indeed, the government affects the level of investment in three ways. Firstly, it affects the business case for investing in hydrogen, such as by providing fiscal incentives for hydrogen investment, or introducing regulations for decarbonization and carbon pricing that make it more costly to make use of fossil fuels. Secondly, it can enforce regulations that make it a requirement for the system to decarbonize or make use of hydrogen, such as through hydrogen blending mandates. In order to comply with these requirements, investment in hydrogen increases. Lastly, the government can provide investment itself, especially in the case of government-owned energy assets, or enable investments in collaboration with other stakeholders, such as through public-private partnerships and innovation funding. Altogether, the Investment sub-system is enabled by the existing banking and financial institutions, represented as a catalyst/barrier on the map. The ultimate outcome of private and public investment in hydrogen is research, development and innovation (RD&I) and the development of hydrogen infrastructure, which are elements captured in the Technology sub-system.



"Sub-system"
Technology

Description

The Technology sub-system captures the drivers and impact of technology in the hydrogen system. Hydrogen research, development and innovation (RD&I) channels private and public sector investment into the development of the hydrogen economy. Firstly, RD&I contributes to the development of use cases for hydrogen, which subsequently exerts a positive pressure on hydrogen demand. Secondly, it spurs the development of hydrogen production technology, both of hydrogen itself as well as of its derivatives, including ammonia, ethanol and sustainable aviation fuels.

This element subsequently enables the realm of possibilities for green and 'mature' hydrogen production captured in the Supply sub-system. Thirdly, it enables the development of infrastructure, illustrated in the sub-system in the form of hydrogen utilization infrastructure, hydrogen production infrastructure and hydrogen transport and storage infrastructure. All of these are further enabled by talent (i.e., human capital) in the system as well as knowledge networks, which are both designated as a catalyst/barrier to the sub-system.

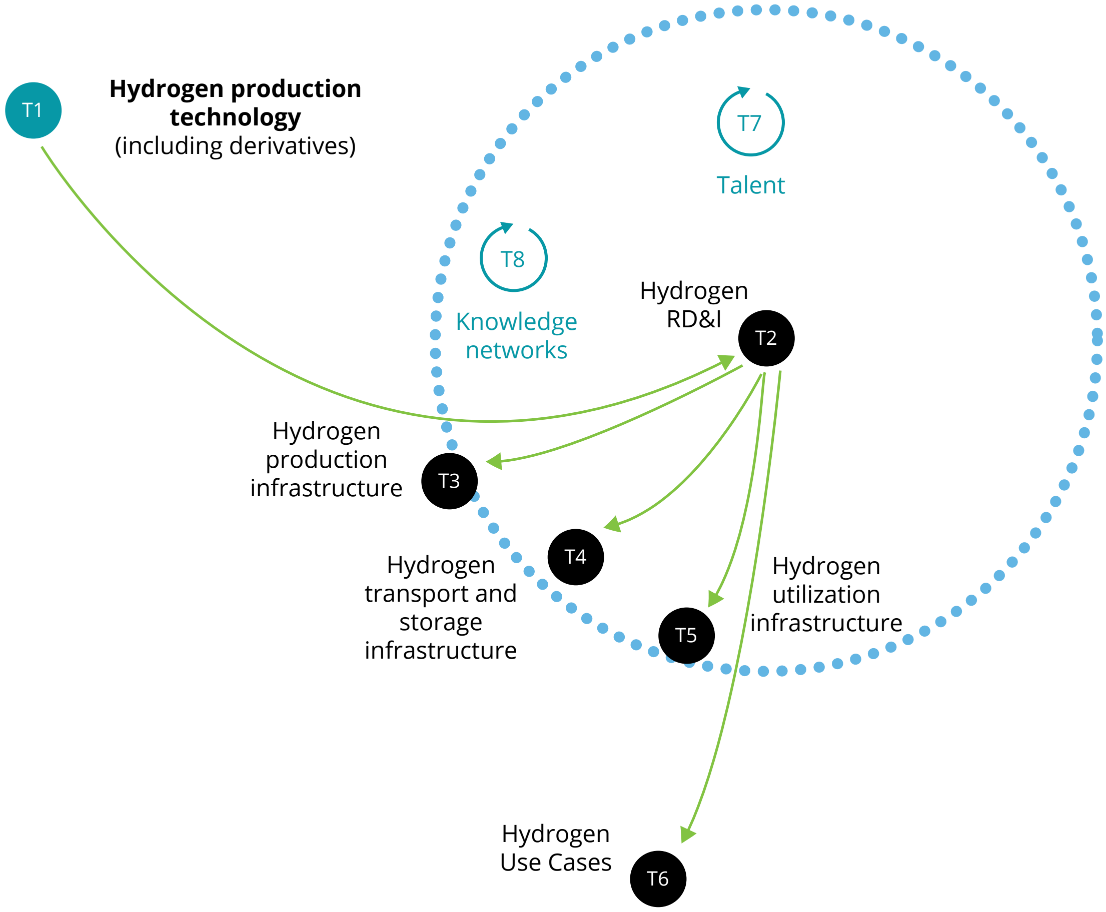
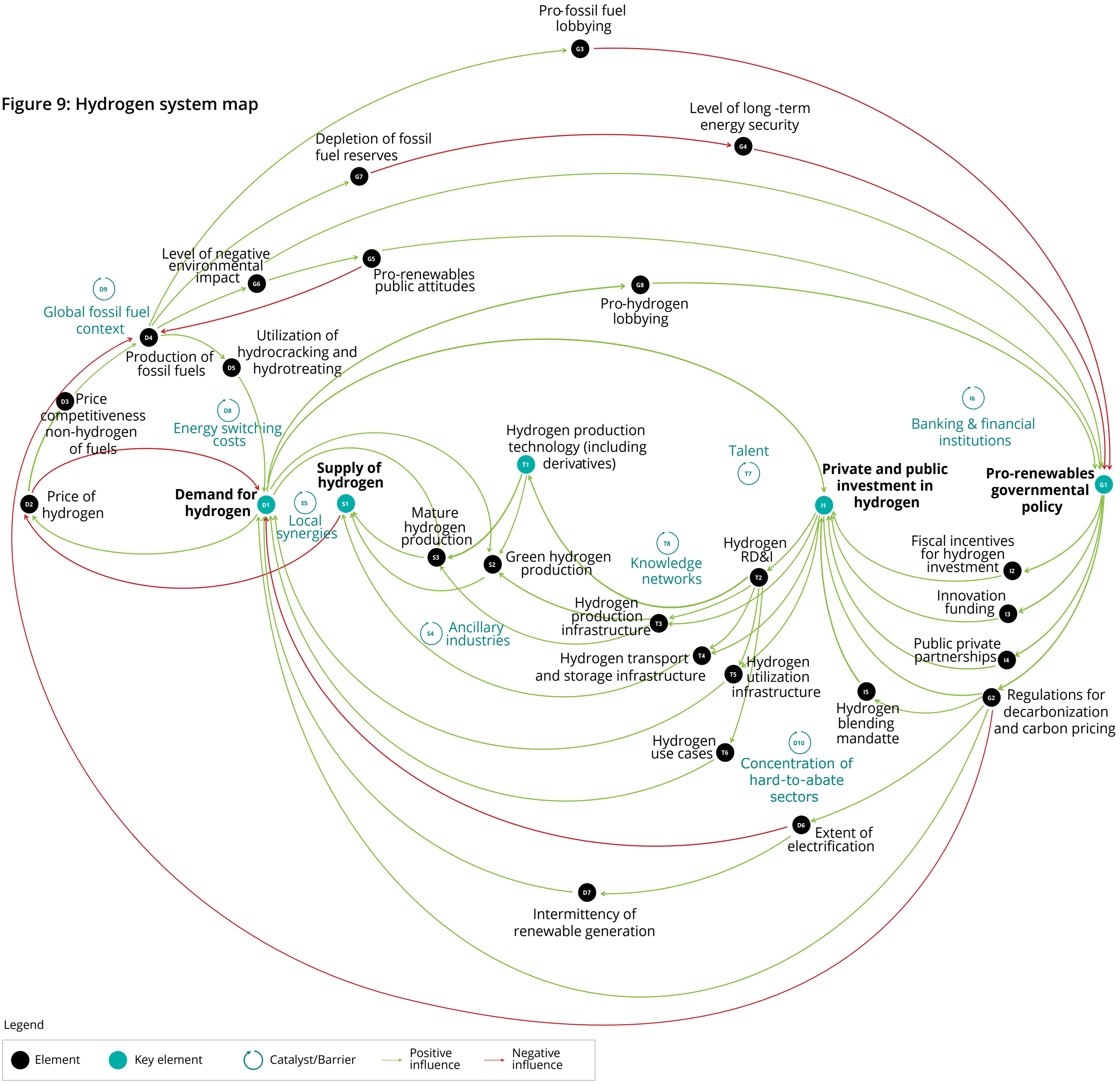


Figure 9: Hydrogen system map



What are the benefits of a systems approach?

Visually mapping the various components of the hydrogen ecosystem and their feedback loops can enable decision-makers to visualize the dynamics and interdependencies of the system, as shown in Figure 9. In doing so, private and public players can better identify the decision-making processes of the different actors within the system, and the short and long-term impact of their actions. A systems perspective helps deepen the key actors' understanding of challenges in the hydrogen ecosystem by giving decision-makers insight into the 'what' and 'when', as well as the 'how' and 'why'. Moreover, a systems approach recognizes the importance of every player in the ecosystem and the way in which they interact. This recognition will lead to a comprehensive planning effort rather than a fragmented approach. As such, a systems approach negates the human tendency to become side-tracked by personal agendas by encouraging stakeholders to work towards a unified and collective goal. It encourages more strategic planning by ensuring decision-makers collaborate across the ecosystem and focus on a small number of ways to achieve change on a large scale rather than producing a laundry list of activities that rarely produce desired outcomes.

Applying a systems approach to the future of hydrogen:

An integrated approach to the future of hydrogen will become increasingly important in light of today's shifting energy landscape. As energy carriers are required to become more climate-friendly to decarbonize economic sectors and end-user applications, the significance of the elements that reside within the hydrogen ecosystem will change. Private and public decision-makers must proactively navigate the future of hydrogen by addressing the impact of these forces and their effects on the design of the hydrogen ecosystem. They must also be prepared to grasp the complexities of this reality and understand how their actions have systemic consequences. They must anticipate the challenges that the future of hydrogen presents and design solutions to help relevant stakeholders to overcome them.

The road to success: key next steps for the GCC

It is crucial that private and public decision-makers in the GCC have a better understanding of the complexity of challenges and solutions pertaining to enabling and accelerating the future of hydrogen. Initial steps in the right direction would be:

1. Coherent acknowledgement that the hydrogen ecosystems are evolving and interconnected, not static and standalone pieces.

2. Recognition of the differences between the points at which systems contend with interventions and the ground-level implications of policies, investments and technological elements. Interventions must be designed and implemented by empowering constituencies on the ground.

3. An understanding that traditionally outdated approaches to key elements of the hydrogen system are linear and one-dimensional. Hence, the traditional approach of a certain class without involving the broader relevant stakeholders will not be effective in achieving desired outcomes.

4. An acknowledgement of the need for accurate information on the broader aspects of enabling the hydrogen systems to provide decision-makers with a full and integrated line of sight on the hydrogen market creation.

5. An acknowledgment of the need for a new and more comprehensive set of metrics to measure sustained performance outcomes.

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References

1. International Institute for Environment and Development

2. International Energy Agency

3 ,4 ,6 ,16. Monitor Deloitte Analysis

5. Dansk Energi

7. Norsk Elbilforening

8. British Petroleum

9. The World Bank

10 ,11. Reuters

12. Emirates News Agency

13. Bloomberg

14. Bahrain News Agency

15. Petroleum Development Oman

16. Springer Nature

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